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Natural Resource Assessment Methodologies for the Proposed High-Level Waste Repository at Yucca Mountain, Nye County, Nevada

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NATURAL RESOURCE ASSESSMENT METHODOLOGIES FOR THE PROPOSED HIGH-LEVEL WASTE REPOSITORY AT YUCCA MOUNTAIN, NYE COUNTY, NEVADA

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PREFACE

This document is an adaptation of "Natural Resource Assessment Methodologies for Proposed High-Level Waste Repositories" prepared by the U.S. Bureau of Mines (BOM) for the Nuclear Regulatory Commission (NRC) under Interagency Agreement NRC-02-84-004 in January 1987. The 1987 document describes natural resource assessment methodologies for all fuel and energy minerals (metals, nonmetals, industrial minerals, mineral brines, and hydrocarbons) and can be generally applied to any geologic environment in the United States. By contrast, the current work is specific to the proposed high-level waste (HLW) repository site at Yucca Mountain, southern Nye County, NV, and is limited in scope to those methodologies applied to metallic ores. A separate report on potable water, hydrocarbon (oil and gas), and geothermal resources in and around the proposed site is in preparation by the Center for Nuclear Waste Regulatory Analyses (CNWRA), San Antonio, TX.

A considerable amount of introductory material from the 1987 document on the regulatory basis for resource assessment at proposed HLW sites, regulatory compliance, and the general resource assessment method has been updated and incorporated into the current document. Similarly, most reference material, including the extensive bibliography, was also updated, augmented, and included. The bibliography was not screened to exclude non-site specific references as it was felt that to do so would significantly lessen its value. Instead, a separate subsection (6.12) was added to the bibliography that lists the more important works on the geology of the Yucca Mountain area and of the broader southern Basin and Range Province.

Unlike the 1987 document, the current work includes 18 models of mineral deposits that, on the basis of recent geologic investigations, postulates, and hypotheses, may exist on or proximal to Yucca Mountain. Also included is an extensive section on cost engineering that demonstrates the methods and level of detail required to determine the net present value of three mineral deposit types that could possibly exist on site.

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ABSTRACT

Resource assessment of proposed high-level waste (HLW) repository sites and adjacent areas is mandated by Title 10 of the Code of Federal Regulations (10 CFR) Part 60. The intent of this document is threefold. First, it provides information to the U.S. Department of Energy (DOE) on accepted methods of metallic resource assessment applicable to the proposed Yucca Mountain, Nevada HLW repository site so DOE can demonstrate to the U.S. Nuclear Regulatory Commission (NRC) compliance with regulations governing resource identification and evaluation. Secondly, it provides information that NRC can use in making a finding of DOE's compliance with the requirements of 10 CFR Part 60. And lastly, it will provide input for the NRC's technical position and review guide for natural resource assessment.

Methods of resource assessment, including but not limited to, geologic mapping and sampling, geochemical surveys, geophysical surveys, deposit modeling, and geomathematical studies, along with the advantages, disadvantages, and uncertainties associated with the use of the various methods, are discussed. Resource quantification, qualification, and evaluation methods are presented, as well as techniques for estimating capital and operating costs for development and extraction of potential resources. Extraction/economic models for three selected deposit types are also presented.

INTRODUCTION

1. REGULATORY BASIS FOR ASSESSMENT OF NATURAL RESOURCES

1.1 Definitions

For purposes of clarity and brevity, it is necessary to define several frequently used terms.

"Resources" as used here is a collective term for metallic minerals and ores. Ground or surface water in the usual sense (i.e., potable, agricultural, or industrial water at ambient temperature at relatively shallow depths), hydrocarbons (oil, gas, tar sands, asphalt, etc.), and geothermal occurrences are addressed in a separate report by the Center for Nuclear Waste Regulatory Analyses (CNWRA), San Antonio, TX.

"Resource exploration or exploitation activities" as used here means " . . . any action, such as borehole drilling or sinking of shafts, in the search for mineral commodities (1)."1/ The term "mineral commodities" is synonymous with "resources."

The term "deposit" is used in reference to the physical occurrence of a resource.

"Site characterization" as defined by 10 CFR Section 60.2 (2) is

> "The program of exploration and research, both in the laboratory and in the field, undertaken to establish the geologic conditions and the ranges of those parameters of a particular site relevant to the procedures in 10 CFR Part 60. Site characterization includes borings, surface excavations, excavation of exploratory shafts, limited lateral excavations and borings, and in situ testing at depth needed to determine the suitability of the site for a geologic repository, but does not include preliminary borings and geophysical testing needed to decide whether site characterization should be undertaken."

Geological, geochemical, geophysical, or engineering data acquired during site characterization for other purposes, when applied to resource assessment, may be incomplete or contain significant uncertainty. This notwithstanding, integration of such data in the resource assessment program may prove to be of value in assessing the site's resource potential and, of greater importance, the potential for post-closure human interference.

1/Underlined numbers in parentheses [e.g., (1)] refer to items in the list of references in Section 1.5 or Section 2.5.

1.2 Regulations Mandating Resource Assessment

DOE is required by 10 CFR Part 60, Subpart B (2), to apply to NRC for a license to receive and possess source, special nuclear, and byproduct material at a geologic repository operations area (GROA). License applications shall consist of general information and a Safety Analysis Report that includes provisions set forth in 10 CFR Section 60.21(c) (1-15) (2).

Resource assessment requirements as specified in 10 CFR Section 60.21(c)(13), (2) state that the Safety Analysis Report shall include:

> "An identification and evaluation of the natural resources of the geological setting, including estimates as to undiscovered deposits, the exploitation of which could affect the ability of the geologic repository to isolate nuclear wastes. Undiscovered deposits of resources characteristic of the area shall be estimated by reasonable inference based on geological and geophysical evidence. This evaluation of resources, including undiscovered deposits, shall be conducted for the site and for areas of similar size that are representative of and are within the geologic setting. For natural resources with current markets the resources shall be assessed, with estimates provided of both gross and net value. The estimate of net value shall take into account current development, extraction and marketing costs. For natural resources without current markets, but which would be marketable given credible projected changes in economic or technological factors, the resources shall be described by physical factors such as tonnage or other amount, grade, and quality."

DOE is further required by 10 CFR Part 60, Subpart E (2) to identify existing or potential resources within the controlled area whose exploration for or exploitation of may constitute an adverse condition appertaining to the repository's ability to isolate radionuclides from the accessible environment. These potentially adverse conditions are specified in 10 CFR Section 60.122(c)(17-19) (2):

> (17) "The presence of naturally occurring materials, whether identified or undiscovered, within the site, in such form that: (i) Economic extraction is currently feasible or potentially feasible during the foreseeable future; or (ii) Such materials have greater gross value or net value than the average for other areas of similar size that are representative of and located within the geologic setting."
>
> (18) "Evidence of subsurface mining for resources within the site."
>
> (19) "Evidence of drilling for any purpose within the site."

1.3 Regulatory Compliance

The intent of this document is to: (1) provide information to DOE on accepted methods of resource assessment to demonstrate to NRC compliance with regulations governing resource identification and evaluation as part of site characterization at Yucca Mountain, (2) provide information that may be used by NRC in making a finding of DOE's compliance with the requirements of 10 CFR Part 60, and (3) provide input to the NRC resource assessment technical position and Standard Review Plan (SRP).

1.4 Resource Assessment Methods Available for Use as Part of Site Characterization

Geological, geochemical, geophysical, and engineering data acquired for other purposes as part of site characterization, supplemented by information from activities conducted specifically for resource assessment, may form the basis for new mineral deposit models or may be employed to augment existing models, the use of which may indicate undiscovered resources within the geologic setting. In addition to resource exploration methods, this document outlines mineral deposit models in current use that are available for a resource assessment program or that may be of value to other activities within the overall site characterization program.

1.5 References

1. Harbaugh, J. W. Resource Exploration. Techniques for Determining Probabilities of Events and Processes Affecting the Performance of Geologic Repositories, R. L. Hunter and C. J. Mann, eds., Sandia National Laboratories, Albuquerque, NM, 1989, NUREG/CR-3964, pp. 2-1 - 2-37.

2. U.S. Code of Federal Regulations. 10 CFR Part 60.21(c)(1-15), 10 CFR Part 60.122(c)(17-19).

2. RESOURCE ASSESSMENT METHODS

Resource assessment within and near the Yucca Mountain site is mandated by Federal regulations to identify and evaluate the possibility that exploration-exploitation activities in the past, present, or future do not adversely affect the site's ability to isolate radionuclides from the accessible environment. The objective of Section 2 is to outline those methods and deposit models applicable to Yucca Mountain and commonly employed in performing resource assessments, and to present methods, techniques, and guidelines for the economic evaluation of resources.

For purposes of clarity, Section 2 presents the resource assessment process in a linear fashion with resource identification, followed by resource quantification and qualification, and finally followed by resource evaluation. It must be understood, however, that information acquired in later stages of an assessment program may require modification, refinement, or abandonment of exploration methods, deposit models used, or conclusions reached in earlier stages.

Conceptually, the resource assessment process is a three-step linear progression in which: (1) an area's resources are identified; (2) estimates are made of resource quantity and quality; and (3) studies are conducted to determine gross and net value of the resource. In practice, however, it is best described as an iterative and intricate process; inherent within the process is an infinite number of certainty levels (0-100 percent certainty range) that depend on the type and abundance of available data. For example, information acquired during the course of quantification and qualification may indicate the presence of additional resource commodities not recognized in the resource identification step. Figure 1 is a simplistic diagram of the rather complex resource assessment process applied to site characterization.

The three-step resource assessment approach is employed by the BOM in its mission to provide input for consideration in policies that affect national minerals issues (such as supply/demand analysis and wilderness area withdrawals) and by the private sector for purposes of eventual resource extraction. The basic difference between BOM and private sector assessments lies in the amount of resources (time, effort, funding, etc.) committed to the assessment. Typically, industry assessments involve greater expenditures of funds and manpower and carefully weigh the risks of committing large sums of money against the potential rewards.

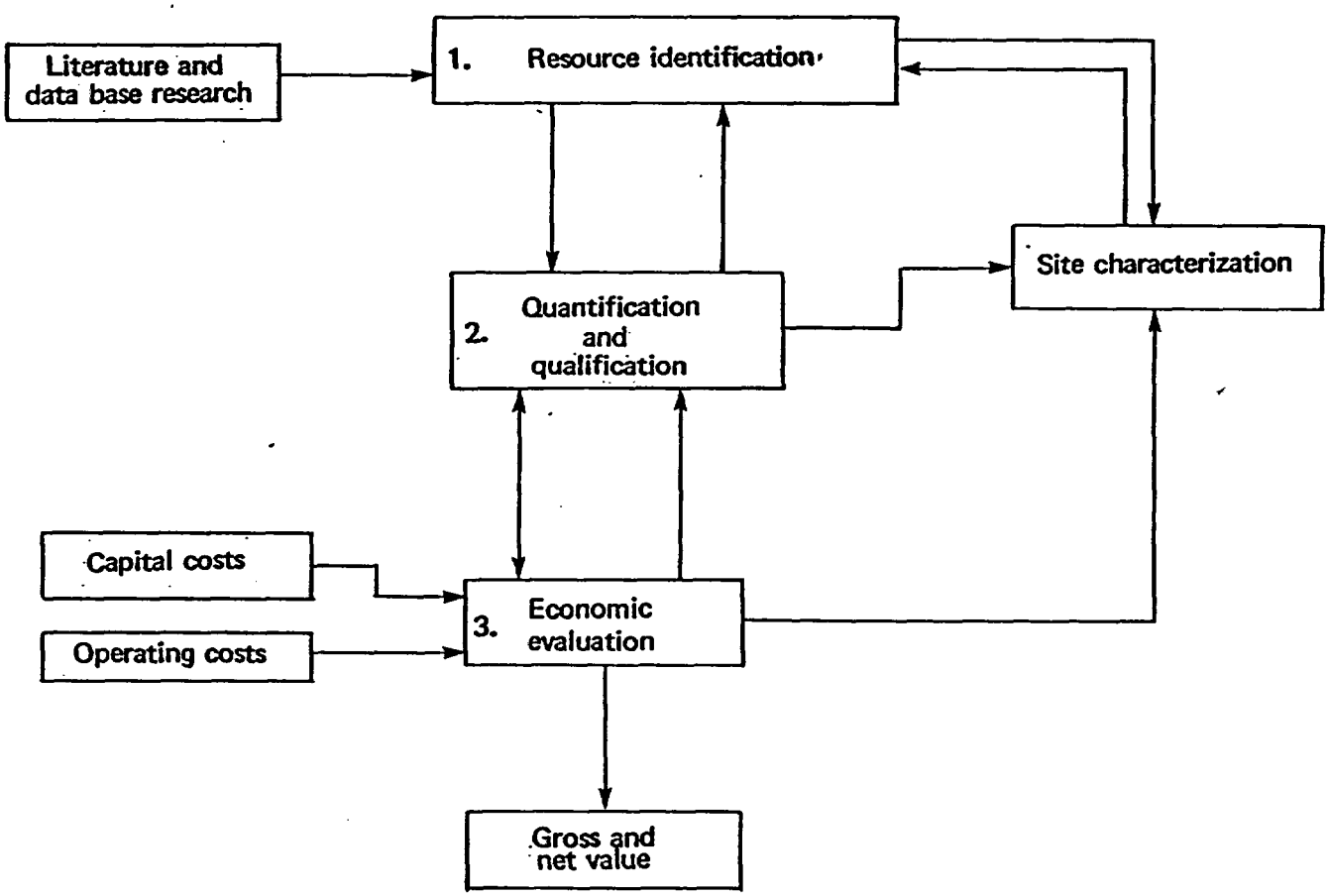


FIGURE 1. – Resource assessment process

Resource identification includes, but is not limited to, a host of activities and studies such as background literature research, deposit modeling, field activities, data analysis and evaluation, and geomathematical studies; methods for conducting these studies are presented in Section 2.1. Methods for deriving resource quantity and quality are discussed in Section 2.2; methods employed for estimating gross and net resource value as required by 10 CFR Part 60 (1) are outlined in Section 2.3. The last Section, 2.4, presents an example of how the methods discussed in the previous section could be applied.

Exploration drilling, trenching, and other piercement methods are normally employed to identify and evaluate resources. Data acquired using these techniques (in conjunction with other methods and techniques) are used to define deposit limits, determine resource quantity and quality, lithology, mineralogy, structure, and geometry, and to develop new or refine existing deposit models. However, in resource assessment of the Yucca Mountain site, the use of piercement methods is somewhat limited due to the necessity of maintaining repository integrity [10 CFR Section 60.15(d)(1-4)] (1). Accurate delineation of an ore body, for example, may require many boreholes on close centers in direct conflict with provisions of 10 CFR Section 60.15(d)(1-4). The use of test adits, raises, winzes, or deep surface pits are similarly restricted. Because of these regulatory restrictions, a significant level of uncertainty regarding the existence, extent, quantity, and quality of resources within and in proximity to Yucca Mountain is unavoidable. In view of this, non-piercement exploration and evaluation methods such as geological mapping, surface sampling, geochemical and geophysical surveys, and geomathematical techniques must be relied upon to provide much of the data necessary for resource assessment.

Resource assessment methodologies, techniques, and deposit models presented here are not all-inclusive; only the most important or widely used (with applications to Yucca Mountain) are discussed. However, the fact that a particular methodology, deposit model, or technique is neither included nor discussed in detail does not preclude its use. Infrequently-used or esoteric techniques [e.g., vapor sampling using sulfide-sniffing dogs (2, p. 30)] or those that require extensive multidisciplinary knowledge (biogeochemical prospecting, geozoological prospecting, etc.) may certainly be employed if necessary or desirable.

Geologic conditions on and/or near the proposed HLW site will ultimately dictate the exploration methods employed. For example, some electrical and electromagnetic geophysical methods are decreasingly effective with increasing depth and may be of little or no practical use in assessing the mineral potential of Paleozoic and older units underlying the site; seismic reflection methods employed in past studies near the site have reportedly produced less than satisfactory results; the lack of standing bodies of water and perennial streams limits hydrogeochemical surveys to ground water; sparse vegetation and small faunal populations similarly limit geobotanical, biogeochemical, and geozoological surveys.

Detailed information on resource assessment methodologies, deposit models, and techniques is presented in references included in the References and Bibliography sections of this report.

2.1 Resource Identification

2.1.1 Background Data Collection

The body of geologic literature available to the researcher is enormous and ranges widely in quality. Older studies and references may or may not be valid in light of more recent investigations. Therefore, care must be exercised to ensure data incorporated in the resource assessment program is of the highest quality and is as current as possible.

2.1.1.1 Literature and Database Research

Resource identification begins with comprehensive research of the literature and computerized databases maintained by a host of entities including Federal, State, and local governmental agencies, the private sector, and academic institutions. The objective of the research is to amass regional and site-specific data to: (1) identify those areas that have been the object of resource exploration and/or exploitation; (2) develop preliminary deposit models; (3) define areas for geological, geochemical, and geophysical examination; (4) define areas for preliminary borehole drilling; and (5) provide data for geomathematical studies and comparisons. These applications are discussed in Section 2.1.2.1.

Sources of information include, but are not limited to, the following:

Federal Government

BOM--Results of BOM research, investigations, and studies are routinely issued as Reports of Investigations (RI), Information Circulars (IC), Bulletins, mineral commodity reports, Mineral Land Assessment (MLA) reports, Mineral Yearbooks, and other publications. The Bureau maintains extensive mineral property files that may include War Minerals Reports, Defense Minerals Exploration Administration (DMEA) reports, borehole and sample data, and other valuable information. Additionally, the BOM's computerized Minerals Industry Location System (MILS) (the nonconfidential segment of the Minerals Availability System [MAS]) contains location and identification information on over 180,000 mines, prospects, geothermal wells, and mineral locations in the United States, including Alaska and Hawaii (3).

U.S. Geological Survey (USGS)--The USGS collects, compiles, and publishes a great volume of geotechnical information in its Bulletins, Circulars, Professional Papers, Water Supply Papers, topographic, geologic, and hydrographic maps, Memoirs, Mineral Resources Data System (formerly Computerized Resource Information Bank - CRIB) database (4), reports, files, open-file reports, and miscellaneous publications. Additionally, personal journals, notes, unpublished reports, and other data sources may be available at local USGS offices.

Other Federal sources of information include reports, files, notes, memoirs, and databases maintained by the Bureau of Land Management (BLM) which maintains current mineral-interest and claim recordation files; Office of Surface Mining (OSM); Mine Safety and Health Administration (MSHA); National Archives (NA); Library of Congress (LC), U.S. Department of Agriculture Forest Service (USFS); U.S. Department of Commerce (DOC); U.S. Department of Defense (DOD); DOE; U.S. Department of Labor (DOL); and the U.S. Internal Revenue Service (IRS).

Nevada State and Local Governments

Nevada State information sources include the Nevada Bureau of Mines and Geology; historical society; office of mine inspector; agencies with permitting or licensing responsibilities; highway department commission; utility commission (e.g., gas, power, water); and libraries.

Local government sources include clerk and/or recorder records; city and county tax assessor's records; highway and road departments; public utilities; libraries; and agencies with permitting and/or licensing responsibilities.

Private Sector

Business and nonprofit organization sources of information include mining and/or exploration companies; historical societies and museums; industry and/or trade associations; consultants; and commercial databases.

Educational Institutions

Sources of information may include, but are not limited to, college and university departments of geology, mining, geophysics, geochemistry, hydrology, history, economics, social science, and their associated libraries. University Microfilms International, 300 N. Zeeb Road, Ann Arbor, MI 48106, maintains a clearinghouse for doctoral dissertations that are available for a fee as Xerox copies or on microfiche. The Geological Society of America (GSA) periodically publishes bibliographies of theses and dissertations.

Other Sources of Information

Other sources of information, including bibliographies, indices, abstracts, translations of foreign research papers, directories, periodicals, information retrieval systems, and literature on geology and associated disciplines are presented in Section 6.1.

2.1.1.2 Personal Contacts

Valuable information is often gained through personal contacts with knowledgeable individuals. Information such as unpublished and generally unavailable geologic, mineralogical, and engineering data, personal reports, notes, memoirs, or files is often obtained by direct contact with authors, editors, compilers, and others associated with works identified over the course of literature/data base research. Other sources of information may include interviews with industry representatives (such as geologists, engineers, cartographers, drillers, and miners); local residents (ranchers, loggers, prospectors); members of geological, mineralogical, speleological, or historical societies or associations; State or local labor unions; professional associations [e.g., Geological Society of America (GSA); American Institute of Mining, Metallurgical, and Petroleum Engineers; Northwest Mining Association]; college and university professors; and former Federal, State, and local government employees.

2.1.2 Identification of Natural Resources of the Geologic Setting

2.1.2.1 Application of Background Data

Background data are compiled and analyzed to determine a number of factors for incorporation in an assessment program. These include, but are not necessarily limited to:

(1) Documentation of resource exploration or exploitation that has ensued on or near the site;

(2) Identification of specific sites for geological, geophysical, and geochemical surveys;

(3) Enumeration of possible resources that could be reasonably inferred to exist on site or in analog areas;

(4) Determination of a deposit model or models that may apply to the site vicinity;

(5) Identification of preliminary drilling targets; and

(6) Cataloging of open boreholes (or boreholes that will be reopened as part of site characterization) for possible well-logging, or additional sampling such as sidewall sampling.

2.1.3 Field Data Collection, Compilation, and Interpretation

Information acquired and analyses conducted during literature searches are subsequently supplemented and refined based on data collected through detailed geological mapping, surface and subsurface sampling, geochemical and geophysical surveys, borehole drilling, and other field investigations. The results of the field examinations may indicate the need for further site-specific studies to delineate any discovered resources, to provide data for additional deposit modeling, geomathematical analyses, or tonnage-grade estimations.

The availability and application of methods used in field data collection and their subsequent compilation, and interpretation are presented in the following Sections.

2.1.4 Deposit Modeling and Deposit Models

This section examines the resources and associated resource deposit models that could be expected to exist in the vicinity of Yucca Mountain and the rationale for selecting each. Geological, geochemical, geophysical, and other exploration methods applicable to the particular resource are discussed in Section 2.1.5.

Although briefly mentioned in the following discussions, geothermal, hydrocarbon, and potable water resources are not addressed at length in this report. (These commodities are addressed in detail in a separate report by CNWRA).

A mineral deposit model is a concept or an analog that represents in text, tables, and diagrams the essential characteristics or attributes of a deposit type (5). The use of deposit models in resource assessment alerts the resource investigator to indications of a mineralized zone. Further, familiarity with deposit models that may be applicable for the area in and around Yucca Mountain may be of value in geological, geochemical, geophysical, and drilling activities conducted for site characterization purposes other than resource assessment.

Resource deposit models are the keys to any deposit identification, since valid exploration models of known mineral deposits aid the researcher to focus on critical geologic attributes of a target area. Furthermore, deposit models can conserve time and funds that might otherwise be expended to collect data not critical to identifying a resource. A comprehensive listing of references on deposit models and deposit modeling is presented in Section 6.2.

Deposit modeling terminology is somewhat confusing and often inconsistent in its application. Most terms, however, are analogous to two fundamental model types: empirical and genetic deposit models. Empirical models (also known as "occurrence" or "descriptive" models) are based solely on observation and fact. Genetic models (also known as "process," "conceptual," or "interpretive" models) incorporate empirical data and an analysis of the genetic components of the deposit and their interactions. The two fundamental models [(1) empirical and (2) genetic] are employed to identify those data compilations and field activities that may be conducted to test an area for the presence of a particular deposit type. The combined use of empirical and genetic models at Yucca Mountain and in analog areas allows the researcher to identify those geologic criteria that are most reliably related to resource occurrences. This combination of fundamental models is generally referred to as an "exploration" or "recognition criteria" model (5).

Use of deposit models facilitates extrapolation into relatively unexplored areas (6) and, when combined with one or more methods of geomathematical resource assessment, may allow reasonable estimates to be made of an area's resource potential.

Descriptive models presented in this section are modified from USGS Bulletin 1693, Mineral Deposit Models, Dennis P. Cox and Donald A. Singer, editors (7). Each descriptive model presented is referenced to its author by appropriate footnotes.

It is appropriate to include, by way of an introduction to deposit modeling, the preface to Bulletin 1693 authored by Paul B. Barton. The decision to include Barton's preface verbatim, rather in synopsis or abstract form, was based on: (1) an attempt on the part of the authors to minimize the confusion and inconsistencies alluded to above, (2) the necessity for the reader to be aware of the background and evolution of the models presented here without any editorial bias, and (3) the need for the reader to understand the uncertainties inherent in the formulation and application of the models. References cited by Barton are footnoted at the end of the discussion.

> "Conceptual models that describe the essential characteristics of groups of similar deposits have a long and useful role in geology. The first models were undoubtedly empirical attempts to extend previous experiences into future success. An example might be the seeking of additional gold nuggets in a stream in which one nugget had already been found, and the extension of that model to include other streams as well. Emphasis within the U.S. Geological Survey on the synthesis of mineral deposit models (as contrasted with a long line of descriptive and genetic studies of specific ore deposits) began with the collation by R. L. Erickson 1/ of 48 models. The 85 descriptive deposit models and 60 grade-tonnage models presented here are the culmination of a process that began in 1983 as part of the USGS-INGEOMINAS Cooperative Mineral

Resource Assessment of Colombia 2/. Effective cooperation on this project required that U.S. and Colombian geologists agree on a classification of mineral deposits, and effective resource assessment of such a broad region required that grade-tonnage models be created for a large number of mineral deposit types.

A concise one-page format for descriptive models was drawn up by Dennis Cox, Donald Singer, and Byron Berger, and Singer devised a graphical way of presenting grade and tonnage data (not presented here). Sixty-five descriptive models 3/, 4/ and 37 grade-tonnage models 5/, 6/ (not included here) were applied to the Colombian project. Because interest in these models ranged far beyond the Colombian activity, it was decided to enlarge the number of models and to include other aspects of mineral deposit modeling. Our colleagues in the Geological Survey of Canada have preceded this effort by publishing a superb compilation of models of deposits important in Canada 7/. Not surprisingly, our models converge quite well, and in several cases we have drawn freely from the Canadian publication.

It is a well-known axiom in industry that any excuse for drilling may find ore; that is, successful exploration can be carried out even though it is founded upon an erroneous model. Examples include successful exploration based on supposed (but now proven erroneous) structural controls for volcanogenic massive sulfide deposits in eastern Canada and for carbonate-hosted zinc in east Tennessee. As the older ideas have been replaced, additional ore has been found with today's presumably more valid models.

Although models have been with us for centuries, until recently they have been almost universally incomplete when descriptive and unreasonably speculative when genetic. What is new today is that, although we must admit that all are incomplete in some degree, models can be put to rigorous tests that screen out many of our heretofore sacred dogmas of mineral formation. Examples are legion, but to cite a few: (1) fluid-inclusion studies have shown conclusively that the classic Mississippi Valley-type ores cannot have originated from either syngenetic processes or unmodified surface waters; (2) epithermal base-and precious-metal ores have been proved (by stable-isotope studies) to have formed through the action of meteoric waters constituting fossil geothermal systems; and (3) field and laboratory investigations clearly show that volcanogenic massive sulfides are the products of syngenetic, submarine, exhalative processes, not epigenetic replacement of sedimentary or volcanic rocks. Economic geology has evolved quietly from an "occult art" to a respectable science as the speculative models have been put to definitive tests.

Several fundamental problems that may have no immediate answers revolve around these questions: Is there a proper number of models? Must each deposit fit into one, and only one, pigeon-hole? Who decides (and when?) that a model is correct and reasonably complete? Is a model ever truly complete? How complete need a model be to be useful?

In preparing this compilation we had to decide whether to discuss only those deposits for which the data were nearly complete and the interpretations concordant, or whether to extend coverage to include many deposits of uncertain affiliation, whose characteristics were still subjects for major debate. This compilation errs on the side of scientific optimism; it includes as many deposit types as possible, even at the risk of lumping or splitting types incorrectly. Nevertheless, quite a few types of deposits have not been incorporated.

The organization of the models constitutes a classification of deposits. The arrangement used emphasizes easy access to the models by focusing on host-rock lithology and tectonic setting, the features most apparent to the geologist preparing a map. The system is nearly parallel to a genetic arrangement for syngenetic ores, but it diverges strongly for the epigenetic where it creates some strange juxtapositions of deposit types. Possible ambiguities are accommodated, at least in part, by using multiple entries in the master list (this refers to a table not included here).

In considering ways to make the model compilation as useful as possible, we have become concerned about ways to enhance the ability of the relatively inexperienced geoscientist to find the model(s) applicable to his or her observations. Therefore, we have included extensive tables of attributes in which the appropriate models are identified.

Our most important immediate goal is to provide assistance to those persons engaged in mineral resource assessment or exploration. An important secondary goal is to upgrade the quality of our model compilation by encouraging (or provoking?) input from those whose experience has not yet been captured in the existing models. Another target is to identify specific research needs whose study is particularly pertinent to the advance of the science. We have chosen to err on the side of redundancy at the expense of neatness, believing that our collective understanding is still too incomplete to rule out some alternative interpretations. Thus we almost certainly have set up as separate models some types that will ultimately be blended into one, and there surely are groupings established here that will subsequently be divided. We also recognize that significant gaps in coverage still exist. Even at this stage the model compilation is still experimental in several aspects and continues to evolve. The

product in hand can be useful today. We anticipate future editions, versions, and revisions, and we encourage suggestions for future improvements."

1/Erickson, R. L. (compiler). Characteristics of Mineral Deposit Occurrences. USGS Open-File Rep. 82-795, 1982.

2/Hodges, C. A., D. P. Cox, D. A. Singer, J. E. Case, B. R. Berger, and J. P. Albers. U.S. Geological Survey-INGEOMINAS Mineral Resource Assessment of Columbia. USGS Open-File Rep. 84-345, 1984.

3/Cox, D. P., ed. U.S. Geological Survey-INGEOMINAS Mineral Resource Assessment of Columbia; Ore Deposit Models. USGS Open-File Rep. 83-423, 1983a.

4/Cox, D. P. U.S. Geological Survey-INGEOMINAS Mineral Resource Assessment of Columbia; Additional Ore Deposit Models. USGS Open-File Rep. 83-901, 1983b.

5/Singer, D. A. and D. L. Mosier, eds. Mineral Deposit Tonnage-Grade Models. USGS Open-File Rep. 83-623, 1983a.

6/_____. Mineral Deposit Tonnage-Grade Models II. USGS Open-File Rep. 83-902, 1983b.

7/Eckstrand, O. R., ed. Canadian Mineral Deposit Types, a Geological Synopsis. Geol. Surv. of Canada, Econ. Geol. Rep. 36, 1984.

2.1.4.1 Model Selection Rationale

The rationale for selection of deposit models for inclusion in this document is based on information and hypotheses taken from the literature on Yucca Mountain and the southern Basin and Range Province, and assumptions made about the Yucca Mountain vicinity in consideration of such information. The principal information sources used in the selection process include, but are not limited to, the following:

(1) U.S. Geological Survey Bulletins, Professional Papers, Information Circulars, Maps, Bulletins, and Open-file Reports, primarily dealing with Yucca Mountain and vicinity;

(2) Publications of the Nevada Bureau of Mines and Geology;

(3) NRC and NRC contractor publications;

(4) Publications by Lawrence Livermore and Los Alamos National Laboratories;

(5) U.S. Bureau of Mines publications;

(6) Various text and reference volumes;

(7) DOE publications including Environmental Assessment of the Yucca Mountain Site (8), Consultation Draft, Site Characterization Plan (9), and the Site Characterization Plan (10). Information on tectonic history and the regional tectonic setting was taken largely from Chapter 1 (Geology) of the Site Characterization Plan (10).

Information from the above sources was examined and a number of important points on which to base assumptions, and subsequently, the selection of deposit models, were identified; these points are listed below:

(1) Yucca Mountain consists in the main of a thick sequence of calc-alkaline ash-flow tuffs (11).

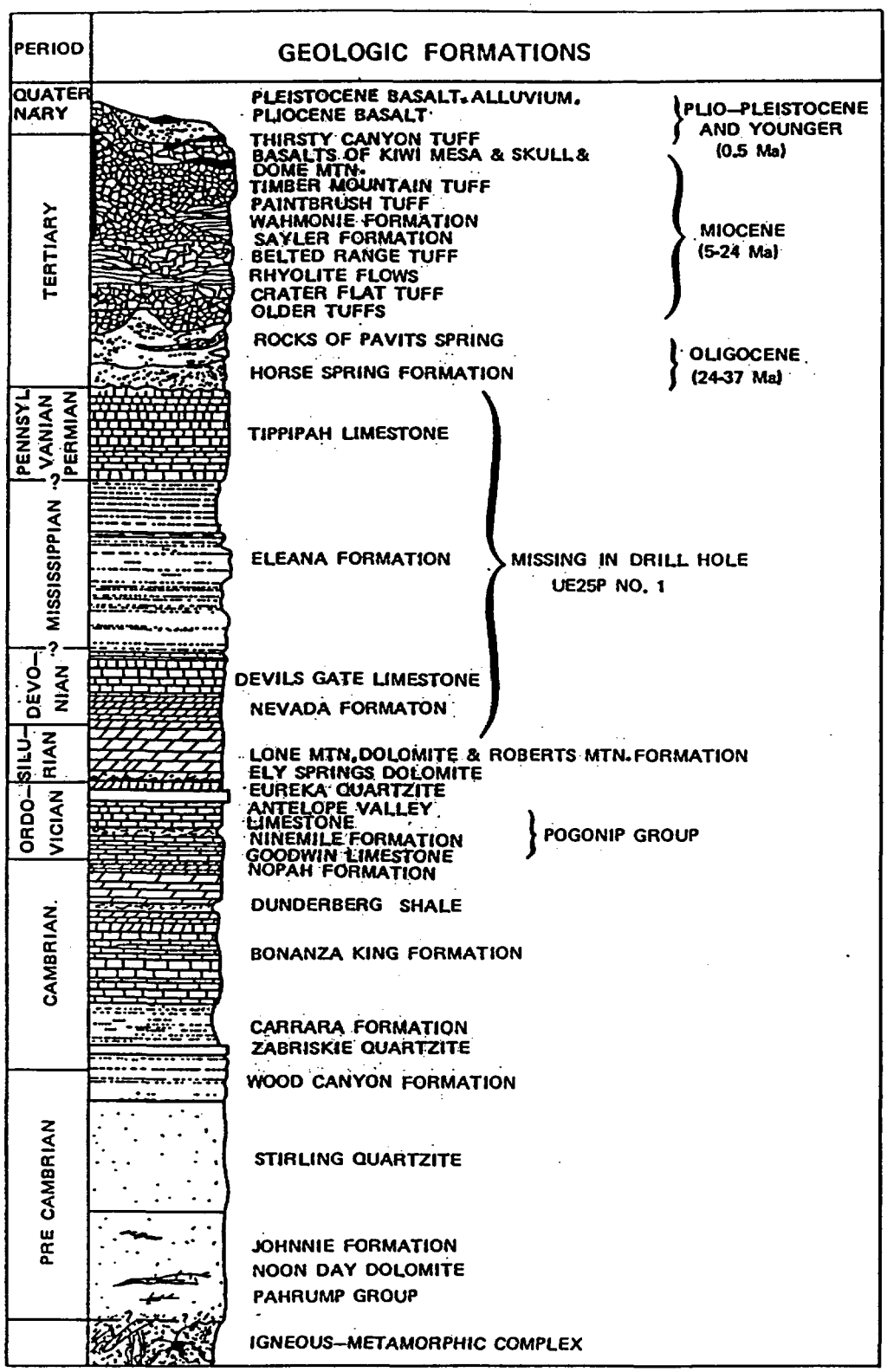
(2) The site is underlain at various depths by Paleozoic rocks of undetermined thickness (12) that may host resources in a wide variety of deposit types (see Figure 2). Possible depositional scenarios may include, but are not limited to: A. mineralization of Paleozoic and/or Tertiary rocks by hydrothermal fluids emanating from deeply buried plutons (most likely granitic, but mafic bodies cannot be ruled out) postulated to exist beneath and proximal to the site (13, 14); B. mineral deposits related to an underlying metamorphic core complex (15); C. mineralization related to possible contact metasomatism; or D. dissolution, concentration, transportation, and subsequent redeposition of mineral material along one or more postulated underlying low-angle faults (16) by circulating meteoric waters heated by a magma source beneath Crater Flat and adjacent to Yucca Mountain. The circulating hot water scenario has been suggested by Odt (17) as a possible genetic model for the emplacement of gold deposits in Paleozoic rocks at the Sterling Mine on the east flank of Bare Mountain.

(3) Potentially large fault/breccia zones such as Windy Wash Fault, Solitario Canyon Fault, Bow Ridge Fault, Fran Ridge Fault, and Ghost Dance Fault have been identified on the flanks and cutting Yucca Mountain. These zones, especially those on the margin of Crater Flat (Windy Wash, Solitario Canyon), may represent sites of mineral deposition.

(4) Underlying Paleozoic rocks may be lithologically and structurally similar to rocks northeast of the site that are documented hydrocarbon producers (18). Further, Chamberlain (18) hypothesizes that an overthrust belt, analogous to that in Utah/Wyoming, in which Mesozoic thrusting has placed permeable Devonian carbonates over organic-rich Mississippian rocks exists in central Nevada. Both rock types, presumably, are capped by relatively impervious Mississippian black shales.

(5) Postulated heat sources (perhaps related to the Crater Flat/Prospector Pass Caldera Complex or buried plutons) and circulating ground water may constitute yet to be identified geothermal resources or may have formed mineralized areas within fossil geothermal systems. Figure 3 shows the spatial relationship of Yucca Mountain to major calderas and caldera complexes in the southwestern Nevada volcanic field.

(6) The tectonic setting of Yucca Mountain is generally characterized by Proterozoic continental rifting; Paleozoic subsidence with deposition of miogeosynclinal sediments; late Cretaceous-early Tertiary east-directed faulting; widespread Tertiary extensional tectonism and volcanism (19, pp. 84-88).



Modified from Yucca Mtn Site Characterization Plan (1988)

FIGURE 2.– Generalized stratigraphic column, Yucca Mountain area

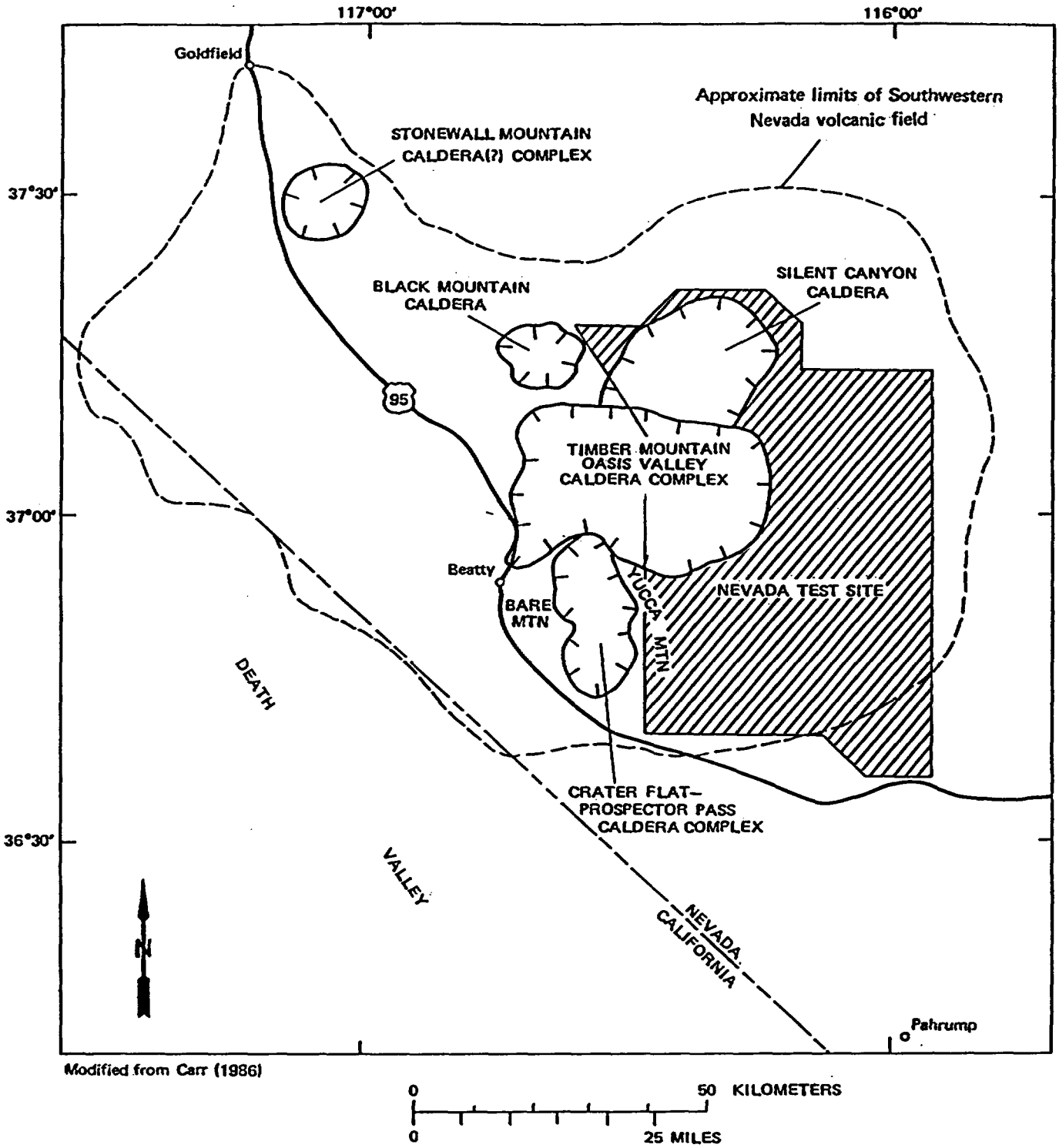


FIGURE 3.– Location of Yucca Mountain with respect to calderas and caldera complexes in southwestern Nevada volcanic field

Based on the above information and for the purpose of selecting possible deposit models applicable to Yucca Mountain, the following assumptions have been made:

(1) Paleozoic sediments underlie Yucca Mountain at depth;

(2) Plutonic rocks possibly underlie and intrude the Paleozoic sediments under at least a portion of the proposed site;

(3) A metamorphic core complex may exist beneath Yucca Mountain (Figure 2);

(4) Crater Flat represents a portion of the Crater Flat/Prospector Pass Caldera Complex as suggested by Carr and others (20);

(5) Based on assumptions in 4 above and the presence of basaltic cones in Crater Flat, and basaltic dikes on Yucca Mountain, a magma chamber possibly underlies Crater Flat at an undetermined depth;

(6) It is possible that technical advances over the next 10,000 years will allow economic extraction of resources resources at much greater depths than currently feasible;

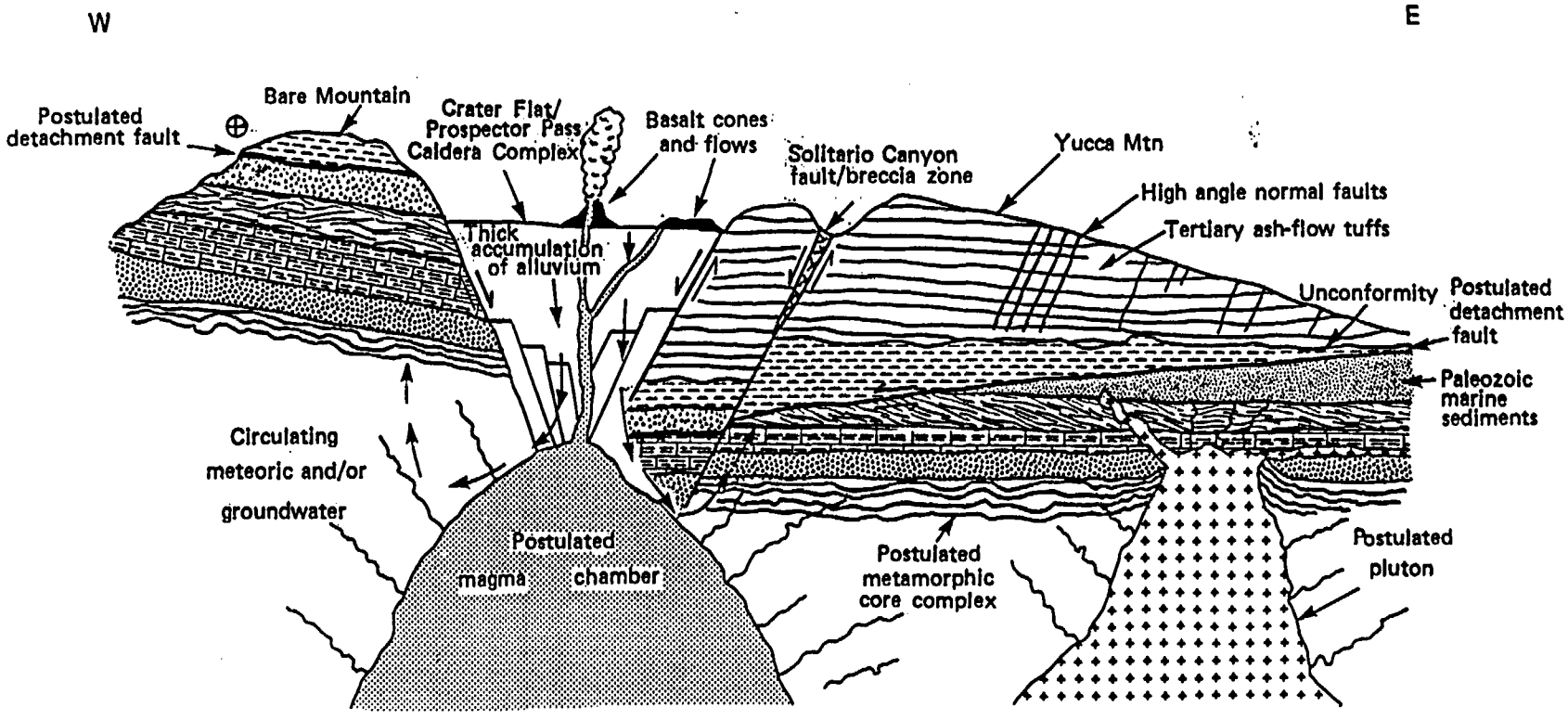
(7) Advances in drilling technology over the next 10,000 years will allow large boreholes to be drilled to much greater depths in much shorter times;

(8) Depletion of near surface resources and changes in economics over the next 10,000 years will make exploration/extraction at greater depths more likely.

Information and assumptions presented above were compiled and summarized and are schematically presented in Figure 4 to illustrate possible environments that could engender one or more of the deposit models presented here. The diagram is not drawn to scale, bedding attitudes may not conform to map data, and specific rock types are not identified with the exception of a distinction between Paleozoic and Tertiary accumulations. Furthermore, relative sizes of the features (e.g., buried pluton, magma chamber, detachment fault), attitudes of underlying low-angle normal or reverse faults, and spatial relationships are purely conjectural. Possible geothermal, hydrocarbon, or potable water resources are not included.

2.1.4.2 Descriptive Models

The following descriptive models have been selected as representing possible resources that may occur on, in, beneath, or proximal to Yucca Mountain. Geochemical and geophysical exploration methods applicable to a particular model or models are presented in Sections 2.1.5.3 and 2.1.5.4, respectively. The locations of deposits used as examples for the model (country, state, or other political subdivision, etc.) are listed in Appendix A.



EXPLANATION

⊕ Fault movement into page

FIGURE 4.– Cartoon showing possible geological features and environments underlying and proximal to Yucca Mountain; possible hydrocarbon resources not included

HOT-SPRING AU-AG 1/, 2/

(See Figure 5)

DESCRIPTION: Fine-grained silica and quartz in silicified breccia with Au, pyrite, and Sb and As sulfides.

PRIMARY REFERENCE(S): (21).

GEOLOGIC ENVIRONMENT:

Rock Type: Rhyolite.

Textures: Porphyritic, brecciated.

Age Range: Mainly Tertiary and Quaternary.

Depositional Environment: Subaerial rhyolitic volcanic centers, rhyolite domes, and shallow parts of related geothermal systems.

Tectonic Setting: Through-going fracture systems related to volcanism above subduction zone, rifted continental margins. Leaky transform faults.

Associated Deposit Types: Epithermal quartz veins, hot spring Hg, placer Au.

DEPOSIT DESCRIPTION:

Mineralogy: Native Au + pyrite + stibnite + realgar; or arsenopyrite ± sphalerite ± fluorite; or native Au + Ag-selenide or tellurides + pyrite.

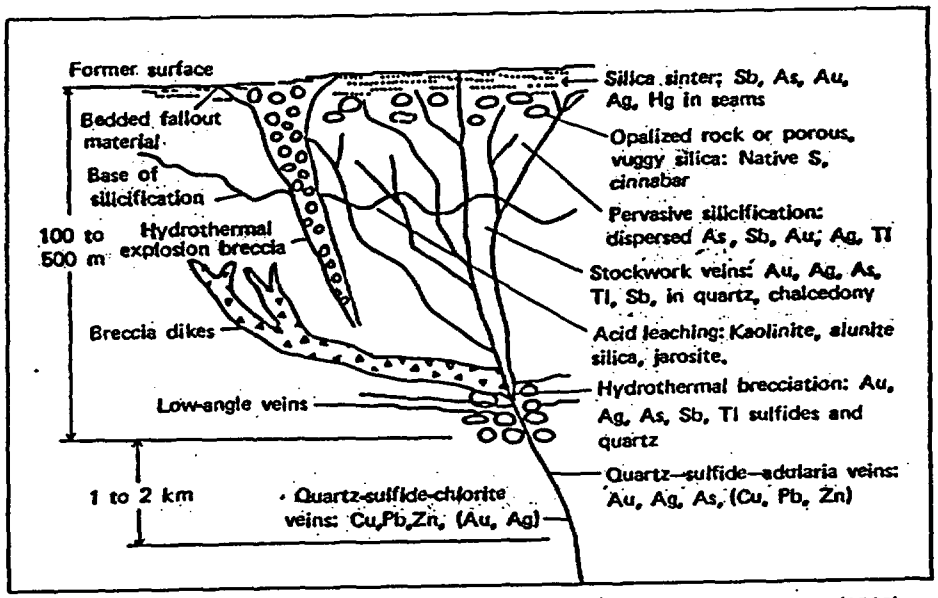
Texture/Structure: Crustified banded veins, stockworks, breccias (cemented with silica or uncemented). Sulfides may be fine grained and disseminated in silicified rock.

Alteration: Top to bottom of system: chalcedonic sinter, massive silicification, stockworks of quartz + adularia and breccia cemented with quartz, quartz + chlorite. Veins generally chalcedonic, some opal. Some deposits have alunite and pyrophyllite. Ammonium feldspar (buddingtonite) may be present.

Ore Controls: Through-going fracture systems, brecciated cores of intrusive domes; cemented breccias important carrier of ore.

1/Modified from Berger, B. R. Descriptive Model of Hot-Spring Au-Ag. Paper in Mineral Deposit Models, D. P. Cox and D. A. Singer, eds. USGS Bull. 1693, 1986, p. 143.

2/An economic/extraction model for this deposit type is presented in Section 2.4.3.



Redrawn from Cox and Singer (1986)

FIGURE 5.– Schematic cross-section of hot-spring Au-Ag deposit

Weathering: Bleached country rock, yellow limonites with jarosite and fine-grained alunite, hematite, goethite.

Geochemical Signature: Au + As + Sb + Hg + Tl higher in system, increasing Ag with depth, decreasing As + Sb + Tl + Hg with depth. Locally, NH4, W.

Examples:

McLaughlin, USCA 2/, (22,23) *.
Round Mountain, USNV, (24) **.
Delamar, USID, (25) *.

* Additional nonproprietary information available through BOM Mineral Industry Location System (MILS).
** Additional information available in Lowe, Raney, and Norberg, BOM IC 9035, pp. 162.

HOT-SPRING Hg 1/

APPROXIMATE SYNONYM: Sulfur Bank type of White (26) or sulfurous type of Bailey and Phoenix (27).

DESCRIPTION: Cinnabar and pyrite disseminated in siliceous sinter superjacent to graywacke, shale, andesite, and basalt flows and diabase dikes.

PRIMARY REFERENCE(S): (26),(28).

GEOLOGIC ENVIRONMENT

Rock Types: Siliceous sinter, andesite-basalt flows, diabase dikes, andesitic tuffs, and tuff breccias.

Age Range: Tertiary.

Depositional Environment: Near paleo ground water table in areas of fossil hot spring system.

Tectonic Setting(s): Continental margin rifting associated with small volume mafic to intermediate volcanism.

Associated Deposit Types: Hot-spring Au.

DEPOSIT DESCRIPTION

Mineralogy: Cinnabar + native Hg + minor marcasite.

Texture/Structure: Disseminated and coatings on fractures in hot spring sinter.

Alteration: Above paleo ground water table, kaolinite-alunite-Fe oxides, native sulfur; below paleo ground water table, pyrite, zeolites, potassium feldspar, chlorite, and quartz. Opal deposited at the paleo water table.

Ore Controls: Paleo ground water table within hot spring systems formed along high-angle faults.

Geochemical Signature: Hg + As + Sb $\pm$ Au.

Examples: Sulfur Bank, USCA (28).

1/Modified from White, D. E. Descriptive Model - Hot-Spring Hg. Paper in Mineral Deposit Models, D. P. Cox and D. A. Singer, eds. USGS Bull. 1693, 1986, p. 178.

CREEDE EPITHERMAL VEINS 1/

(See Figure 6)

APPROXIMATE SYNONYM: Epithermal gold (quartz-adularia) alkali-chloride-type, polymetallic veins.

DESCRIPTION: Galena, sphalerite, chalcopyrite, sulfosalts, ± tellurides, ± gold in quartz-carbonate veins hosted by felsic to intermediate volcanics. Older miogeosynclinal evaporites or rocks with trapped seawater are associated with these deposits.

GENERAL REFERENCES: (29), (30).

GEOLOGICAL ENVIRONMENT

Rock Types: Host rocks are andesite, dacite, quartz latite, rhyodacite, rhyolite, and associated sedimentary rocks. Mineralization related to calc-alkaline or bimodal volcanism.

Textures: Porphyritic.

Age Range: Mainly Tertiary (most are 29-4 m.y.).

Depositional Environment: Bimodal and calc-alkaline volcanism. Deposits related to sources of saline fluids in prevolcanic basement such as evaporites or rocks with entrapped seawater.

Tectonic Setting: Through-going fracture systems; major normal faults, fractures related to doming, ring fracture zones, joints associated with calderas. Underlying or nearby older rocks of continental shelf with evaporite basins, or island arcs that are rapidly uplifted.

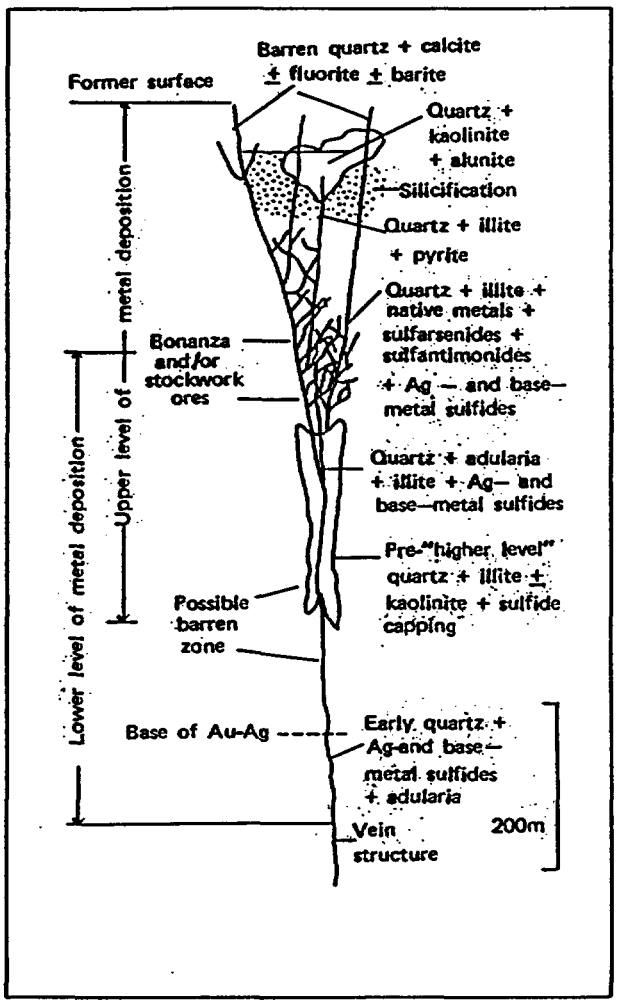
Associated Deposit Types: Placer gold, epithermal quartz-alunite, Au, polymetallic replacement.

DEPOSIT DESCRIPTION

Mineralogy: Galena + sphalerite + chalcopyrite + copper sulfosalts + silver sulfosalts ± gold ± tellurides ± bornite ± arsenopyrite. Gangue minerals are quartz + chlorite ± calcite + pyrite + rhodochrosite + barite ± fluorite ± siderite ± ankerite ± sericite ± adularia ± kaolinite. Specularite and alunite may be present.

Texture/Structure: Banded veins, open space filling, lamellar quartz, stockworks, colloform textures.

1/Modified from Mosier, D. L., T. Sato, N. J. Page, D. A. Singer, and B. R. Berger. Descriptive Model of Creede Epithermal Veins. Paper in Mineral Deposit Models, D. P. Cox and D. A. Singer, eds. USGS Bull. 1693, 1986, p. 145.



Redrawn from Cox and Singer (1986)

FIGURE 6.– Schematic cross-section of typical Creede-type epithermal vein deposit

Alteration: Top to bottom: quartz ± kaolinite + montmorillonite ± zeolites ± barite ± calcite; quartz + illite; quartz + adularia ± illite; quartz + chlorite; presence of adularia is variable.

Ore Controls: Through-going or anastomosing fracture systems. High-grade shoots where vein changes strike or dip and at intersections of veins. Hanging-wall fractures are particularly favorable.

Weathering: Bleached country rock, goethite, jarosite, alunite--supergene processes often important factor in increasing grade of deposit.

Geochemical Signature: Higher in system Au + As + sb + Hg; au + ag + Pb + Zn + Cu; Ag + Pb + Zn, Cu + Pb + Zn. Base metals generally higher grade in deposits with Ag. W + Bi may be present.

Examples: Creede, CO (31),(32) *
Pachuca, MXCO (33)
Toyoha, JAPN (34)

* Additional non-proprietary information available through BOM Mineral Industry Location System (MILS).

REPLACEMENT SN 1/

APPROXIMATE SYNONYM: Exhalative Sn (35),(36).

DESCRIPTION: Stratabound cassiterite-sulfide (chiefly pyrrhotite) replacement of carbonate rocks and associated fissure lodes related to underlying granitoid complexes.

PRIMARY REFERENCE(S): (37).

GEOLOGIC ENVIRONMENT:

Rock Type: Carbonate rocks (limestone or dolomite); granite, monzogranite, quartz porphyry dikes generally present; quartz-tourmaline rock; chert, pelitic and Fe-rich sediments, and volcanic rocks may be present.

Textures: Plutonic (equigranular, seriate, porphyritic).

Age Range: Paleozoic and Mesozoic most common; other ages possible.

Depositional Environment: Epizonal granitic complexes in terranes containing carbonate rocks. NOTE: The genetic replacement classification for these deposits has been questioned and an alternative exhalative synsedimentary origin followed by postdepositional metamorphic reworking hypothesis proposed (35), (36), (38).

Tectonic Setting(s): Late orogenic to post orogenic passive emplacement of high-level granitoids in foldbelts containing carbonate rocks; alternatively, Sn and associated metals were derived from submarine exhalative processes with subsequent reequilibration of sulfide and silicate minerals.

Associated Deposit Types: Greisen-style mineralization, quartz-tourmaline-cassiterite veins, Sn-W-Mo stockworks, Sn-W skarn deposits close to intrusions.

DEPOSIT DESCRIPTION:

Mineralogy: Pyrrhotite + arsenopyrite + cassiterite + chalcopyrite (may be major) + ilmenite + fluorite; minor: pyrite, sphalerite, stannite, tetrahedrite, magnetite; late veins: sphalerite + galena + chalcopyrite + pyrite + fluorite.

Texture/Structure: Vein stockwork ores, and massive ores with laminations following bedding in host rock, locally cut by stockwork veins, pyrrhotite may be recrystallized.

1/Modified from Reed, B. L. Descriptive Model of Replacement Sn. Paper in Mineral Deposit Models, D. P. Cox and D. A. Singer, eds. USGS Bull. 1693, 1986, p. 61.

Alteration: Griesenization (± cassiterite) near granite margins; sideritic alteration of dolomite near sulfide bodies; tourmalinization of clastic sediments; proximity to intrusions may produce contact aureoles in host rocks.

Ore Controls: Replacement of favorable carbonate units; fault-controlled fissure lodes common. Isolated replacement ore bodies may lie above granitoid cupolas; faults provide channels for mineralizing fluids.

Geochemical Signature: Sn, As, Cu, B, W, F, Li, Pb, Zn, Rb.

Examples: Renison Bell, AUTS (37).
Cleveland, AUTS (39).
Mt. Bischoff, AUTS (40).
Changpo-Tongkeng, CINA (41).

EPITHERMAL QUARTZ-ALUNITE Au 1/

APPROXIMATE SYNONYM: Acid-sulfate, or enargite gold (42).

DESCRIPTION: Gold, pyrite, and enargite in vuggy veins and breccias in zones of high-alumina alteration related to felsic volcanism.

PRIMARY REFERENCE(S): (42).

GEOLOGIC ENVIRONMENT

Rock Types: Volcanic: dacite, quartz latite, rhyodacite, rhyolite. Hypabyssal intrusions or domes.

Textures: Porphyritic.

Age Range: Generally Tertiary, but can be any age.

Depositional Environment: Within the volcanic edifice, ring fracture zones of calderas, or areas of igneous activity with sedimentary evaporites in basement.

Tectonic Setting(s): Through-going fracture systems: keystone graben structures, ring fracture zones, normal faults, fractures related to doming, joint sets.

Associated Deposit Types: Porphyry copper, polymetallic replacement, volcanic hosted Cu-As-Sb. Pyrophyllite, hydrothermal clay, and alunite deposits.

DEPOSIT DESCRIPTION

Mineralogy: Native gold + enargite + pyrite + silver-bearing sulfosalts ± chalcopyrite ± bornite ± precious-metal tellurides ± galena ± sphalerite ± huebnerite. May have hypogene oxidation phase with chalcocite ± covellite ± luzonite with late-stage native sulfur.

Alteration: Highest temperature assemblage: quartz + alunite + pyrophyllite may be early stage with pervasive alteration of host rock and veins of these minerals; this zone may contain corundum, diaspore, andalusite, or zunyite. Zoned around quartz-alunite is quartz + alunite + kaolinite + montmorillonite; pervasive propylitic alteration (chlorite + calcite) depends on extent of early alunitization. Ammonium-bearing clays may be present.

1/Modified from Berger, B. R. Descriptive Model of Epithermal Quartz--Alunite Au. Paper in Mineral Deposit Models, D. P. Cox and D. A. Singer, eds. USGS Bull. 1693, 1986, p. 158.

Ore Controls: Through-going fractures, centers of intrusive activity. Upper and peripheral parts of porphyry copper systems.

Weathering: Abundant yellow limonite, jarosite, goethite, white argillization with kaolinite, fine-grained white alunite veins, hematite.

Geochemical Signature: Higher in system: Au + As + Cu; increasing base metals at depth. Also Te and (at El Indio) W.

Examples: Goldfield, USNV (43) *, **.
Kasuga Mine, JAPN (44).
El Indio, CILE (45).
Summitville, USCO (46) *.
Iwato, JAPN (47).

* Additional nonproprietary information available through BOM Mineral Industry Location System (MILS).
** Additional information available in Lowe, Raney, and Norberg, BOM IC 9035. p. 115.

PORPHYRY MO, LOW-F 1/

APPROXIMATE SYNONYM: Calc-alkaline Mo stockwork (48).

DESCRIPTION: Stockwork of quartz-molybdenite veinlets in felsic porphyry and in its nearby country rock.

PRIMARY REFERENCE(S): (48).

GEOLOGIC ENVIRONMENT

Rock Types: Tonalite, granodiorite, and monzogranite.

Textures: Porphyry, fine aplitic groundmass.

Age Range: Mesozoic and Tertiary.

Depositional Environment: Orogenic belt with calcalkaline intrusive rocks.

Tectonic Setting(s): Numerous faults.

Associated Deposit Types: Porphyry Cu-Mo, Cu skarn, volcanic hosted Cu-As-Sb.

DEPOSIT DESCRIPTION

Mineralogy: Molybdenite + pyrite ± scheelite ± chalcopyrite ± argentian tetrahedrite. Quartz ± K-feldspar ± biotite ± calcite ± white mica and clays.

Texture/Structure: Disseminated and in veinlets and fractures.

Alteration: Potassic outward to propylitic. Phyllic and argillic overprint.

Ore Controls: Stockwork in felsic porphyry and in surrounding country rock.

Weathering: Yellow ferrimolybdite after molybdenite. Secondary copper enrichment may form copper ores in some deposits.

Geochemical Signature: Zoning outward and upward from Mo + Cu ± W to Cu + Au to Zn + Pb, + Au, + Ag. F may be present but in amounts less than 1,000 ppm.

1/Modified from Theodore, T. G. Description of Porphyry Mo, Low-F. Paper in Mineral Deposit Models, D. P. Cox and D. A. Singer, eds. USGS Bull. 1693, 1986, p. 120.

Examples: Buckingham, USNV (49) *, **.
USSR deposits (50).

* Additional nonproprietary information available through BOM Mineral Industry Location System (MILS).
** Additional information available in Lowe, Raney, and Norberg, BOM IC 9035. p. 90.

EPITHERMAL MN 1/

DESCRIPTION: Manganese mineralization in epithermal veins, filling, faults, and fractures in subaerial volcanic rocks.

PRIMARY REFERENCE: None.

GEOLOGIC ENVIRONMENT

Rock Types: Flows, tuffs, breccias, and agglomerates of rhyolitic, dacitic, andesitic or basaltic composition.

Age Range: Tertiary.

Depositional Environment: Volcanic centers.

Tectonic Setting(s): Through-going fracture systems.

Associated Deposit Types: Epithermal gold-silver.

DEPOSIT DESCRIPTION

Mineralogy: Rhodochrosite, manganocalcite, calcite, quartz, chalcedony, barite, and zeolites.

Texture/Structure: Veins, bunches, stringers, nodular masses, and disseminations.

Alteration: Kaolinitization.

Ore Controls: Through-going faults and fractures; brecciated volcanic rocks.

Weathering: Oxidization zone contains abundant manganese oxides, psilomelane, pyrolusite, braunite, wad, manganite, cryptomelane, hollandite, coronadite, and Fe oxides.

Geochemical Signature: Mn, Fe, P (Pb, Ag, Au, Cu). At Talamantes, W is important.

Examples: Talamantes, MXCO (51).
Gloryana, USNM (52) *.
Sardegna, ITLY (53).

* Additional nonproprietary information available through BOM Mineral Industry Location System (MILS).

1/Modified from Mosier, D. L. Descriptive Model of Epithermal Mn. Paper in Mineral Deposit Models, D. P. Cox and D. A. Singer, eds. USGS Bull. 1693, 1986, p. 165.

CARBONATE-HOSTED AU-AG 1/, 2/

APPROXIMATE SYNONYM: Carlin-type or "invisible" (microscopic) gold.

DESCRIPTION: Fine-grained gold and sulfides disseminated in carbonaceous calcareous rocks and associated jasperoids.

PRIMARY REFERENCE(S): (54).

GEOLOGIC ENVIRONMENT

Rock Types: Host rocks: thin-bedded silty or argillaceous carbonaceous limestone or dolomite, commonly with carbonaceous shale. Intrusive rocks: felsic dikes.

Textures: Dikes are generally porphyritic.

Age Range: Mainly Tertiary, but can be any age.

Depositional Environment: Best host rocks formed as carbonate turbidites in somewhat anoxic environments. Deposits formed where these are intruded by igneous rocks under nonmarine conditions.

Tectonic Setting(s): High-angle normal fault zones related to continental margin rifting.

Associated Deposit Types: W-Mo skarn, porphyry Mo, placer Au, and stibnite-barite veins.

DEPOSIT DESCRIPTION

Mineralogy: Native gold (very fine-grained) + pyrite + realgar + orpiment ± arsenopyrite ± cinnabar ± fluorite ± barite ± stibnite. Quartz, calcite, and carbonaceous matter.

Texture/Structure: Silica replacement of carbonate. Generally less than 1 percent fine-grained sulfides.

1/Modified from Berger, B. R. Descriptive Model of Carbonate-Hosted Au-Ag. Paper in Mineral Deposit Models, D. P. Cox and D. A. Singer, eds. USGS Bull. 1693, 1986, p. 175.

2/An economic/extraction model for this deposit type is presented in Section 2.4.2.

Alteration: Unoxidized ore: jasperoid + quartz + illite + kaolinite + calcite. Abundant amorphous carbon locally appears to be introduced. Hypogene oxidized ore: kaolinite + montmorillonite + illite + jarosite + alunite. Ammonium clays may be present.

Ore Controls: Selective replacement of carbonaceous carbonate rocks adjacent to and along high-angle faults, or regional thrust faults or bedding.

Weathering: Light-red, gray, and (or) tan oxides, light-brown to reddish-brown iron-oxide-stained jasperoid.

Geochemical Signature: Au + As + Hg + W $\pm$ Mo; As + Hg + Sb + Tl $\pm$ F (this stage superimposed on preceding); NH_3 important in some deposits.

Examples: Carlin, USNV (55) *, **.
Getchell, USNV (56) *, **.
Mercur, USUT (57) *.

* Additional nonproprietary information available through BOM Mineral Industry Location System (MILS).
** Additional information available in Lowe, Raney, and Norberg, BOM IC 9035, pp. 96, 112, respectively.

SIMPLE SB DEPOSITS 1/

APPROXIMATE SYNONYM: Deposits of quartz-stibnite ore (58).

DESCRIPTION: Stibnite veins, pods, and disseminations in or adjacent to brecciated or sheared fault zones.

PRIMARY REFERENCE(S): (59, 60).

GEOLOGIC ENVIRONMENT

Rock Types: One or more of the following lithologies is found associated with over half of the deposits: limestone, shale (commonly calcareous), sandstone, and quartzite. Deposits are also found with a wide variety of other lithologies including slate, rhyolitic flows and tuffs, argillite, granodiorite, granite, phyllite, siltstone, quartz mica and chloritic schists, gneiss, quartz porphyry, chert, diabase, conglomerate, andesite, gabbro, diorite, and basalt.

Textures: Not diagnostic.

Age Range: Known deposits are Paleozoic to Tertiary.

Depositional Environment: Faults and shear zones.

Tectonic Setting(s): Any orogenic area.

Associated Deposit Types: Stibnite-bearing veins, pods, and disseminations containing base metal sulfides ± cinnabar ± silver ± gold ± scheelite that are mined primarily for lead, gold, silver, zinc, or tungsten; low-sulfide Au-quartz veins; epithermal gold and gold-silver deposits; hot springs gold; carbonate-hosted gold; tin-tungsten veins; hot springs and disseminated mercury, gold-silver placers; infrequently with polymetallic veins and tungsten skarns.

DEPOSIT DESCRIPTION

Mineralogy: Stibnite + quartz ± pyrite ± calcite; minor other sulfides frequently less than 1 percent of deposit and included ± arsenopyrite ± sphalerite ± tetrahedrite ± chalcopyrite ± scheelite ± free gold; minor minerals only occasionally found include native antimony, marcasite, calaverite, berthierite, argentite, pyrargyrite, chalcocite, wolframite, richardite, galena, jamesonite; at least a third (and possibly more) of the deposits contain gold or silver. Uncommon gangue minerals include chalcedony, opal (usually identified to be christobalite by X-ray), siderite, fluorite, barite, and graphite.

1/Modified from Bliss, J. D. and G. J. Orris. Description Model of Simple Sb Deposits. Paper in Mineral Deposit Models, D. P. Cox and D. A. Singer, eds. USGS Bull. 1693, 1986, p. 183.

Texture/Structure: Vein deposits contain stibnite in pods, lenses, kidney forms, pockets (locally); may be massive or occur as streaks, grains, and bladed aggregates in sheared or brecciated zones with quartz and calcite. Disseminated deposits contain streaks or grains of stibnite in host rock with or without stibnite vein deposits.

Alteration: Silicification, sericitization, and argillization; minor chloritization; serpentinization when deposit in mafic, ultramafic rocks.

Ore Controls: Fissures and shear zones with breccia usually associated with fault; some replacement in surrounding lithologies; infrequent open-space filling in porous sediments and replacement in limestone. Deposition occurs at shallow to intermediate depth.

Weathering: Yellow to reddish kermesite and white cerrantite or stibiconite (Sb oxides) may be useful in exploration; residual soils directly above deposits are enriched in antimony.

Geochemical Signature: Sb $\pm$ Fe $\pm$ As $\pm$ Au $\pm$ Ag; Hg $\pm$ W $\pm$ Pb $\pm$ Zn may be useful in specific cases.

Examples: Amphoe Phra Saeng, THLD (61).
Caracota, BLVA (62).

GOLD ON FLAT AND ASSOCIATED HIGH-ANGLE FAULTS 1/

DESCRIPTION: Disseminated gold in breccia along low-angle faults.

PRIMARY REFERENCE(S): (63).

GEOLOGIC ENVIRONMENT

Rock Types: Breccia derived from granitic rocks, gneiss, schist, mylonite, and unmetamorphosed sedimentary and volcanic rocks. Rhyolitic dikes and plugs.

Textures: Chaotic jumble of rock and vein material.

Age Range: Unknown. Examples in southern California and southwestern Arizona are mainly Mesozoic and Tertiary.

Depositional Environment: Permeable zones: source of heat and fluids unknown.

Tectonic Setting(s): Low-angle faults in crystalline and volcanic terrane. Includes detachment faults related to some metamorphic core complexes and thrust faults related to earlier compressive regimes.

Associated Deposit Types: Epithermal quartz adularia veins in hanging-wall rocks of some districts.

DEPOSIT DESCRIPTION

Mineralogy: Gold, hematite, chalcopyrite, minor bornite, barite, and fluorite.

Texture/Structure: Micrometer-size gold and specular hematite in stockwork veining and brecciated rock.

Alteration: Hematite, quartz, and chlorite. Silicification. Carbonate minerals.

Ore Controls: Intensely brecciated zones along low-angle faults. Steep normal faults in hanging wall. Sheeted veins.

Weathering: Most ore is in oxidized zone because of lower cost of recovery. Mn oxides.

Geochemical Signature: Au, Cu, Fe, F, Ba. Very low level anomalies in Ag, As, Hg, and W.

1/Modified from Bouley, B. A. Descriptive Model of Gold on Flat Faults. Paper in Mineral Deposit Models, D. P. Cox and D. A. Singer, eds. USGS Bull. 1693, 1986, pp. 251.

Examples: Picacho, USCA (64) *.
Copper Penny and Swansea, USAZ (65) *.

* Additional nonproprietary information available through BOM Mineral Industry Location System (MILS).

BEDDED BARITE 1/

APPROXIMATE SYNONYM: Stratiform barite.

DESCRIPTION: Stratiform deposits of barite interbedded with dark-colored cherty and calcareous sedimentary rocks.

PRIMARY REFERENCE: None.

GEOLOGIC ENVIRONMENT

Rock Types: Generally dark-colored chert, shale, mudstone, limestone or dolostone. Also with quartzite, argillite, and greenstone.

Age Range: Proterozoic and Paleozoic.

Depositional Environment: Epicratonic marine basins or embayments (often with smaller local restricted basins).

Tectonic Setting(s): Some deposits associated with hinge zones controlled by synsedimentary faults.

Associated Deposit Types: Sedimentary exhalative Zn-Pb.

DEPOSIT DESCRIPTION

Mineralogy: Barite ± minor witherite ± minor pyrite, galena, or sphalerite. Barite typically contains several percent organic matter plus some H_2S in fluid inclusions.

Texture/Structure: Stratiform, commonly lensoid to poddy; ore laminated to massive with associated layers of barite nodules or rosettes; barite may exhibit primary sedimentary features. Small country rock inclusions may show partial replacement by barite.

Alteration: Secondary barite veining; weak to moderate sericitization has been reported in or near some deposits in Nevada.

Ore Controls: Deposits are localized in second- and third-order basins.

Weathering: Indistinct, generally resembling limestone or dolostone; occasionally weather-out rosettes or nodules.

Geochemical Signature: Ba; where peripheral to sediment-hosted Zn-Pb, may have lateral (Cu)-Pb-Zn-Ba zoning or regional manganese haloes. High organic C content.

1/Modified from Orris, G. J. Descriptive Model of Bedded Barite. Paper in Mineral Deposit Models, D. P. Cox and D. A. Singer, eds. USGS Bull. 1693, 1986, p. 216.

Examples: Meggen, GRMY (66).
Magnet Cove, USAR (67) *.
Northumberland, USNV (68) **.

* Additional nonproprietary information available through BOM Mineral Industry Location System (MILS).
** Additional information available in Lowe, Raney, and Norberg, BOM IC 9035, p. 143.

REPLACEMENT MN 1/

DESCRIPTION: Manganese oxide minerals occur in epigenetic veins or cavity fillings in limestone, dolomite, or marble, which may be associated with intrusive complexes.

PRIMARY REFERENCE: None.

GEOLOGIC ENVIRONMENT

Rock Types: Limestone, dolomite, marble, and associated sedimentary rocks; granite and granodiorite plutons.

Age Range: Mainly Paleozoic to Tertiary, but may be any age.

Depositional Environment: Miogeosynclinal sequences intruded by small plutons.

Tectonic Setting(s): Orogenic belts, late orogenic magmatism.

Associated Deposit Types: Polymetallic vein, polymetallic replacement, skarn Cu, skarn Zn, and porphyry copper.

DEPOSIT DESCRIPTION

Mineralogy: Rhodochrosite ± rhodonite + calcite + quartz ± barite ± fluorite ± jasper ± manganocalcite ± pyrite ± chalcopyrite ± galena ± sphalerite.

Texture/Structure: Tabular veins, irregular open space fillings, lenticular pods, pipes, and chimneys.

Ore Controls: Fracture permeability in carbonate rocks. May be near intrusive contact.

Weathering: Mn oxide minerals: psilomelane, pyrolusite, and wad form in the weathered zone and make up the richest parts of most deposits. Limonite and kaolinite.

Geochemical Signature: Mn, Fe, P, Cu, Ag, Au, Pb, Zn.

Examples: Lake Valley, USNM (69 *.
Philipsburg, USMT (70) *.
Lammereck, ASTR (71).

* Additional nonproprietary information available through BOM Mineral Industry Location System (MILS).

1/Modified from Mosier, D. L. Descriptive Model for Replacement Mn. Paper in Mineral Deposit Models, D. P. Cox and D. A. Singer, eds. USGS Bull. 1693, 1986, p. 105.

POLYMETALLIC REPLACEMENT DEPOSITS 1/

(See Figure 7)

APPROXIMATE SYNONYM: Manto deposits.

DESCRIPTION: Hydrothermal, epigenetic, Ag, Pb, Zn, Cu minerals in massive lenses, pipes and veins in limestone, dolomite, or other soluble rock near igneous intrusions.

PRIMARY REFERENCE(S): (72).

GEOLOGIC ENVIRONMENT

Rock Types: Sedimentary rocks, chiefly limestone, dolomite, and shale, commonly overlain by volcanic rocks and intruded by porphyritic, calc-alkaline plutons.

Textures: The textures of the replaced sedimentary rocks are not important; associated plutons typically are porphyritic.

Age Range: Not important, but many are late Mesozoic to early Cenozoic.

Depositional Environment: Carbonate host rocks that commonly occur in broad sedimentary basins, such as epicratonic miogeosynclines. Replacement by solutions emanating from volcanic centers and epizonal plutons. Calderas may be favorable.

Tectonic Setting(s): Most deposits occur in mobile belts that have undergone moderate deformation and have been intruded by small plutons.

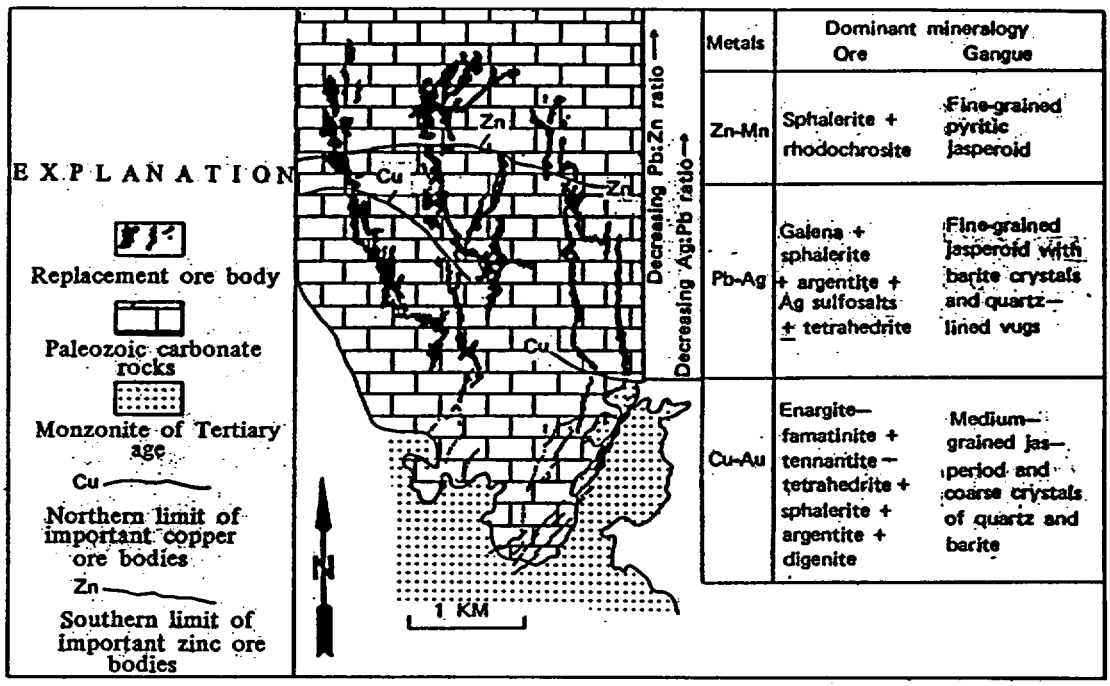
Associated Deposit Types: Base metal skarns, and porphyry copper deposits.

DEPOSIT DESCRIPTION

Mineralogy: Zonal sequence outward: enargite + sphalerite + argentite + tetrahedrite + digenite ± chalcopyrite, rare bismuthinite; galena + sphalerite + argentite ± tetrahedrite ± proustite ± pyrargyrite, rare jamesonite, jordanite, bournonite, stephanite, and polybasite; outermost sphalerite + rhodochrosite. Widespread quartz, pyrite, marcasite, and barite. Locally, rare gold, sylvanite, and calaverite.

Texture/Structure: Ranges from massive to highly vuggy and porous.

1/Modified from Morris, H. T. Descriptive Model of Polymetallic Replacement Deposits. Paper in Mineral Deposit Models, D. P. Cox and D. A. Singer, eds. USGS Bull. 1693, 1986, p. 99.



Modified from Cox and Singer (1986)

FIGURE 7.– Generalized map, metal and mineral zoning in polymetallic replacement deposits in the Main Tintic district, Utah

Alteration: Limestone wallrocks are dolomitized and silicified (to form jasperoid); shale and igneous rocks are chloritized and commonly are argillized; where syngenetic iron oxide minerals are present, rocks are pyritized. Jasperoid near ore is coarser grained and contains traces of barite and pyrite.

Ore Controls: Tabular, podlike, and pipelike ore bodies are localized by faults or vertical beds; ribbonlike or blanketlike ore bodies are localized by bedding-plane faults, by susceptible beds, or by preexisting solution channels, caverns, or cave rubble.

Weathering: Commonly oxidized to ochreous masses containing cerrusite, anglesite, hemimorphite, and cerargyrite.

Geochemical Signature: On a district-wide basis ore deposits commonly are zoned outward from a copper-rich central area through a wide lead-silver zone, to a zinc- and manganese-rich fringe. Locally Au, As, Sb, and Bi. Jasperoid related to ore can often be recognized by high Ba and trace Ag content.

Examples: East Tintic district, USUT (73) *.
Eureka district, USNV (74) *.
Manto deposit, MXCO (75)

* Additional nonproprietary information available through BOM Mineral Industry Location System (MILS).

FE SKARN DEPOSITS 1/

DESCRIPTION: Magnetite in calc-silicate contact metasomatic rocks.

PRIMARY REFERENCE(S): (76, 77).

GEOLOGIC ENVIRONMENT

Rock Types: Gabbro, diorite, diabase, syenite, tonalite, granodiorite, granite, and coeval volcanic rocks. Limestone and calcareous sedimentary rocks.

Textures: Granitic texture in intrusive rocks; granoblastic to hornfelsic textures in sedimentary rocks.

Age Range: Mainly Mesozoic and Tertiary, but may be any age.

Depositional Environment: Contacts of intrusion and carbonate rocks or calcareous clastic rocks.

Tectonic Setting(s): Miogeosynclinal sequences intruded by felsic to mafic plutons. Oceanic island arc, Andean volcanic arc, and rifted continental margin.

DEPOSIT DESCRIPTION

Mineralogy: Magnetite ± chalcopyrite ± Co-pyrite ± pyrite ± pyrrhotite. Rarely cassiterite in Fe skarns in Sn-granite terranes.

Texture/Structure: Granoblastic with interstitial ore minerals.

Alteration: Diopside-hedenbergite + grossular-andradite + epidote. Late stage amphibole ± chlorite ± ilvaite.

Ore Controls: Carbonate rocks, calcareous rocks, igneous contacts, and fracture zones near contacts. Fe skarn ores can also form in gabbroic host rocks near felsic plutons.

Weathering: Magnetite generally crops out or forms abundant float.

Geochemical and Geophysical Signature: Fe, Cu, Co, Au, possibly Sn. Strong magnetic anomaly.

1/Modified from Cox, D. P. Descriptive Model of Fe Skarn Deposits. Paper in Mineral Deposit Models, D. P. Cox and D. A. Singer, eds. USGS Bull. 1693, 1986, p. 94.

Examples: Shinyama, JAPN (78)
Cornwall, USPA (79) *.
Iron Springs, USUT (80) *.

* Additional nonproprietary information available through BOM Mineral Industry Location System (MILS).

ZN-PB SKARN DEPOSITS 1/

DESCRIPTION: Sphalerite and galena in calc-silicate rocks.

PRIMARY REFERENCE(S): (81, 82).

GEOLOGIC ENVIRONMENT

Rock Types: Granodiorite to granite, diorite to syenite. Carbonate rocks, calcareous clastic rocks.

Textures: Granitic to porphyritic; granoblastic to hornfelsic.

Age Range: Mainly Mesozoic, but may be any age.

Depositional Environment: Miogeoclinal sequences intruded by generally small bodies of igneous rock.

Tectonic Setting(s): Continental margin, late-orogenic magmatism.

Associated Deposit Types: Copper skarn.

DEPOSIT DESCRIPTION

Mineralogy: Sphalerite + galena ± pyrrhotite ± pyrite ± magnetite ± chalcopyrite ± bornite ± arsenopyrite ± scheelite ± bismuthinite ± stannite ± fluorite. Gold and silver do not form minerals.

Texture/Structure: Granoblastic, sulfides massive to interstitial.

Alteration: Mn-hedenbergite ± andradite ± grossularite ± spessartine ± bustamite ± rhodonite. Late stage Mn-actinolite ± ilvaite ± chlorite ± dannemorite ± rhodochrosite.

Ore Controls: Carbonate rocks especially at shale-limestone contacts. Deposit may be hundreds of meters from intrusive.

Weathering: Gossan with strong Mn oxide stains.

Geochemical Signature: Zn, Pb, Mn, Cu, Co, Au, Ag, As, W, Sn, F, possibly Be. Magnetic anomalies.

Examples: Ban Ban, AUQU (83).
Hanover-Fierro district, USNM (84) *.

* Additional nonproprietary information available through BOM Mineral Industry Location System (MILS).

1/Modified from Cox, D. P. Descriptive Model of Zn-Pb Skarn Deposits. Paper in Mineral Deposit Models, D. P. Cox and D. A. Singer, eds. USGS Bull. 1693, 1986, p. 90.

CU SKARN DEPOSITS 1/

(See Figure 8)

DESCRIPTION: Chalcopyrite in calc-silicate contact metasomatic rocks.

PRIMARY REFERENCE(S): (85, 86).

GEOLOGIC ENVIRONMENT

Rock Types: Tonalite to monzogranite intruding carbonate rocks or calcareous clastic rocks.

Textures: Granitic texture, porphyry, granoblastic to hornfelsic in sedimentary rocks.

Age Range: Mainly Mesozoic, but may be any age.

Depositional Environment: Miogeosynclinal sequences intruded by felsic plutons.

Tectonic Setting(s): Continental margin late orogenic magmatism.

Associated Deposit Types: Porphyry Cu, zinc skarn, polymetallic replacement, Fe skarn.

DEPOSIT DESCRIPTION

Mineralogy: Chalcopyrite + pyrite ± hematite ± magnetite ± bornite ± pyrrhotite. Also molybdenite, bismuthinite, sphalerite, galena, cosalite, arsenopyrite, enargite, tennantite, loellingite, cobaltite, and tetrahedrite may be present. Au and Ag may be important products.

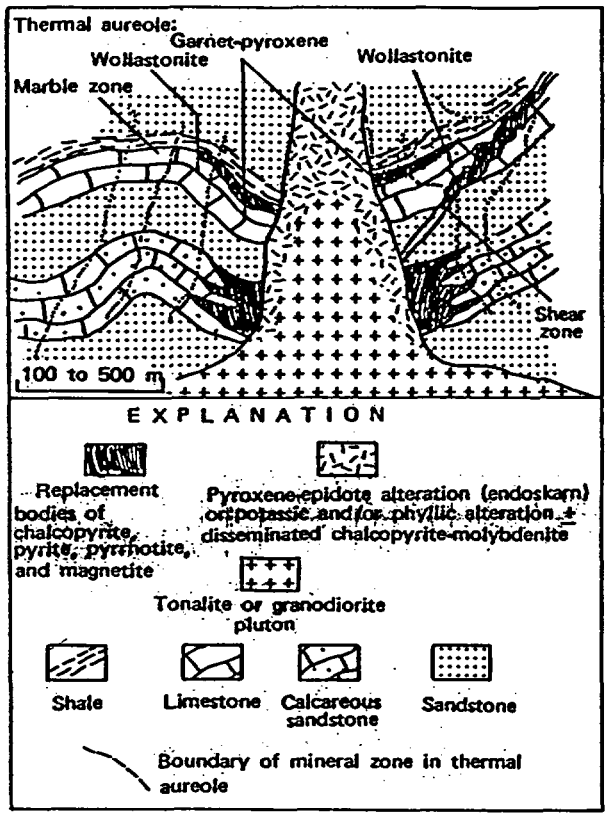
Texture/Structure: Coarse granoblastic with interstitial sulfides. Bladed pyroxenes are common.

Alteration: Diopside + andradite center; wollastonite ± tremolite outer zone; marble peripheral zone. Igneous rocks may be altered to epidote + pyroxene + garnet (endoskarn). Retrograde alteration to actinolite, chlorite, and clays may be present.

Ore Controls: Irregular or tabular ore bodies in carbonate rocks and calcareous rocks near igneous contacts or in xenoliths in igneous stocks. Breccia pipe, cutting skarn at Victoria (NV), is host for ore. Associated igneous rocks are commonly barren.

Weathering: Cu carbonates, silicates, Fe-rich gossan. Calc-silicate minerals in stream pebbles are a good guide to covered deposits.

1/Modified from Cox, D. P. Descriptive Model of Cu Skarn Deposits. Paper in Mineral Deposit Models, D. P. Cox and D. A. Singer, eds. USGS Bull. 1693, 1986, p. 86.



Redrawn from Cox and Singer (1986)

FIGURE 8.– Schematic cross-section of Cu skarn deposit

Geochemicall Signature: Rock analyses may show Cu-Au-Ag-rich inner zones grading outward to Au-Ag zones with high Au:Ag ratio and outer Pb-Zn-Ag zone. Co-As-Sb-Bi may form anomalies in some skarn deposits. Magnetic anomalies.

Examples: Mason Valley, USNV (87) *.
Victoria, USNV (88) *, **.
Copper Canyon, USNV (89) *, **
Carr Fork, USUT (90) *

* Additional nonproprietary information available through BOM Mineral Industry Location System (MILS).
** Additional information available in Lowe, Raney, and Norberg, BOM IC 9035, pp. 178, 78, respectively.

W SKARN DEPOSITS 1/, 2/

DESCRIPTION: Scheelite in calc-silicate contact metasomatic rocks.

PRIMARY REFERENCE(S): (91), (92).

GEOLOGIC ENVIRONMENT

Rock Type: Tonalite, granodiorite, quartz monzonite; limestone.

Textures: Granitic, granoblastic.

Age Range: Mainly Mesozoic but may be any age.

Depositional Environment: Contacts and roof pendants of batholith and thermal aureoles of apical zones of stocks that intrude carbonate rocks.

Tectonic Setting(s): Orogenic belts. Syn-late orogenic.

Associated Deposit Types: Sn-W skarns, Zn skarns.

DEPOSIT DESCRIPTION

Mineralogy: Scheelite ± molybdenite ± pyrrhotite ± sphalerite ± chalcopyrite ± bornite ± arsenopyrite ± magnetite ± traces of wolframite, fluorite, cassiterite, and native Bi.

Alteration: Diopside-hedenbergite ± grossular-andradite. Late stage spessartine + almandine. Outer barren wollastonite zone. Inner zone of massive quartz may be present.

Ore Controls: Carbonate rocks in thermal aureoles of intrusions.

Geochemical Signature: W, Mo, Zn, Cu, Sn, Bi, Be, As.

Examples: Pine Creek, USCA, (93) *.
MacTung, CNBC, (94)
Strawberry, USCA, (95) *.

* Additional nonproprietary information available through BOM Mineral Industry Location System (MILS).

1/Modified from Cox, D. P. Descriptive Model of W Skarn Deposits. Paper in Mineral Deposit Models, D. P. Cox and D. A. Singer, eds. USGS Bull. 1693, 1986, p. 55.

2/An economic/extraction model for this deposit type is presented in Section 2.4.1.

FLUORIDE-RELATED BERYLLIUM DEPOSITS 1/

DESCRIPTION: Beryllium minerals in non-pegmatitic rocks.

PRIMARY REFERENCE(S): (96).

GEOLOGIC ENVIRONMENT

Rock Types: Carbonate rocks or calcareous clastic or volcano-clastic rocks most favorable. Silicic volcanic rocks, especially rhyolite rich in Be, K, Si, and F. Also in hypothermal veins in ordinary (non-carbonate) schist, gneiss, and amphibolite at highly-productive Boomer Mine in Colorado.

Depositional Environment: Hypothermal and epithermal veins; replacement deposits; contact metamorphic deposits (beryllian tactites).

Tectonic Setting(s): Regions characterized by high-angle faults--most commonly block-faulted areas like the Basin and Range Province; caldera ring fractures.

DEPOSIT DESCRIPTION

Mineralogy: Primary minerals: beryl, bertrandite, phenakite, chrysoberyl, helvite, and barylite. Associated minerals: fluorite, topaz, quartz, magnetite, hematite, maghemite, siderite, minor pyrite, bismuthinite, wolframite, scheelite, cassiterite, and rare base metal sulfides.

Alteration: Beryllian tactites; Ca, Fe, and Mg silicates, fluorite common, less common magnetite. Hypothermal and epithermal veins; K-feldspar, quartz-white mica greisen, bertrandite-mica aggregates, euclase widespread in hypothermal deposits, kaolinite and smectite in epithermal deposits.

Weathering: Beryllium minerals resistant to weathering, sometimes Be mineral crystals found loose in disaggregated vein material.

Geochemical Signature: Be, F, Fe, W, Sn, topaz common.

Examples: Boomer, USCO, (97) *.
York Mountains Deposits, USAK, (98) *.

Additional Reference: (99)

* Additional nonproprietary information available through BOM Mineral Industry Location System (MILS).

1/Modified from Griffitts, W. R. Characteristics of Mineral Deposits. R. L. Erickson, ed. USGS Open-file Rep. 82-795, 1982, pp. 62-66.

SPOR MOUNTAIN BE-F-U 1/

DESCRIPTION: Be-F-U minerals in tuffs, tuffaceous breccias, and associated fault breccias. The Be-F-U deposits at Spor Mountain are the only ones of this type of economical value, but the existence of numerous minor occurrences elsewhere indicates that a class of ore deposits exists that resembles those at Spor Mountain and that additional economic deposits will be found (100).

PRIMARY REFERENCE(S): (100)

GEOLOGIC ENVIRONMENT

Rock Types: Tuffs, tuffaceous breccias, and associated fault breccias interlayered with volcanic dome-and-flow complexes of high-silica, high-fluorine, commonly topaz-bearing rhyolite; carbonate rocks are present in basement beneath the rhyolite.

Tectonic Setting(s): Regions characterized by high-angle faults--most commonly block-faulted areas like the Basin and Range Province; caldera ring fractures.

DEPOSIT DESCRIPTION

Mineralogy: Bertrandite, fluorite, secondary yellow uranium minerals, Mn oxides, and topaz.

Alteration: Extensive argillic (smectite) alteration displaying distinctive "popcorn" texture.

Geochemical Signature: Be, F, Li, Cs, Mn, Nb, Y, U, Th, and topaz common. Mo, Sn, and W may be anomalous.

Examples: Spor Mountain, USUT, (100) *.

Additional References: (101), (102), (103), (104), (105).

* Additional nonproprietary information available through BOM Mineral Industry Location System (MILS).

1/Modified from Lindsey, D. A. and D. R. Shawe. Characteristics of Mineral Deposits, R. L. Erickson, ed. USGS Open-file Rep. 82-795, 1982, pp. 67-69.

2.1.5 Exploration Methods

Section 2.1.5 discusses generally accepted methods and practices that could be used for purposes of locating and assessing metallic mineral resources at Yucca Mountain by describing standard assessment methodologies employed in the minerals industry and in government. It also addresses the rationale for selecting a particular methodology or hybrid methodology and includes a description of uncertainties associated with those methodologies.

Geologic/geochemical/geophysical activities planned for purposes other than resource assessment may provide valuable information. Every effort should be made to integrate data gained through these investigations, along with pre-existing data, into the resource assessment program.

2.1.5.1 Geological Mapping

Natural resource assessment of an area should include a program of detailed geologic mapping on as large a scale as is practical using photogrammetry [air photos, Earth Resource Technology Satellite (ERTS) and LANDSAT imagery, Thematic Mapper, SPOT (Systeme Probatoire d'Observation de la Terre) imagery and simulation data, etc.], topographic and geologic maps, cross sections, and other data acquired in background research or provided by other data gathering activities. Field and background data should be employed to produce detailed composite geological maps on which rock formations, geologic structures, faults, alteration, mineral assemblages, bed or formation attitudes, and other germane data are plotted. Mapping results should be analyzed and interpreted to produce structural analyses, cross sections, stratigraphic columns, and other map-related products for further study and to identify target areas for subsequent sampling, drilling, or geochemical/geophysical surveys.

2.1.5.2 Sampling Methods

Sampling is a systematic process of obtaining a representative unit of ore, rock, soil, gas, fluid, faunal or floral parts, or other material for the purpose of analysis. Sampling is conducted as part of an exploration program to locate and determine the quantity and/or quality of a potential resource. An important use of sample analyses is in the construction of suites of elements for the various rock types that occur or are postulated to occur at the site. Suites of elements should be constructed for silicic tuffs, skarns, carbonate and other sedimentary rocks, and for plutonic rocks.

Samples may be obtained from rock outcrops; stream or wash sediments; fan, playa, or other deposits; stream, spring, geothermal, mine, or well waters; soil; air; drill cores, cuttings, or sludges; flora; fauna; mines, mine dumps, tailings, or ore piles; processing plant dumps, tailings, or slag; and exploration pits, trenches, and adits. Each sample should be suitably containerized and clearly marked with sampler's name and project, sample location, date, type of analysis desired, and other pertinent information.

The most important or widely used sample types include, but are not limited to, those presented in Table 1; these methods may be employed in exploration for both metallic and nonmetallic resources. Methodologies employed in obtaining representative samples are discussed in detail in references listed in Section 6.3.

The nature, composition, and percentage of special constituents of samples collected in the field may be determined by various physical, atomic, or chemical means that include, but are not limited to, those methods presented in Table 2.

2.1.5.3 Geochemical Exploration Methods

According to Levinson (2):

> "Exploration geochemistry, also called geochemical prospecting, is the practical application of theoretical geochemical principles to mineral exploration. Its specific aim is to find new deposits of metals, nonmetals, or accumulations of crude oil and natural gas, and to locate extensions of existing deposits, by employing chemical methods. The methods used involve the systematic measurement of one or more chemical elements or compounds, which usually occur in small amounts. The measurements are made on any of several naturally occurring, easily sampled substances such as rocks, stream sediments, soils, waters, vegetation, glacial debris, or air."

Geochemical exploration is accomplished by the employment of various methods in a geochemical survey of the area under consideration. The objective of a geochemical survey is to identify anomalous concentrations of elements or compounds that may indicate the presence of a mineral deposit or hydrocarbon accumulation.

Exploration geochemical surveys are classified in two general categories: reconnaissance surveys and detailed surveys. Each classification may employ any or all of the various survey methods.

Reconnaissance surveys are conducted to evaluate a large area (from hundreds to tens of thousands of square kilometers) with the purpose of delineating possible mineralized (or hydrocarbon) areas for followup studies, and to eliminate (from future consideration) barren ground. Typically, reconnaissance surveys incorporate a low sample density, perhaps one sample per square kilometer or one sample per 100 square kilometers.

TABLE 1. Common Surface and Subsurface Sample Types - Advantages, Disadvantages, and Applications

Sample type	Advantages	Disadvantages	Applications
Channel	Provides reliable information for tonnage and grade calculations	Difficult to collect in hard rock; costly in terms of time required; bulky	In mineral exploration employed to determine tonnage and grade
Chip	May be considered quantitative for tonnage and grade calculations; random samples may be considered qualitative for homogenous bodies; less bulk than channel samples	Less reliable than channel samples	Employed in sampling hard rocks in mineral exploration
Grab	Provides information pertaining to presence of economic minerals; overall composition, maximum grades possible for mineralized zones	Cannot be used for tonnage/grade calculations	Used in mineralogic, petrographic, or chemical analysis; character samples
Bulk	Provides metallurgical information from large volume of material	Costly; large volumes (up to several tons)	Used to determine metallurgical properties of material; information gathered used to design beneficiation plant
Soil	Provides geochemical data pertaining to minerals or elements that may occur anomalously in the under-	Requires large number of samples taken on a grid or lines; time-consuming	Normally employed as a followup survey when geochemical or geophysical anomaly encountered
Sediment	Provides information pertaining to minerals, elements, hydrocarbons within a drainage or catchment area; useful in placer deposit identification	Requires large number of samples; time-consuming	May be employed as a calculate tonnage and grade of placer deposits; to gather mineralogical or chemical data in a drainage or catchment area
Drill	Depending on type of drilling method employed, provides information pertaining to subsurface lithology, mineralogy, structure, etc.	Costly, time-consuming; may be unable to drill in rough terrain	Employed to gather subsurface data in mineral exploration; normally used after one or more of the methods has shown positive results

TABLE 2. Comparison of Commonly Used Analytical Methods

Name	Lower detection limit	Advantages	Disadvantages
Atomic Absorption	Generally less than 10 ppm;some elements in ppb range	Rapid, sensitive, specific, accurate, and relatively inexpensive Several elements may be determined from same solution About 40 elements applicable to exploration geochemistry Partial or total analyses possible	Accuracy suffers with high abundances Not satisfactory for some important elements such as Th, U, Nb, Ta, and W Destructive
Colorimetry	Generally less than 10 ppm for elements commonly analyzed	Inexpensive, simple, sensitive, specific, accurate, and portable Partial or total analyses possible	Only one element (or a small group) determined at one time Not suitable for high abundances Some reagents unstable Tests not available for some important metals Destructive
Emission Spectrography	a. Usually only major and minor elements detected (visual detection) b. Generally from 1-100 ppm for most elements of interest (photograph detection) c. Generally from 1-100 ppm for most elements of interest (electronic-direct reader)	Multi-element capabilities (for all instruments) Only small sample required (for all instruments)	Complex spectra Requires highly trained personnel Generally slow (except for direct reader) Sample preparation very critical and time-consuming Destructive
X-ray Fluorescence	50-200 ppm on routine basis; more sensitive with special procedures	Simple spectra Good for high abundances of elements Uses relatively large sample All elements from fluorine to uranium are practical on modern equipment Certain liquids (e.g., brines) can be analyzed directly Excellent for rapid qualitative checks Non-destructive	Sensitivities not as good as other methods for many elements Analyses slower than some other methods Analyses are relatively expensive
Chemical Analysis	100 ppm	Precise, accurate Can be used with instrumental techniques	Less sensitive and more time-consuming than instrumental analysis Usually not suitable for determination of noble metals
Fire Assay	Less than 0.005 oz/ton Au; 0.001 oz/ton platinum group metals when used in fire assay-spectrographic procedure	Can be used for all ores, concentrates, or alloys if properly performed	Normally applied to noble metals (Au, Ag, platinum group metals); time-consuming; requires special laboratory equipment

Detailed surveys are carried out on a local, much smaller scale from a few square kilometers to tens of square kilometers with an objective of locating as exactly as possible individual resource occurrences or indications of structures favorable for resource occurrence. Sample intervals in a detailed survey may be as small as 3 meters or less, especially where veins or small targets are sought.

The most widely used exploration geochemical survey methods, or types, include, but are not limited to, soil, rock, stream sediment, water, vegetation, and vapor (including soil gases and air). Samples collected may be analyzed using one or more of the procedures listed in Table 2 or other procedures such as petrographic analysis and microprobe, as needed.

Soil surveys entail sampling of soil and other residual deposits to test for anomalous concentrations of elements or compounds released from the host rock by the processes of weathering and leaching.

Rock surveys (lithogeochemical or bedrock surveys) are based on the analysis of a whole rock sample [which may include, but is not limited to, petrographic, stable isotope, and instrumental neutron activation analysis (INAA)] or of contained minerals or fluid inclusions 2/ within a rock sample. This type of survey has great potential for outlining favorable geochemical or metallogenic provinces and for identifying favorable host rocks.

Particularly useful in exploration for hydrothermal ore deposits is the presence of hydrothermal alteration products. An essential component of hydrothermal alteration is the conversion of an initial mineral assemblage and texture to a new set of minerals that reflect hydrothermal conditions of temperature, pressure, and fluid composition 3/. Common alteration products associated with particular deposit types are presented under the heading "Deposit Description" for the deposit models described in Section 2.1.4.2.

Rock surveys are almost universally incorporated in well-conceived geochemical exploration programs.

Stream sediment surveys are employed almost exclusively for reconnaissance studies in drainage basins, and if properly collected, the samples represent the best composite of materials from the catchment area upstream from the sampling site (2). This type of survey may conducted in flowing streams (not found on Yucca Mountain) or in ephemeral stream beds or washes. Other sediments such as terraces, fans, and playas may also be sampled.

2/See Roedder (107) for detailed information pertaining to fluid inclusion studies.

3/See Rose and Burt (1979) in Section 6.4 for a detailed description of hydrothermal alteration.

Water or hydrogeochemical surveys are based on the collection of samples of ground or surface water for qualitative and quantitative analysis of dissolved elements or compounds. The technique is useful in the identification of dispersal trains and haloes that may be indicators of the presence of a mineral or hydrocarbon occurrence. Water surveys are particularly useful in areas where it is difficult to obtain rock, soil, or sediment samples. Because of the paucity of surface water at Yucca Mountain, water surveys will probably be limited to ground water sampling.

Vegetation surveys fall into two general categories: (1) Geobotanical surveys that involve a visual survey of vegetation, and (2) biogeochemical surveys that consist of the collection and chemical analyses of whole plants, selected plant tissues, or humus 4/.

Geobotanical studies include the recognition of the presence or absence of particular plant species or communities that may be indicative of certain elements or compounds, or the recognition of deformed or oddly-colored plants whose characteristics are the result of deleterious or toxic effects caused by an excess of certain trace elements (2). Table 3 presents a description of visual changes in plants that may result from elevated concentrations of some trace elements in soils.

Biogeochemical exploration methods involve chemical analyses of plants or parts of plants that may have incorporated certain elements or compounds in their tissues. Trees and phreatophytes, with their deep root systems, are particularly amenable to biogeochemical analysis.

Recent studies by the USGS suggest that *Artemisis tridentata Nutt.*, a sagebrush common to the western United States, absorbs gold and may be useful as a tool in exploration (106).

The use of vegetation surveys as a guide to mineral resources is more complex than any other geochemical method and may require special skills in execution and interpretation. In spite of the drawbacks, this geochemical exploration method has been successfully employed in unglaciated terranes in Canada and desert terranes in the southern United States and northern Mexico (2) 5/.

Vapor (soil gas and air) surveys have been successfully used for more than 30 years in the Soviet Union and were recently investigated by the USGS with encouraging results (see reference 13 in Appendix B). The method involves collecting samples of the air or soil gases in the vicinity of suspected resource occurrences. The most common elements or compounds associated with vapor surveys are presented in Table 4. Vapor surveys are complex, require skilled collection and analytical personnel, and most often the results are very difficult to reproduce.

4/Biogeochemical techniques may also be applied to animal tissues.
5/See Cannon (1952, 1960a, 1960b) in Section 6.4.

TABLE 3. Changes in Plants due to Increased Concentration of Some Trace Elements

Element	Character of Changes
U, Th, Ra	When present in small amounts, causes acceleration of growth in plants; high concentrations lead to the appearance of deformities in vegetative shoots, dwarfism, dark-colored or blanched leaves
Fluorine (topaz greisens)	Premature yellowing and falling of leaves
B	Slow growth and ripening of seeds, dwarfism, procumbent forms; dark green leaves, deustate at edges; high concentration in the soil causes total or partial disappearance of vegetation
Mg	Reddening of stems and leaf stalks, coiling and drying of leaf edges
Cr	Yellowing of leaves; in some cases, thinning of vegetation until its total disappearance
Cu	Blanching of leaves, necrosis in leaf tips, reddening of stems, appearance of procumbent, degenerating forms; in some cases, total disappearance of vegetation
Ni	Degeneration and disappearance of some forms, appearance of white spots on leaves, deformities, reduction of corrolar petals
Co	Appearance of white spots on leaves
Pb	Thinning of vegetation, appearance of suppressed forms, development of abnormal forms in flowers
Zn	Chlorosis of leaves and drying of their tips. Appearance of blanched, underdeveloped, dwarfed forms
Nb	Appearance of white deposits on the blades or leaves of some types of plants
Be	Deformed shoots in young individuals of pines
Rare earths	Sharp increase in the size of leaves in some wood species

Source: Beus and Grigorian (1975)--see Section 6.4.

TABLE 4. Vapor Indicators of Mineralized Zones

Vapor	Type of Deposit
Mercury (Hg)	Ag-Pb-Zn sulfides; U, Au, Sn-Mo ores; polymetallic (Hg-As-Sb-Bi-Cu) ores; pyrites
Sulfur dioxide (SO_2)	All sulfide ores
Hydrogen sulfide (H^2S)	Do.
Carbon dioxide, oxygen (CO_2, O_2)	Do.
Halogens and halides (F, Br, I)	Pb-Zn sulfides; porphyry copper deposits
Noble gases (He, Ne, Ar, Kr, Xe, Rn)	U-Ra ores; Hg sulfides; potash deposits
Organometallics such as (CH_3,$2HgAsH_3$ and compounds of Pb, Cu, Ag, Ni, Co, etc.	Possibly all sulfides

Source: Levinson (1974) (2).

Other methods that may or may not have applications at Yucca Mountain include heavy mineral surveys, chemical analysis of tissues from fish or other fauna, isotope surveys, geozoological techniques (use of animals or insects in mineral prospecting) 6/, and overburden surveys.

In exploration geochemistry, "primary dispersion" has become synonymous with the distribution of elements in unweathered rocks and minerals regardless of their origin. A knowledge of primary dispersion in an area is often of assistance in the interpretation of both stream sediment and soil sampling surveys as it indicates what background ranges might be expected over specific rock types and assists in distinguishing between anomalies due to possible mineralization and those due to high-background unmineralized rocks (108). The mean values for a number of elements in some of the major igneous and sedimentary rock types are summarized after Reedman (108) in Table 5.

6/See Brooks, 1983, pp. 85-108--"Geozoology in Mineral Exploration" (Section 6.5) for a detailed discussion of the use of animals and insects in mineral exploration.

TABLE 5. Mean values (ppm) for some important elements in major igneous and sedimentary rock types

	Igneous rocks				Sedimentary rocks			
Element	Ultrabasic	Basic	Acid	Alkaline	Sandstone	Limestone	Shale	Black shale
Antimony	0.1	0.2	0.2	-	1	-	1-3	-
Arsenic	1-2.8	2	1.5	-	-	2.5	4-15	75-225
Barium	2-15	250-270	600-830	-	100-500	20-200	300-800	450-700
Beryllium	0.2	0.1-1.5	3-5	2-12	1	<1-1	1-7	1
Bismuth	0.02	0.15	0.1	-	0.3	-	0.2-1	-
Boron	5	5-10	15	9	-	9-10	10-100	-
Cadmium	0.1	0.2	0.1-0.2	0.1	-	0.1	0.2-0.3	-
Chromium	2000-3400	200-340	2-4	1	10-100	5-10	100-160	10-500
Cobalt	150-240	25-75	1-8	8	1-10	0.2-4	10-50	5-50
Copper	10-80	100-150	10-30	-	10-40	5-20	20-150	20-300
Fluorine	100	340-500	480-810	570-1000	180-200	220-330	500-940	-
Gold	0.1	0.035	0.01	-	-	-	-	-
Lanthanum	3.3	10-27	25-46	-	-	6	20-40	25-100
Lead	0.1	5-9	10-30	-	10-40	5-10	16-20	20-400
Lithium	2	10-15	30-70	28	7-29	2-20	50-60	17
Manganese	1100-1300	2200	600-965	-	-	385	670-890	-
Mercury	-	0.08-0.09	0.04-0.08	-	0.03-0.1	0.03-0.05	0.4-0.5	-
Molybdenum	0.3-0.4	1-1.4	2	-	0.1-1	0.1-1	1-3	10-300
Nickel	800-3000	50-160	2-8	2-4	2-10	3-12	20-100	20-300
Niobium	15	20	20	30-900	-	-	20	-
Silver	0.3	0.3	0.15	-	0.4	0.2	0.9	-
Tantalum	<1-1	0.5-1	3-4	1-2	-	-	2-3.5	-
Tin	0.5	1	3	-	-	-	-	-
Titanium	3000	9000	2300	-	4400	-	4300-4500	-
Tungsten	0.5	1	2	-	-	0.5	2	-
Uranium	0.001-0.03	0.6-0.8	3.5-4.8	-	-	2	3.2-4	-
Vanadium	50-140	200-250	20-25	34	10-60	2-20	50-300	50-2000
Zinc	50	90-130	40-60	-	5-20	4-25	50-300	100-1000
Zirconium	20-70	100-150	170-200	300-680	-	20	120-200	10-20

Source: Reedman (1979).

It follows that "secondary dispersion" pertains to the dispersal of elements due to the breakdown of the original rocks by physical and chemical processes. The degree whereby an element is dispersed in the secondary environment is expressed by its "mobility ." Dispersal is instituted and/or controlled by numerous factors that may include a rock's resistance to weathering (thus aiding or inhibiting the release of one or more elements to the secondary environment), association with more mobile elements, pH, Eh, and other chemical processes. Table 6 presents a summary of the dispersion of various elements in the secondary environment and applications in geochemical exploration.

It is sometimes advantageous to use associated elements as an indicator of the element sought, these are known as "pathfinders" or "pathfinder elements". Table 7 presents some of the more commonly-used pathfinders and associated elements.

Table 8 summarizes the most important or widely used exploration geochemical survey types and advantages, disadvantages, and applications associated with their use. The selection of a particular geochemical exploration type (and associated executionary method or methods) may include, but is not limited to, those listed in Table 8. Detailed discussions of these and other methods are presented in cited references listed in Section 2.5; additional references are presented in Section 6.4.

Table 9 presents the types of geochemical exploration methods that may be of value in assessing the resource potential of Yucca Mountain. Each method is keyed to one or more of the descriptive deposit models presented in the preceding section.

The success of geochemical methods in mineral exploration is often difficult to evaluate. In most cases, more than one geochemical method has been employed to locate a particular mineral deposit, and it is not always possible to assign credit to a single method. Further, the techniques or methods employed in a successful exploration program are not always reported by the company or institution sponsoring the program, although numerous discoveries can be credited to geochemical exploration.

Levinson (2), for example, cites the following deposits that were discovered primarily through the use of geochemical exploration methods: Carlin-type gold deposits, Nevada; the auriferous Muruntau deposit in Uzbec, U.S.S.R.; the Beltana and Aroona willemite deposits, South Australia; the McArthur River and Lady Loretta lead-zinc deposits, Australia; the Husky lead-zinc-silver deposit, Keno Hill, Yukon; the Island Copper porphyry deposit, British Columbia; and the Sam Goosley copper-silver-molybdenum deposit in British Columbia.

TABLE 6. Summary of the Dispersion of Various Elements in the Secondary Environment and Applications in Exploration

	ANTIMONY
Soils:	5 ppm.1/
Waters:	1 ppb.1/
Mobility:	Low.
Uses:	Geochemical prospecting for Sb has been undertaken, but is not very important. It has been used as a pathfinder for gold and may produce coincident anomalies over some base metal deposits.
	ARSENIC
Stream sediments:	1-50 ppm.1/
Soils:	1-50 ppm.1/
Waters:	1-30 ppb.1/
Plant ash:	1-2 ppm, >10 ppm may indicate mineralization. Concentrations up to 1% observed in certain plants growing over mineralized zones.
Mobility:	Fairly low, readily scavenged by iron oxides.
Uses:	Has been mainly used as a pathfinder for Au and Ag vein-type deposits.
	BARIUM
Soils:	100-3000 ppm.1/ Anomalous concentrations over barite mineralization >5000 ppm. Peaks at many percent.
Waters:	10 ppb.
Mobility:	Low.
Uses:	Has been used in geochemical prospecting for barite, but dispersion limited by low mobility.
	BERYLLIUM
Stream sediments:	<2 ppm.1/ Values >2 ppm may delineate areas of beryl mineralization.
Soils:	<2-6 ppm. Values >10 ppm may define beryl-bearing pegmatites. Peak values >100 ppm over rich zones.
Mobility:	Low to moderate.
Uses:	Be has been used in geochemical exploration for beryl deposits. Similar anomalous values may occur over unmineralized alkaline rocks.
	BISMUTH
Soils:	<1 ppm.1/ Values >10 ppm may define Bi mineralization.
Mobility:	Low.
Uses:	Little work has been done with geochemical prospecting for Bi. Most Bi is produced as a by-product of other ores and there are only a few very small deposits that have been worked for Bi alone. Surveys in Zambia show peak values of 200 ppm over Bi-bearing vein deposits. May also have value as a pathfinder for certain vein Au deposits.

See footnote at end of table.

TABLE 6. Summary of the Dispersion of Various Elements in the Secondary Environment and Applications in Exploration--Continued

	CADMIUM
Soils:	<1-1 ppm.1/ Values over a few ppm are anomalous and may be due to mineralization containing traces of Cd.
Mobility:	High--closely follows Zn.
Uses:	As in the case of Bi, Cd is produced as a by-product of other ores (lead-zinc) so that there has been little work done on prospecting for Cd. It has been used as an aid in lead-zinc prospecting to distinguish between anomalies likely to be due to mineralization (Zn + Cd) from those unlikely to be due to mineralization (Zn only). Surveys in Ireland have shown that this can be misleading since very high Cd values (>200 ppm) have been found with a Zn anomaly apparently unrelated to mineralization and low Cd values (a few ppm) are associated with a strong Zn anomaly related to good mineralization.
	COBALT
Stream sediments:	5-50 ppm.1/
Soils:	5-40 ppm.1/ Anomalous concentrations over mineralization >100-500 ppm.
Waters:	0.2 ppb.1/
Plant ash:	9 ppm.
Mobility:	Moderately high, but readily scavenged and held by Fe-Mn oxides.
Uses:	Has been used for Co prospecting, but, since Co is generally produced as a by-product of other metals, surveys are rarely conducted for Co alone. Useful as an ancillary element in surveys for other base metals which may be accompanied by Co mineralization.

See footnote at end of table.

TABLE 6. Summary of the Dispersion of Various Elements in the Secondary Environment and Applications in Exploration--Continued

	COPPER
Stream sediments:	5-80 ppm.1/ >80 ppm may be anomalous.
Soils:	5-100 ppm.1/ Anomalies >150 ppm may indicate mineralization. High background basic rocks can give rise to values of many hundreds of ppm.
Waters:	8 ppb.1/ >20 ppb may be anomalous, but hydrogeochemistry rarely used for Cu owing to limited mobility.
Plant ash:	90 ppm.1/ Values >140 ppm may be anomalous.
Mobility:	High at pH's below 5.5, low at neutral or alkaline pH. Also may be adsorbed by organic matter and coprecipitated with Fe-Mn oxides, but Cu is less readily scavenged by Fe-Mn oxides than other base metals (e.g. Co, Zn, Ni).
Uses:	Stream sediment and soil sampling surveys have been widely used in all parts of the world in Cu prospecting and there is a large literature on the subject. Biogeochemical methods have also been used with some success. To help distinguish anomalies due to unmineralized basic rocks from anomalies likely to result from mineralization, the Co/Ni ratio has been used in soil surveys. A high Co/Ni ratio (>1) indicates that anomalous Cu values are more likely to be due to mineralization than Cu anomalies accompanied by low Co/Ni ratios.
	FLUORINE
Soils:	200-300 ppm.1/ Anomalies over mineralization >1000 ppm with peaks at many thousands of ppm.
Waters:	50-500 ppb.1/ Values >1000 ppb in river waters may be due to mineralization.
Mobility:	Fairly low.
Uses:	Geochemical surveys have been undertaken for fluorite in various parts of the world using soils, groundwaters and river waters as sampling media. F now commonly used as a direct indicator, but Pb and/or Zn generally used as pathfinders before advent of specific-ion electrode analytical technique.

See footnote at end of table.

TABLE 6. Summary of the Dispersion of Various Elements in the Secondary Environment and Applications in Exploration--Continued

	GOLD
Soils:	<10-50 ppb.1/ Values >100 ppb may indicate mineralization.
Waters:	0.002 ppb.1/
Mobility:	Generally extremely low under neutral, alkaline and reducing conditions, but may be moderately high with formation of complex ions under oxidizing conditions in both acid and alkaline environments.
Uses:	A number of soil surveys using Au as a direct indicator of Au mineralization have been conducted in various parts of the world with considerable success. Before cheap and sensitive AAS analytical method for Au was available, the use of pathfinders such as As and Sb was common, but not used so widely nowadays.
	HELIUM
Atmosphere:	5.2 ppm by volume.1/
Waters:	4.76×10^{-8} cm^3 STP/g.1/
Mobility:	Extremely high as an inert gas dissolved in waters and diffusing through overburden and fractures in rock.
Uses:	Pathfinder for U and hydrocarbons using both soil gas and He dissolved in groundwaters.
	LEAD
Stream sediments:	5-50 ppm.1/
Soils:	5-80 ppm.1/ Values >100 ppm may indicate Pb mineralization.
Waters:	3 ppb.1/
Plant ash:	70 ppm.1/
Mobility:	Low.
Uses:	Geochemical surveys for Pb using soils and stream sediments have been successfully employed all over the world. Biogeochemical and hydrogeochemical surveys have also been used with a certain amount of success. Owing to the low mobility of Pb, Zn is often a better indicator of Pb or Pb-Zn mineralization. Pb has been used as a pathfinder for barite and fluorite mineralization.

See footnote at end of table.

TABLE 6. Summary of the Dispersion of Various Elements in the Secondary Environment and Applications in Exploration--Continued

	LITHIUM
Stream sediments:	10-40 ppm.1/
Soils:	5-200 ppm.1/
Waters:	3 ppb.1/
Mobility:	Moderate to high.
Uses:	Stream sediment and soil surveys have been used in regional reconnaissance prospecting for various pegmatite deposits since complex Li-bearing pegmatites generally contain minerals of interest such as beryl, cassiterite, pollucite, columbite, in addition to the Li minerals which are of potential economic value. Rarely used.
	MANGANESE
Stream sediments:	100-5000 ppm.1/
Soils:	200-3000 ppm.1/
Waters:	<1-300 ppb.1/
Plant ash:	4800 ppm.1/
Mobility:	Usually very low, may become mobile under acid, reducing conditions as divalent ion.
Uses:	Soil and vegetation surveys have been conducted in prospecting for Mn ores, but Mn is more commonly used as an ancillary element in geochemical surveys to aid interpretation.
	MERCURY
Stream sediments:	<10-100 ppb.1/
Soils:	<10-300 ppb.1/ Values >50 ppb may indicate mineralization such as Pb-Zn-Ag ores.
Soil gas:	10-100 ng/m^3, >200 ng/m^3 over base metal ores.
Waters:	0.01-0.05 ppb. Values >0.1 ppb may be due to Hg mineralization. Hg in waters readily adsorbed by solids, so waters are not good prospecting medium.
Mobility:	Generally low, but high as vapor phase.
Uses:	Has been used successfully in prospecting for Hg ores using stream sediments and waters and soils. Also used as a pathfinder of base metal ores. The vapor phase which can be detected in very small amounts in soil gas or the atmosphere has potential as a pathfinder of many ores. However, this is only true if Hg is present in elemental state. Many ores which contain Hg in sulfides may not release any Hg vapor unless undergoing weathering.

See footnote at end of table.

TABLE 6. Summary of the Dispersion of Various Elements in the Secondary Environment and Applications in Exploration--Continued

	MOLYBDENUM
Stream sediments:	<1-5 ppm.1/ >10 ppm may indicate Mo mineralization.
Soils:	<1-5 ppm.1/ >10 ppm may indicate Mo mineralization.
Waters:	<1-3 ppb.1/
Plant ash:	13 ppm.1/ Very high Mo concentrations (>1%) have been found in the ash of certain plants growing over Mo deposits.
Mobility:	Generally high, but is low under acid and reducing conditions when it is readily adsorbed by iron oxides and clay minerals.
Uses:	Stream sediment, soil and vegetation surveys have all been successfully employed in prospecting for Mo deposits. Mo is also used as a pathfinder for porphyry Cu deposits.
	NIOBIUM
Stream sediments:	5-200 ppm.1/ Values >200 ppm may indicate Nb-bearing minerals.
Soils:	5-200 ppm.1/ Values >200 ppm may indicate Nb-bearing minerals.
Mobility:	Low.
Uses:	Both stream sediment and soil surveys have been successfully employed to locate pyrochlore-bearing carbonatites and columbite-bearing pegmatites. Unmineralized or poorly mineralized alkaline rocks may give high values in stream sediments and soils.
	PHOSPHORUS
Stream sediments:	100-3000 ppm.1/
Soils:	100-3000 ppm.1/ Values >5000 ppm may indicate phosphate-rich rocks.
Mobility:	Despite the fact that P is essential to life and is taken up by plants from soils, P generally occurs only in sparingly soluble compounds and overall mobility is low.
Uses:	Geochemical prospecting for P has only been used rarely, but it works extremely well in locating phosphate-rich rocks.
	RADIUM
Stream sediments:	Measured in terms of radioactivity, usually picocuries/gram (pCi/g). 0.2 pCi/g.1/ Values >1.0 pCi/g may indicate U mineralization.
Mobility:	Fairly low, adsorbed by organic matter.
Uses:	Can be used as a pathfinder for U in stream sediments and soils.

See footnote at end of table.

TABLE 6. Summary of the Dispersion of Various Elements in the Secondary Environment and Applications in Exploration--Continued

	RADON
Soil gas:	Measured by α counts. Over U mineralization values may be several hundred α counts/min with short measuring time of radon emanometer.
Waters:	Measured in terms of radioactivity, usually picocuries/litre (pCi/litre). 10-30 pCi/litre.1/ Values >100 pCi/litre may be due to U mineralization.
Mobility:	Extremely high as an inert gas dissolved in waters and diffusing through overburden and fractures in rock.
Uses:	Rn in soil gas and waters is widely used as a pathfinder for U mineralization. Extensive dispersion haloes cannot form owing to the short half-life.
	RARE EARTHS
	Of the rare earths (RE) Ce, La and Y have been used in geochemistry most commonly and some figures for La (pathfinder of cerian sub-group) and Y (representative of yttrium sub-group) are given.
Stream sediments:	20-500 ppm La.1/
Soils:	20-1000 ppm La.1/ Values several thousand ppm+ may indicate RE mineralization.
	<10-100 ppm Y.1/
Plant ash:	16 ppm (total RE).1/
Mobility:	Moderately low.
Uses:	La has been used successfully in stream sediment and soil surveys for locating carbonatites with which RE minerals may be associated. RE elements may also occur replacing Ca in minerals such as apatite and perovskite and may result in soil values similar to those due to the presence of discrete RE minerals such as monazite.
	SILVER
Soils:	<0.1-1 ppm.1/ Values >0.5 ppm may indicate mineralization.
Waters:	0.01-0.7 ppb.1/
Mobility:	Fairly low.
Uses:	Has been used in prospecting for Ag and Ag-Au deposits. Sometimes also a useful ancillary element for surveys for complex ores which are accompanied by significant Ag contents.

See footnote at end of table.

TABLE 6. Summary of the Dispersion of Various Elements in the Secondary Environment and Applications in Exploration--Continued

	TIN
Stream sediments:	<5-10 ppm.1/ Values >20 ppm may indicate mineralized areas.
Soils:	<5-20 ppm.1/ Values >50 ppm may indicate mineralization.
Mobility:	Low.
Uses:	Stream sediment and soil surveys have been successfully employed in Sn prospecting in various parts of the world. Owing to the ease of identifying cassiterite in heavy mineral concentrates, however, traditional prospecting methods are often better than geochemical methods if Sn is present in the coarser size fractions.
	TITANIUM
Stream sediments:	500-10,000 ppm.1/
Soils:	500-10,000 ppm.1/
Waters:	3 ppb.1/
Mobility:	Low.
Uses:	Owing to ease of identifying ilmenite and rutile in heavy mineral concentrates, geochemical prospecting for Ti has hardly ever been undertaken. Often used as an ancillary element in regional surveys where it often has considerable value for delineating different rock types.
	TUNGSTEN
Stream sediments:	<2-10 ppm.1/ Values >10 ppm may indicate mineralized areas.
Soils:	<2-20 ppm.1/ Values >20 ppm may indicate mineralization and values >200 ppm observed over main ore zones.
Mobility:	Low to moderate.
Uses:	Stream sediment and soil surveys have been successfully employed in various parts of the world in prospecting for tungsten deposits.

See footnote at end of table.

TABLE 6. Summary of the Dispersion of Various Elements in the Secondary Environment and Applications in Exploration--Continued

	URANIUM
Stream sediments:	<1-5 ppm.1/ Values >5 ppm may be due to mineralization.
Soils:	<1-10 ppm.1/ Values >10 ppm may be due to mineralization.
Waters:	<1-1 ppb.1/ Values >2 ppb may indicate mineralization.
Plant ash:	0.6 ppm.1/
Mobility:	Extremely high, though readily held by organic matter.
Uses:	Stream sediment, soil, vegetation and water surveys have been successfully employed in uranium prospecting.
	VANADIUM
Soils:	20-500 ppm.1/
Waters:	<1 ppb.1/
Plant ash:	22 ppm.1/
Mobility:	Low.
Uses:	Little use has been made of V in geochemical prospecting, though it is sometimes used as an ancillary element in regional surveys. Can be used to indicate V-rich sulfide deposits.
	ZINC
Stream sediments:	10-200 ppm.1/ Values >200 ppm may indicate mineralization.
Soils:	10-300 ppm.1/ Values >300 ppm may indicate mineralization, but residual anomalies over good mineralization generally >1000 ppm.
Waters:	1-20 ppb.1/ Values >20 ppb may indicate mineralization.
Plant ash:	1400 ppm.1/
Mobility:	High, but adsorbed by organic matter and readily scavenged by Mn oxides.
Uses:	Zn has been widely employed in stream sediment, soil, vegetation and water surveys all over the world with considerable success in prospecting for zinc, lead-zinc and complex base metal ores.

See footnote at end of table.

TABLE 6. Summary of the Dispersion of Various Elements in the Secondary Environment and Applications in Exploration--Continued

	ZIRCONIUM
Soils:	50-600 ppm.1/ Values >1000 ppm indicate possible interesting concentrations of zirconiferous minerals.
Mobility:	Extremely low.
Uses:	Zr has been little used in geochemical prospecting. Owing to irregular and widespread distribution of zircon in igneous rocks and as a detrital mineral, soil values often show wide fluctuations.

1/Background values.

Source: Modified from Reedman (1979).

TABLE 7. Examples of Pathfinder Elements Used to Detect Mineralization

Pathfinder (Element(s)	Type of Deposit
As	Au, Ag; vein-type
As	Au-Ag-Cu-Co-Zn; complex sulfide ores
B	W-Be-Zn-Mo-Cu-Pb; skarns
B	Sn-W-Be; veins or greisens
Hg	Pb-Zn-Ag; complex sulfide deposits
Mo	W-Sn; contact metamorphic deposits
Mn	Ba-Ag; vein deposits; porphyry copper
Se, V, Mo	U; sandstone-type
Cu, Bi, As, Co, Mo, Ni	U; vein-type
Mo, Te, Au	Porphyry copper
Pd, Cr, Cu, Ni, Co	Platinum in ultramafic rocks
Zn	Ag-Pb-Zn; sulfide deposits in general
Zn, Cu	Cu-Pb-Zn; sulfide deposits in general
Rn	Sulfide deposits of all types
SO_4	Sulfide deposits of all types

Note: In most cases, several types of material (e.g., rock, soil, sediment, water, and vegetation) can be sampled. In some cases, such as radon only water and soil gas are practical. In the case of sulfate, only water is practical.

Source: Modified from Levinson (1974, 2).

TABLE 8. Comparison of Major Geochemical Exploration Methods (Surveys)

Survey Type	Advantages	Disadvantages	Applications	Scope of survey	Sampling Method(s)	Analysis Types
Soil	Highly reliable, fewer variables and limitations than most methods	Large pct of nonsignificant anomalies encounter	Important in mineral exploration	Local, Detailed; some limited use in reconnaissance surveys; generally used as follow-up to drainage basin survey	Taken on grid system; 15-61 m spacing for detail surveys, 301-1500 m for reconnaissance surveys	Primarily chemical or instrumental
Rock (whole rock; mineral and/or fluid inclusions)	High potential for outlining favorable metallogenic provinces and host rocks	Requires numerous rock outcrops; interpretation often difficult due to large number of rock types and changes in rock texture over short distances	Widely used in mineral exploration	Local, detailed; limited regional application	Chip, channel, core, bulk, grab, and other methods; may be obtained from surface or subsurface	Petrographic, whole rock, mineral or fluid inclusions, fire assay, chemical, instrumental
Stream sediment 1/	Samples may represent best composite of materials from catchment area upstream from sampling site	Best results from streams, lakes, and swamps;1 not applicable to some regions; not site specific	Important in mineral exploration	Reconnaissance or detailed surveys	50 g samples of 80 mesh usually preferred for clay, silt, black sands; larger fractions may be required, however	Primarily chemical or instrumental
Water 1/	Very useful in wooded or mountain areas; accurate field determinations possible with equipment	Metal concentration varies with rainfall; ranges of concentration low (ppb); relatively large samples required; not site specific	Applied to mineral and geothermal exploration	Reconnaissance or detailed surveys	100 ml samples in well-cleaned, hard polyethylene bottles; sampling methods variable, depends on location, type sample required	Primarily chemical or instrumental
Vegetation	Useful in areas with few outcrops and light to heavy vegetation; humus provides a more uniform sampling media	Highly complex, requires considerable skill in execution and interpretation	Applied to mineral exploration	Reconnaissance or detailed surveys	Various, depends on type vegetation, areal extent of survey, expertise of personnel	Primarily chemical or instrumental
Vapor (air or soil)	May be conducted from aircraft; sensitive to many elements and compounds	Soil or air contamination from nearby industrial urban environment requires special systems for collection and interpretation	Applied to mineral exploration	Reconnaissance or detailed surveys	Methods depend on type survey (air or soil gas), taken on ground or from aircraft, type of gas or vapor involved, expertise of personnel	Primarily chemical or instrumental
Other 2/						

1/Very limited application at Yucca Mountain Site.
2/Includes heavy mineral, bog material, fish and other fauna, isotopic, and overburden surveys.

Source: Levinson (1980) (2).

TABLE 9. Geochemical Exploration Methods Applied to Selected Deposit Models

Deposit type	Soil 1/	Rock 2/	Stream sed. 3/,4/	Veg. 5/	Geochemical Signature 6/
Creede epithermal veins	X	X	X	X	High in system Au + As + Sb + Hg, and/or Au + Ag + Pb + Zn + Cu, Ag + Pb + Zn, and/or Cu + Pb + Zn. Base metals generally higher in deposits with Ag. W + Bi may be present.
Hot-spring Au-Ag	X	X	X	X	Au + As + Sb + Hg + Tl higher in system, increasing Ag with depth, decreasing As + Sb + Tl + Hg with depth. Locally, NH_4, W.
Hot-spring Hg	X	X	X	X	Hg + As + Sb ± Au.
Replacement Sn	X	X			Sn, As, Cu, B, W, F, Li, Pb, Zn, Rb.
Epithermal quartz-alunite-Au	X	X		X	Higher in system Au + As + Cu, increasing base metals at depth. Also Te and (at El Indio) W.
Porphyry Mo, low-F	X	X			Zoning outward and upward from Mo + Cu ± W to Cu + Au to Zn + Pb, + Au + Ag. F may be present but in amounts less than 1,000 ppm.
Epithermal Mn	X	X			Mn, Fe, P (Pb, Ag, Au, Cu). At Talamantes, W.
Carbonate-hosted Au-Ag	X	X		X	Au + As + Hg + W ± Mo, As + Hg + Sb + Tl ± F (this stage superimposed on preceding). NH_3 important in some deposits.

See footnotes at end of table.

TABLE 9. Geochemical Exploration Methods Applied to Selected Deposit Models--Continued

Deposit type	Soil 1/	Rock 2/	Stream sed. 3/,4/	Veg. 5/	Geochemical Signature 6/
Simple Sb	X	X			Sb ± Fe ± As ± Au ± Ag, Hg ± W ± Pb ± Zn may be useful in specific cases.
Gold on flat faults	X	X		X	Au, Cu, Fe, F, Ba. Very low-level anomalies in Ag, As, Hg, and W.
Bedded barite	X	X			Ba, where peripheral to sediment-hosted Zn-Pb, may have lateral (Cu), Pb, Zn, Ba zoning or regional Mn haloes. High organic C content.
Replacement Mn	X	X			Mn, Fe, P, Cu, Ag, Au, Pb, Zn.
Polymetallic replacement	X	X		X	On a district-wide basis, ore deposits commonly are zoned outward from a Cu-rich central area through a wide Pb-Ag zone, to a Zn and Mn-rich fringe. Locally Au, As, Sb, and Bi. Jasperoid related to ore can often be recognized by high Ba and trace Ag content.
Fe skarn	X	X		X	Fe, Cu, Co, Au, possibly Sn.
Zn-Pb skarn	X	X		X	Zn, Pb, Mn, Cu, Co, Au, Ag, As, W, Sn, F, possibly Be.

See footnotes at end of table.

TABLE 9. Geochemical Exploration Methods Applied to Selected Deposit Models--Continued

Deposit type	Soil 1/	Rock 2/	Stream sed. 3/,4/	Veg. 5/	Geochemical Signature 6/
Cu skarn	X	X		X	Rock analysis may show Cu-Au-Ag-rich inner zones grading outward to Au-Ag zones with high Au:Ag ratio and outer Pb-Zn-Ag zone. Co-As-Sb-Bi may form anomalies in some skarn deposits.
W-Mo skarn	X	X		X	W, Mo, Zn, Sn, Bi, Be, As.

1/May not be particularly effective for deeply-buried deposits. Pathfinder elements may be detected.

2/Includes whole rock, mineral inclusions, fluid inclusions, etc. on rock outcrops, and core, chips, etc. from drilling.

3/No perennial streams on site; samples from washes and canyons may be barren of fine fractions.

4/Water sampling restricted to groundwater. Samples may detect anomalous concentrations of elements but may be difficult to determine source.

5/Could be useful in Au exploration, especially if *Artemesis tridentata* *Nutt.* (a species of sagebrush that absorbs Au) is present on or around site. See Erdman, et. al. USGS OFR 88-236, 1988.

6/Radiometric methods may be employed to detect radioactive elements in tuffs or ground water. Also, vapor surveys for radioactive elements and Hg may be useful.

Modified from Cox and Singer (1986).

An overview of case histories and papers pertaining to successful geochemical exploration programs was published in 1971 by the Canadian Institute of Mining and Metallurgy (109, pp. 53-285). The case histories and papers present detailed accounts of the geochemical exploration methods, analytical techniques, and other germane information on the discovery of a wide range of metallic and nonmetallic ore bodies worldwide. References to case histories and papers from the above report and other sources are presented in appendix B.

Basically, exploration geochemistry is a simple technique, but interpretation is often difficult as there are numerous variables and few rules that can be applied universally (108). Therefore, the selection of particular methods or combination of methods, and the uncertainties associated with their use, is largely a function of personnel expertise such as application of method(s), interpretation, and analysis; site and regional geology; resource commodity sought; topography; climate; and time and funding constraints.

2.1.5.4 Geophysical Exploration Methods

Geophysical exploration methods involve the application of geophysical principles to the search for mineral deposits (as well as hydrocarbon accumulations and geothermal occurrences), and may be divided into the following general methods:

(1) Seismic
(2) Gravity
(3) Magnetic
(4) Electrical and electromagnetic
(5) Radiometric
(6) Well-logging (borehole geophysical methods)
(7) Miscellaneous chemical, thermal, and other methods.

Seismic Methods

Seismic exploration methods (110) consist of generating seismic waves and measuring the time required for the waves to travel from the source to a series of receivers, usually disposed along a line directed toward the source. From a knowledge of travel times to the various receivers and the velocity of the waves, one attempts to reconstruct the paths of the seismic waves. Structural information is derived principally from paths which fall into two main categories: head-wave or refracted (seismic refraction) paths in which the principal portion of the path is along the interface between two rock layers, and reflected paths (seismic reflection) in which the wave travels downward initially and at some point is reflected back to the surface. For both types of path, the travel times depend upon the physical properties of the rock and the attitudes of the beds. The objective of seismic exploration is to deduce information about the physical properties of the rocks, especially about the thickness and attitudes of the beds, from the observed arrival times and (to a limited extent) from variations in amplitude and frequency.

Jones and others (111) report that seismic reflection profiling at Yucca Mountain has been less than satisfactory and provide possible explanations for the poor record. For a discussion of the problems pertaining to reflection profiling at the site, see Jones (111, pp. 112-116). Catchings and Mooney (112), however, report successful seismic penetration of 5 to 12 km of Columbia River Basalt and underlying sediments to obtain the first detailed look at the structure beneath the central Columbia Plateau. The technique used by Catchings and Mooney, "high-resolution full-wavefield seismic profiling," may be useful in determining structure, depth-to-basement, and other factors on and around the Yucca Mountain site.

Gravity Methods

Gravity exploration methods (gravity prospecting) involve the measurement of variations in the gravitational field of the earth by ground, airborne, and underground surveys. Gravity surveys, like magnetics, radioactivity, and a few of the minor electrical techniques, are a natural source method 7/ in which local variations in the density of rocks near the surface cause changes in the main gravity field. Although primarily employed as a reconnaissance tool for hydrocarbon exploration, gravity exploration methods have recently become more popular for detailed followup of magnetic and electromagnetic anomalies detected in integrated base-metal surveys in mineral exploration.

Magnetic Methods

Magnetic exploration methods have much in common with gravitation methods in that they both seek anomalies caused by changes in the physical properties of subsurface rocks, require fundamentally similar interpretation techniques (although interpretation of magnetic data is more complex), and are used mainly for reconnaissance (110, 113).

Whereas gravity methods attempt to locate mineral deposits by the measurement of small changes in the earth's gravitational field, magnetic methods measure variations in the earth's magnetic field caused by the presence of magnetic constituents in an ore body. Further, where maps produced on the basis of gravitational data show mainly regional effects, the magnetic map appears to be a multitude of residual anomalies which are the result of large variations in the fraction of magnetic minerals contained in the near-surface rocks (110, 113).

7/Natural source methods do not require the introduction of artificial energy sources such as explosions or vibrations as in seismic methods, or currents, potentials, and fields as in several of the electrical methods.

Electrical and Electromagnetic Methods

Electrical exploration methods (electrical or geoelectrical prospecting) involve the detection of surface effects produced by electric current flow in the ground (110) and represent a greater variety of techniques available than other geophysical methods. It is the enormous variation in electrical conductivity found in different rocks and minerals that makes these methods important exploration tools. Electrical methods are almost entirely confined to mineral exploration as they have proved effective only for shallow exploration and have seldom provided data on subsurface features deeper than 305 to 460 meters (113, p. 339). Telluric and magnetotelluric methods (including controlled source audio-frequency magnetotellurics--CSAMT), however, are routinely used in hydrocarbon exploration as the associated fields and currents are able to penetrate to the depths where oil and gas are normally found (113). These methods may be of value in mineral exploration of the Paleozoic rocks underlying Yucca Mountain.

Major electrical exploration methods include self-potential, telluric currents and magnetotellurics (MT), audio-frequency magnetic fields (AFMAG), resistivity, equipotential point and line and mise-a-la-masse, electromagnetic (EM), and induced polarization (IP).

Radiometric Method

The radiometric method is used to locate mineral deposits that contain radioactive elements or compounds. Of the 20 or more naturally occurring elements known to be radioactive, only uranium, thorium, and an isotope of potassium are of importance in exploration (110). One other element, rubidium, is useful for determining the age of rocks. The radiometric method is not as widely used as other geophysical techniques.

These and other geophysical exploration methods (and applications) are discussed in detail in Telford and others (110), Dobrin (113), Parasnis (114), Eve and Keys (115), and Sheriff (116); additional references are presented in Section 6.4. Case histories and papers pertaining to mineral deposits discovered primarily by the use of geophysical exploration methods are presented in Appendix B. The most important or widely used methods and some of the advantages and disadvantages associated with their use are summarized in Table 10.

Surveys using aircraft carrying magnetic, electromagnetic, and other devices are the most rapid method of finding geophysical anomalies. Such areal surveys are also the most inexpensive methods of covering large areas and hence are frequently used for reconnaissance surveys; any anomalies of interest are later investigated using more detailed aerial surveys and/or ground surveys. Seismic exploration is another technique which has been used to explore large areas, both on land and offshore, however, at considerably greater cost, both in time and money.

TABLE 10. Comparison of Major Geophysical Exploration Methods

	Seismic refraction	Seismic reflection	Gravity	Magnetic	Electrical	Radiometric
Principal applications	Reconnaissance exploration for oil Engineering geology Regional geologic studies Geothermal exploration	Detailed exploration for oil Geothermal exploration	Reconnaissance exploration for oil and minerals Regional geologic studies Geothermal exploration	Exploration for magnetic minerals Reconnaissance exploration for oil Regional geologic studies Geothermal exploration	Exploration for minerals Engineering geology Geothermal exploration	Exploration for radioactive minerals
Quantity actually measured	Time for explosion wave to return to surface after refraction by subsurface formations	Time for explosion wave to return to surface after reflection by subsurface formations	Variations in earth's gravitational field attributable to geologic structures	Variation in magnetic elements attributable to geologic structures	Natural potentials Current transmitted between electrodes, resulting potential drop Induced electric field	Natural radioactivity of earth materials
Quantity computed from measurements	Depths to refracting horizons, horizontal speeds of seismic waves	Depths to reflecting horizons, dips	Density contrasts of rocks, depths to zones of anomalous density	Susceptibility contrasts of rocks, approximate depths to zones of anomalous magnetization	Resistivities of beds, approximate depths of interfaces between beds of contrasting resistivity	Uranium content of rocks
Geologic or economic features sought by method	Folded structures	Structural oil traps of all kinds, reefs	Salt domes, structural axes, buried ridges	Basement topography, deposits of magnetic ores, dikes, and similar igneous features	Ore deposits having anomalous electrical properties, depth to bedrock, depth to ground water surface	Uranium deposits
Corrections applied to data	Weathering, elevation, "onset-to-trough" interval	Weathering, elevation, filter shift	Latitude, free-air, Bouguer, terrain	Diurnal variation, normal	NA	Background radioactivity
Size of crew (no. of men)	15 or more	11-20	5	3 (ground)	2 or 3 (ground)	1-4 (ground)
Can measurements be made from aircraft?	No	No	No	Yes	Yes	Yes
Is method used offshore?	Yes	Yes	Yes	Yes	Yes	No
Advantages	Provides data useful to identify beds and to infer bed lithology	Provides large amount of structural data	Useful in oil and mineral exploration; highly sensitive equipment	Simplicity of execution; useful in both hydrocarbon and mineral exploration; rapid, economic, and convenient 1/	Useful in mineral exploration. Can be used from aircraft or offshore	Provides information on radioactive elements
Disadvantages	Provides lower volume and less precise data than reflection; limited application in mineral exploration	Slower and more expensive than most methods; limited applications in mineral exploration	Interpretation complex; requires independent controls; data often ambiguous	Interpretation complex; magnetic effects from rocks may be influenced by small amounts of certain contained minerals; requires independent controls such as drill logs and seismic data	Limited applications in hydrocarbon exploration	Limited applications in hydrocarbon exploration

1/Allows depth to basement estimates to be made; useful in lineament studies.

Table 11 presents the types of geophysical exploration methods that may be of value in assessing the resource potential of Yucca Mountain. Each method is keyed to one or more of the deposit models discussed in Section 2.1.4.2. The selection of a particular method or methods of geophysical exploration may include, but is not limited to, those listed above or in Table 11.

Deciding which method or methods to use on a particular area is extremely important. An effective but costly and time-consuming procedure involves trying every method imaginable and subsequently focusing on the method(s) that produce results.

According to Telford (110):

> "The choice of a geophysical technique or techniques to locate a certain mineral deposit depends on the nature of the mineral and the surrounding rocks. Sometimes a method may give a direct indication of the presence of the mineral being sought, for example, the magnetic method when used to find magnetic ores of iron or nickel; at other times, the method may only indicate whether the conditions are favorable to the occurrence of the mineral sought."

A good example of indirect detection is in the use of seismic techniques in hydrocarbon exploration. The techniques themselves do not generally locate oil but are used as an aid to identify favorable stratigraphy and traps that may be productive of oil. Sphalerite exploration is another good example of indirect detection. This mineral has little or no response to the induced polarization method (IP), but there can be a correlation between sphalerite and associated pyrite or galena, both of which have good IP responses. If a positive correlation exists between sphalerite and pyrite and/or galena, then IP could be a valuable tool in detecting sphalerite zones.

Table 11, in keying geophysical methods to a particular deposit type, is intended as a guide to what methods or combination of methods may be applicable in the Yucca Mountain area. Entries under the heading "Applications-Investigations" includes the materials (minerals, ores, etc.) and/or information that may be directly or indirectly gained by the use of the associated method. For example, telluric methods are useful in structural studies, and are especially useful in Basin and Range studies. Gravity methods may directly detect heavy ores such as chromite, pyrite, chalcopyrite, and lead, and provide indirect information on placer configuration, karstic cavities, basement topography, or structure.

TABLE 11. Geophysical Exploration Methods Applied to Selected Deposit Types

Method	Characteristic physical property	Main causes of anomalies	Applications-Investigations: Direct detection-information	Applications-Investigations: Indirect detection-information	Applicable Deposit Types
Resistivity	Resistivity	Conductive veins, ore bodies, sedimentary layers, resistive layers (limestones, salt domes, volcanic intrusions...), shear zones, faults, weatherings, hot waters	Massive sulfides Clays	Bulk material Base metals P_2O_5 Potash U Coal	See footnote 1/. 1,2,3,5,6,8,10,13,14,15,16,17. 4,7,9,11,12,18,19--Conditional.
Induced Polarization	Ionic-Electronic Over voltage	Conductive mineralizations: Disseminated or massive graphite, sulfides, clay	Conductive sulfides, oxides, Mn oxides	Associated minerals (Zn, Au, Ag, Sn, U)	6,8,9,13,15,16,17,18. 1,2,3,4,5,7,10,12,14,19--Conditional.
Self Potential	Conductivity Oxidation potential	Massive conductive ores Graphite Electro-filtration Faults Geothermal systems	Sulfides: Pyrite, Pyrrhotite, Cu Mn ore	Associated minerals (Pb, Au, Ag, Zn, Ni)	See footnote 2/. 3,5,17. 1,2,6,7,8,9,12,13,15,16--Conditional.
Mise a La Masse	Conductivity	Extension of previously located conductive ore bodies	Conductive ores	Associated minerals (Zn,Sn)	See footnote 3/. 3,6,8,9,10,13,14,15,16,17. 1,2,4,5,7,18,19--Conditional.
Telluric	Conductivity	Conductance of sedimentary series Salt domes	Structural studies Basin and range studies	Regional exploration	1,2,3,6. 13,18--Conditional.
Magnetotelluric	Resistivity Conductivity	Conductive veins, ore bodies, sedimentary layers, shear zones, faults, weatherings, resistive basements	Massive sulfides Clays	Shear zones General tectonics General structure	1,2,3,5,6. 13,14,15,16,17,18--Conditional.
Electromagnetic	Conductivity	Conductive mineralizations Surficial conductors Shear zones	Conductive sulfides, oxides, Mn oxides	Associated minerals Ground follow up Shear zones, weathered zones, conductivity maps	3,7,12,13,14,15,16,17. 2,5,8--Conditional.
Magnetic	Magnetic susceptibility	Contrasts of magnetization Magnetite content of the materials	Magnetite Pyrrhotite Titano-magnetite	Mo Fe ore Chromite Cu ore Geological mapping in terms of magnetic changes and/or discontinuities	See footnote 4/. 1,2,5,6,14,15,16. 3,4,8,9,17--Conditional. 18,19--Highly conditional.
Gravity	Density	Deposits of heavy ores Salt domes (light) Basement rocks	Chromite Pyrite Chalcopyrite Pb	Placer configuration Karstic cavities Basement topography Structure	See footnote 5/. 6,14,15,16,17. 8,10,13,18,19--Conditional. 11--Highly conditional.
Radioactivity	Radioactivity	Radioactive elements U-Th-K_{40}	U Th Monazite P_2O_5	Ground follow up Geological, structural mapping (differentiation in granites)	See footnote 6/. 18,19. 1,2,5,6,17--Conditional.
Seismic: Refraction Reflection	Seismic wave velocity Dynamic modulus	Contrasts of velocity: Markers at variable depth, fissured rocks	Buried channels Faults Morphological traps Basement topography	Sn Heavy minerals U	See footnote 5/. 6,10,11. 1,2,3,4,5,12,13,14,15,16,17--Conditional. 18,19--Highly conditional.

Modified from Northwest Mining Assoc. (1978).

1/Visibility dependent in part on resistance contrast with host rock.
2/Sulfides should be present, preferably pyrite.
3/Visibility dependent in part on resistance contrast with host rock; sulfides should be present.
4/Dependent on magnetic contrast between ore zone and host rock, and magnetite content of ore zone and host.
5/Dependent on rock properties, contrast, and size of deposit.
6/Dependent on contrast between host and ore body.

Types of Deposits

1. Hot-spring Au-Ag
2. Hot-spring Hg
3. Creede epithermal veins
4. Replacement Sn
5. Epithermal quartz-alunite Au
6. Porphyry Mo, low-F
7. Epithermal Mn
8. Carbonate-hosted Au-Ag
9. Simple Sb
10. Gold on flat faults
11. Bedded barite
12. Replacement Mn
13. Polymetallic replacement
14. Fe Skarns
15. Zn-Pb skarns
16. Cu skarns
17. W-Mo skarns
18. Fluoride-related Be deposits
19. Spor Mountain type Be-F-U deposits

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For many of the deposit models shown on Table 11 the associated method is only applicable under certain conditions (e.g., the use of IP in a suspected hot-spring gold environment may be inconclusive unless sulfides are present--"conditional"). Additionally, for several deposits a wide range of conditions or certain rare conditions must be met if the method is to be successfully employed ("highly conditional"). Because uncertainty exists with respect to geologic conditions at Yucca Mountain, the inclusion of these conditional and highly conditional methods for a particular deposit type was deemed necessary.

Geophysical exploration methods are complex and require highly skilled personnel in their application, execution, interpretation, and analysis. Uncertainties associated with their use are largely a function of expertise, as well as depth-to-target, geology, lithology, mineralogy, bedding, foliation, physical properties of the rocks, resource commodity sought, topography, and time and funding constraints.

2.1.5.5 Exploration Drilling Methods

Indications of mineralization gained through the application of the exploration methods discussed above are just that--indications--unless, of course, the deposit is on the surface. Such indications must be confirmed by drilling which is by far the most definitive (and expensive) exploration method. Drilling is normally employed to provide subsurface geological, geochemical, and geophysical information through the recovery of core, chips, and sludge that cannot be obtained through the application of any of the exploration methods discussed so far. Furthermore, boreholes provide channels for geophysical logging and, in the event of a discovery, data for determining a third dimension necessary for calculating deposit volumes and tonnages.

Areas identified in literature research and field investigations as potential drill targets may become foci of a drilling program, the extent of which is a function of several factors that include type and volume of information required, and time and funding constraints. Assessment of the Paleozoic rocks underlying Yucca Mountain, because of their depth, must rely heavily on drill-hole data supplemented by other exploration methods. Several deep boreholes (including the possible reentry and deepening of UE25p#1) may be required to adequately test these rocks. By judicious borehole placement and use of inclined drilling techniques (especially useful in testing for vertical features such as high-angle faults), testing of the Paleozoic rocks could be effected without conflict with the provisions of 10 CFR Section 60.15(d)(1-4). Boreholes drilled over the past few years on and around Yucca Mountain may still be open for deepening or for geophysical logging.

Drillholes that have been completed for site suitability studies and those planned for site characterization studies other than resource assessment may not uniformly cover the controlled area and may not be directed at or intersect features favorable for minerals such as high-angle fault zones, detachment zones, or veins. Further, such drillholes may not be favorably placed or extend to the depths necessary to provide sufficient information to assess the resource potential of pre-Cenozoic rocks and volcanic rocks underlying the site. It is unlikely that vertical drillholes would intersect vertical to near vertical faults or mineralized zones. This notwithstanding, holes drilled for other purposes may provide valuable resource information; efforts should be made to integrate any germane data into the assessment program.

In some cases, holes drilled for resource assessment may serve multiple purposes that may require the use of dry-drilling methods if the use of drilling fluids could compromise the proposed tests or interfere with other tests proposed in the site characterization program.

By far, the most frequently used methods of exploratory drilling are diamond core, rotary, and percussion drilling. Other drilling methods such as continuous core, downhole rotary, downhole hammer, and churn drilling are also available. However, these methods may have little or no application at Yucca Mountain. The principal features of the most frequently applied methods, as well as other drilling methods, are summarized in Table 12. Acker (117), Campbell (118), Cumming and Wicklund (119), and McGregor (120) provide detailed drilling methodologies, descriptions, rationales, applications, and associated costs. Additional references are presented in Section 6.3.

2.1.5.6 Borehole Geophysical Methods

Well-logging (borehole geophysical logging surveys) is a widely used geophysical technique that involves probing the earth with instruments lowered into boreholes; instrument readings are recorded on the surface. Borehole surveys provide direct and indirect lithologic, stratigraphic and structural information, indications of the mineralogy and grade of ore, and index measurements for surface geophysical studies. The many boreholes drilled (or planned) on and around Yucca Mountain could provide channels for a number of borehole geophysical studies.

Well-logging has long been employed in hydrocarbon exploration. However, as Telford (110, p. 771) points out, well-logging has not been used extensively in the search for metallic minerals for several reasons: (1) Smaller hole sizes in diamond drilling impose some limitations on equipment, (2) identification and correlation is more difficult in the complex geologic structure often associated with mineralized areas, and (3) complete recovery of core eliminates the need for logging. Telford goes on to say, however, that it is unfortunate that well-logging is generally underutilized in the mineral industry in that . . . "Well-logging is cheap compared to drilling", and, "A variety of geophysical logging techniques would be valuable aids to correlation and identification of mineral-associated anomalies, particularly where core is lost or difficult to identify."

TABLE 12. Exploration Drilling Methods and Normal Characteristics

	Diamond drill (core)	Rotary	Continuous core	Downhole rotary	Downhole hammer	Percussion	Churn
Geologic information	good	poor	fair	(----------poor----------)			
Sample volume	small	large	small	(----large----)		small	large
Minimum hole diameter	30 mm	50 mm	120 mm	50 mm	100 mm	40 mm	130 mm
Depth limit 1/	3,000 m	3,000 m	1,000 m	3,000 m	300 m	100 m	1,500 m
Speed	low	(----------high----------)					low
Wall contamination	(---variable---)		low	(----------variable----------)			
Penetration-broken or irregular ground	poor	(-----fair-----)		(----------good----------)			
Site; Surface or Underground	S,U	S	S	S,U	S,U	S,U	S
Collar inclination; range from vertical and down	180°	30°	0°	30°	180°	180°	0°
Deflection capability	(---moderate---)		none	high	(--------none----------)		
Deviation from course	(-----high-----)		(---------low----------)			high	low
Drilling medium: Liquid or Air	L	L,A	L	L,A	A	L,A	L
Cost per unit depth	high	low	mod	(--------low---------)			high
Mobilization cost	low	(----------variable----------)				low	variable
Site preparation cost	low	(----------variable----------)				low	high

1/Practical depth limit for mineral exploration. Boreholes using rotary or downhole rotary drilling methods that exceed 9,000 m are common in hydrocarbon exploration.

Source: Peters, 1978, p. 434.

Some of the geophysical exploration methods that have been applied to well-logging include resistivity, induction, self-potential, induced-polarization, and occasionally other electrical methods; detection of gamma-rays and neutrons using radioactivity methods; acoustic logging; and measurement of magnetic and thermal properties. Logging methods and techniques applied to metal and nonmetal deposits are discussed in detail in Dyck (121), Scott and Tibbets (122), Threadgold (123), Baltosser and Lawrence (124), and Tixier (125). Other germane references are listed in Section 6.4.

2.1.5.7 Subjective Regional Resource Assessment Methods

Background

An identification and evaluation of the natural resources of the geologic setting in which a proposed HLW site is located is required by 10CFR60.21(c) (13). The regulation further states that this evaluation of resources, including undiscovered deposits, shall be conducted for the site and for areas of similar size that are representative of and are within the geologic setting (emphasis added).

In the preceding sections, geological, geochemical, geophysical, and borehole drilling methods for resource assessment that may be applied at Yucca Mountain were discussed. However, time and funding constraints and problems related to the entry and evaluation of State or private land may preclude the use of these methods in evaluating areas of similar size within the geologic setting that are beyond site boundaries. The use of geologic analogs and the application of geomathematical or geostatistical assessment methods may be required to evaluate these areas.

In recent years, a number of methods or procedures (commonly referred to as "geomathematical" or "geostatistical" methods) have been developed primarily for regional (rather than local) resource assessment. The creation, development, and evolution of these methods has been driven, in most part, by a need of Congress, as well as agencies with regional planning responsibilities, to assess the mineral and energy endowment of large tracts of land in which the employment of traditional exploration methods would either be too costly or time consuming. Of the many methods developed over the years, 15 are in common use. These include: simple subjective, complex subjective, time-rate, crustal abundance, cumulative tonnage versus grade, Bayesian, frequency, trend, geometric probability, multiple regression, discriminant analysis, modified component, multivariate logistic, cluster analysis or pattern recognition, and simulation (126).

The methods listed above, with the possible exception of the subjective techniques, are best applied to large tracts of land that consist of hundreds of thousands or millions of hectares and may require a specific quantity and/or type of data that may not be available for the site at Yucca Mountain (e.g., production records, economic information, tonnage and grade estimates, borehole data, etc.). Furthermore, resource assessment at Yucca Mountain presents a number of problems not normally encountered in a typical regional assessment. These include: (1) the relatively small target area (less than 800 hectares); (2) applicability of the assessment over extremely long time frames (10,000 or more years);; and (3) regulatory constraints on additional data gathering (primarily drilling).

Of the 15 methods in common use, the subjective methods appear, in the judgement of the authors, to be the most applicable in assessing the resource potential of Yucca Mountain (in conjunction with traditional exploration procedures) and evaluating the resource potential of the larger geologic setting.

Subjective Assessment Methods

Subjective methods of regional resource assessment allow estimates (typically expressed as a probability) to be made of an area's resource potential in a relatively short period of time. The methods are relatively inexpensive and can be applied in many cases where physical data are limited. However, these methods rely in large part on informed judgments of an expert or group of experts and may contain an unacceptably high degree of uncertainty.

Two general categories of subjective assessment methods are in common use: simple subjective and complex subjective methods (126).

Simple subjective methods are the most widely employed by industry and government (126, p. 1008) and produce estimates made directly by one or more persons, based on their individual experience and knowledge. This may involve individuals separately or in concert, and one or more iterations such as those employed by Delphi or Monte Carlo methods. Shawe (127) employed simple subjective methods to assess the mineral potential of the Round Mountain, Nevada 1:24,000 quadrangle.8/

Complex subjective methods employ a collection of rules (inference networks) based on expert opinion on the nature and importance of geologic relationships associated with mineral deposit types. Harris (128) discusses how an inference network representing geologic processes might be used to estimate uranium endowment. (See Section 2.2.2 for a discussion of two complex subjective methods in current use or under development.)

8/Although widely applied, simple subjective methods tend to produce poor results. See Bryan, R. C. in Section 6.8.

Geologic Analogs

Subjective resource assessment methods (both simple and complex) commonly employ the use of analogs--geographic areas within the geologic setting that are analogous to the area under consideration in terms of origin, size, lithology, and postdepositional or postorigin history. Analogs are often identified through information gained during background research supplemented by field data. Factors to be considered in the selection of areas to be used as analogs for resource assessment and comparison to Yucca Mountain site include (129):9/

(1) Analogs should be within the same or similar geologic setting and should contain similar host rocks or associated lithologies as those of the candidate area;

(2) Genesis of rocks in both analog and candidate areas should be similar;

(3) Whereas it may be advantageous for postdepositional (or postgenetic, if other than sedimentary rocks) history of both analog and candidate areas to be similar (including depth of burial), it is not mandatory; and

(4) Analogs must be extensively explored.

Furthermore, each analog must be thoroughly studied by examining existing literature supplemented by laboratory analysis or field tests as necessary noting the status of relevant criteria and one or more measures of mineral density (number of deposits in area, areal extent, quantity and/or quality of mineralized material). These and other relevant data (e.g., deposit size, average grades, mineral assemblages) are compiled, and geological, geochemical, and geophysical differences and similarities, deposit numbers and sizes, and grades across the analog are noted.

In summary, of the many regional resource assessment methods available, the subjective methods appear to be the best suited for use at Yucca Mountain and for the evaluation of the resource potential of areas of similar size within the geologic setting.

Uncertainties associated with the application of subjective assessment methods can be reduced through additional information gathering (including borehole drilling), geological, geophysical, and geochemical exploration, or production, but never totally eliminated, even in extensively explored areas.

9/See Harbaugh, (129--NUREG/cr-3964) for a detailed discussion of analog criteria.

2.1.5.8 Data Analysis and Evaluation

2.1.5.8.1 Map Data Compilation and Correlation of Sample Data

Data acquired in literature research and field investigations are compiled, interpreted, and subsequently employed to produce preliminary detailed geologic maps of the candidate site, controlled area, and analogs. These maps should be drafted at the largest practical scale and should include, but not be limited to, major rock units present; lithologic contacts; faults, folds, and other structural features; attitudes (strike and dip) of formations, bedding planes, and foliation; and sample locations and other pertinent data. It is important that all locations at which samples were taken, or geochemical/geophysical surveys were made, are accurately plotted. Locations of boreholes, trenches, and pits should be similarly noted.

The maps should be accompanied by as many geologic cross sections as is necessary to clearly demonstrate the structure and structural relationships of the map area. Also, stratigraphic columns and other graphic representations of the data should be drafted.

Analysis of the maps and concomitant data may disclose areas that require additional field studies as well as targets for exploratory drilling.

Compton (130), Berkman (131), and Blackader (132) discuss at length the data required for inclusion on a geologic map; additional references are presented in Section 6.3. Map symbols, terms, and data collection techniques are similarly addressed.

2.1.5.8.2 Data Analysis

Data acquired through background research, field investigations, and the integration of germane data from other site characterization programs are compiled and analyzed to determine what, if any, resource(s) may be present at Yucca Mountain. In the event a resource is identified, additional studies would be become necessary to collect data for an economic evaluation of the resource's gross and net value as required by 10 CFR Section 60.21(c)(13). These studies include, but are not limited to:

(1) Additional drill holes to delineate the orebody;

(2) Additional surface/subsurface samples for tonnage and grade; calculations;

(3) Additional large-scale geological mapping;

(4) Geotechnical studies;

(5) Studies related to siting mine, and ancillary/infrastructural facilities.

In the event that a resource is not identified, but the data suggest the existence of undiscovered resources, additional data must be gathered in order to make an estimate of resource tonnage and grade in accordance with 10 CFR Section 60.21(c)(13).

As in the course of any resource assessment, it can never be proven that Yucca Mountain does not host mineral or energy resources. It can be said, however, that . . . "No resources have been identified within the area to the depths tested." Conversely, interception of metal-bearing material is proof that some resource exists regardless of whether the resource is economic or uneconomic given current market conditions.

The following sections (2.2, 2.3, and 2.4) present methods that are available for evaluating identified and unidentified resources that may occur at Yucca Mountain (and analog areas) to fulfill the requirements of 10 CFR Section 60.21(c)(13).

2.2 Resource Estimation

Section 2.2 discusses methods used to estimate the quantity, quality, and classification of mineral resources; methods used to differentiate between discovered and undiscovered resources are described separately. Classification of resources use definitions and guidelines presented in USGS Circular 831 (133). Guidelines for specific resources are also available, such as USGS Circular 882 (134), which classifies phosphate resources, and USGS Bulletin 1450-B (135), which classifies coal resources.

Historically, many resource-reserve classification schemes or systems has been developed. Although these schemes or systems vary in terminology, structure, and purpose, they share a commonality in attempting to provide a consistent method for defining, codifying, and reporting mineral resource quantities. USGS Circular 831 describes the resource classification system developed and employed by the Federal government's principal mineral resource agencies, the BOM and the USGS. This classification system, and associated terminology, is used in this report. Essential components of the system are graphically illustrated in Figures 9 and 10; definitions pertaining to Figures 9 and 10 are presented in Section 5.

2.2.1 Discovered Resources

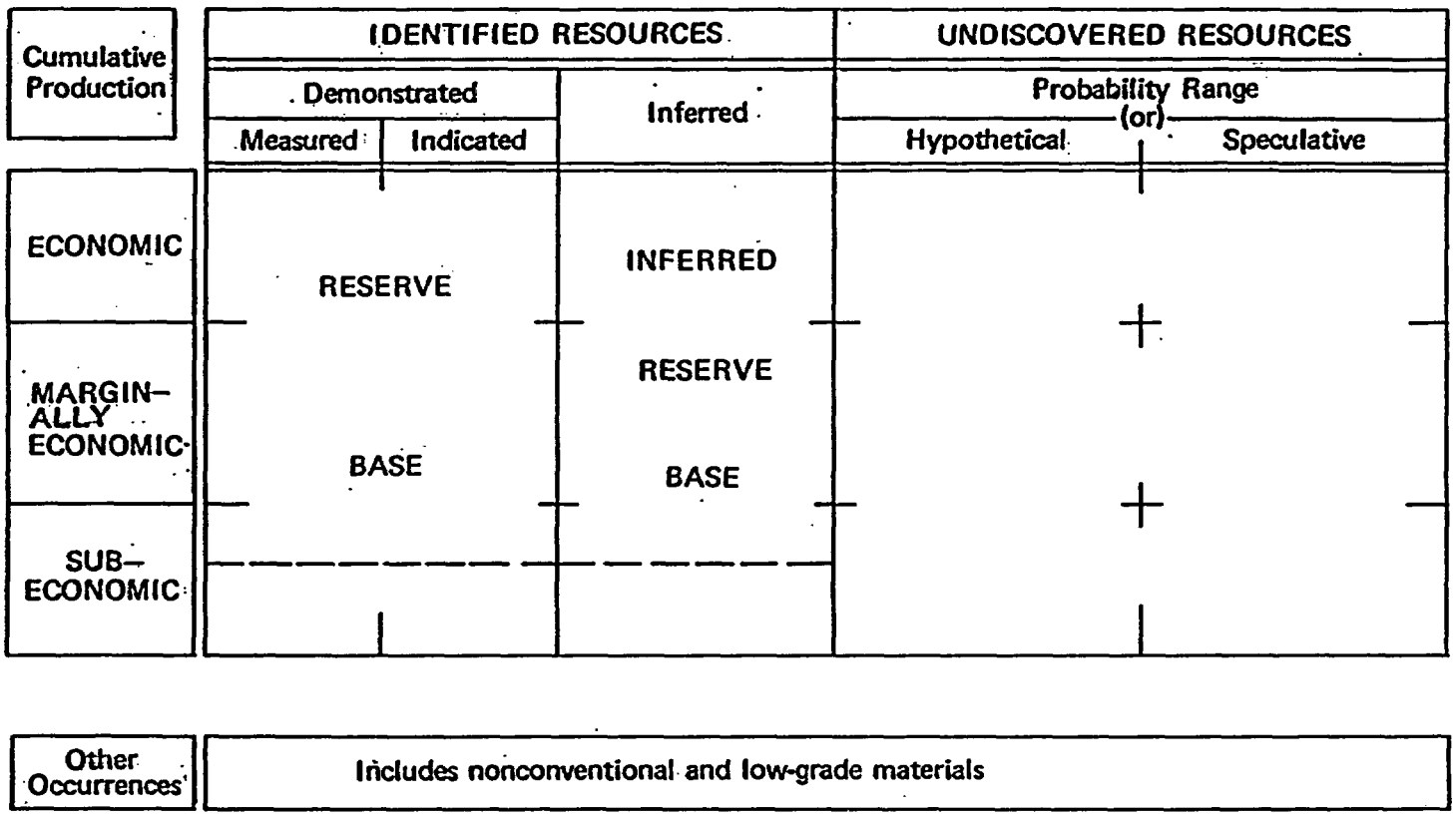
Resource estimation is a technical task designed to determine resource quantity and quality. It involves integration of collected data and selection of appropriate methods for computations.

Cumulative Production	IDENTIFIED RESOURCES			UNDISCOVERED RESOURCES	
	Demonstrated		Inferred	Probability Range (or)	
	Measured	Indicated		Hypothetical	Speculative
ECONOMIC	Reserves		Inferred Reserves		
MARGIN-ALLY ECONOMIC	Marginal Reserves		Inferred Marginal Reserves		
SUB-ECONOMIC	Demonstrated Subeconomic Resources		Inferred Subeconomic Resources		

Other Occurrences	Includes nonconventional and low-grade materials

Adapted from USGS Circ. 831

FIGURE 9.– Major elements of mineral-resources classification, excluding *reserve base* and *inferred reserve base*



Adapted from USGS Circ. 831

FIGURE 10.– *Reserve base* and *inferred reserve base* classification categories

2.2.1.1. Mineral Resources

Methods for resource estimation can be classified into four broad groups: (1) Average factor and area methods, (2) cross section methods, (3) analytical methods, and (4) mining block methods (136). General applications, advantages, and disadvantages for these methods are described in Table 13.

Average Factor and Area Methods

These methods use analogous or geologic blocks within areas delineated by geologic data where the basic elements (thickness, grade, and weight) are determined directly, computed, or inferred from the same or similar deposits. Specific examples of these methods have been described as arithmetic average (137), weighted average (138), average depth and area (138), statistical (139), analogous (140), and geologic block (140) or general outline (141). These methods are typically employed when there is a lack of extensive exploration data (e.g., drilling); therefore, resources calculated by these methods would normally fall into the "Inferred Resources" category (Figures 9 and 10).

Cross Section Methods

These methods involve the delineation of and subsequent resource estimate for a deposit, using engineering drawings constructed from drill intercept and other collected data. Variations include the standard, linear, and isoline methods (136). Accuracy of the final resource estimate, using one or more of these methods, depends on the extent of the data and frequency of sections used to define the resource (e.g. the more sections, the smaller the individual blocks, and the greater the confidence). Thus, resources calculated using the cross section methods are classified either "Indicated" or "Inferred."

Analytical Methods

Analytical methods divide a deposit graphically into blocks of simple geometric forms such as triangles or polygonal prisms. The factors for each block can be determined directly, or averaged mathematically. The polygon method is the most common variation of the analytical methods and is employed in conjunction with a diamond drilling program. Similarly, as with the cross section method, the level of confidence is directly related to the detail of the exploration program (e.g., the closer the drill holes, the greater the confidence). Thus, as with cross-section methods, resources calculated using analytical methods are classified either "Indicated" or "Inferred."

TABLE 13. General Applications, Advantages, and Disadvantages for Standard Mineral Resource Estimation Methods

Method	Applications	Advantages	Disadvantages
Average Factor and Area Methods	Particularly suited to tabular, bedded, and large placer deposits.	Adaptable to most deposit types. Procedures are flexible and require no complex formulas. Allows for rapid and continuous evaluation of factual data.	Accuracy for a deposit may depend on personal interpretation rather than objective geologic observations and sampling.
Cross Section Methods	Applicable to most uniform deposits the isoline. variation of the cross section method is also used in oil and gas resource estimation.	Methods graphically portray the geology of the mineral deposit. Computations are relatively simple and, depending on spacing of sections, can yield accurate results.	Use would be impractical for small deposits or structurally disrupted deposits.
Analytical	Applicable to tabular deposits such as coal, phosphate rock, oil-shale, large lenses, and thick veins.	In conjunction with an adequately designed exploration drilling and sampling program, thickness, grade, and volume are accurately determined.	Morphology of the deposit will not be revealed.
Mining Blocks Methods	Applicable to most mineral deposits with existing underground workings and drill holes.	Computations are are relatively simple and yield accurate resource estimates.	Primarily designed for operating underground mines or well delineated deposits.

Mining Blocks Methods

These methods are typically used to delineate block areas in underground mines and are used mainly for mine planning during extraction. Examples of mining block methods include longitudinal sections (142), mine extraction (138), and mine exploitation (143). These methods are normally employed in operating underground mines; therefore, because of the high degree on certainty, resource quantities estimated are typically classified as "Measured."

2.2.2 Undiscovered Resources

Due to restrictions on the use of piercement or direct sampling methods (drilling, trenching, drifting, etc.) and time constraints during site characterization, geomathematical methods may be useful in estimating the quantity and quality of undiscovered natural resources. For example, tonnages and average grades of well-explored deposits can be employed as quantitative and qualitative resource models for tonnage-grade estimates of undiscovered deposits in geologically similar settings (126). Unfortunately, no subjective/geomathematical discovery model currently exists that could be applied directly in assessing the natural resources of small geographic areas such as HLW repository sites. However, if suitable methods are developed, they would probably incorporate considerations similar to those techniques discussed in PROSPECTOR (144-148), developed by the Stanford Research Institute, and ROCKVAL (149), currently under development by BOM. A brief discussion and detailed references on PROSPECTOR are presented in Section 6.3. Little information has been published on ROCKVAL, therefore, a detailed discussion of this method is presented in the text.

PROSPECTOR

PROSPECTOR is a computer software system that imitates the decision process an expert geologist would use to determine the favorability of a resource prospect.

The program employs techniques of artificial intelligence (AI) to represent empirical judgment knowledge in a formal way and to use that knowledge to perform plausible reasoning. The system represents inference nets and computes probabilities in ways that permit the building and use of larger and more intricate inference nets. As opposed to requiring the geologist to identify all combinations at each level and to rank them, PROSPECTOR methodology requires the geologist to provide only the odds and likelihood ratios for each rule.

Due to the complex methodology of PROSPECTOR, the following references from the Stanford Research Institute should be consulted:

o Duda, R. O., P. E. Hart, N. J. Nilsson, R. Reboh, J. Slocum, and G. L. Sutherland. Development of a Computerbased Consultant for Mineral Exploration. Annu. Rep., SRI Projects 5821 and 6415, Stanford Res. Inst. Internat., Menlo Park, CA, 1977 (147).

o Duda, R. O., P. E. Hart, P. Barrett, J. G. Gaschnig, K. Konolige, R. Reboh, and J. Slocum. Development of the Prospector Consultation System for Mineral Exploration. Final Rep., SRI Projects 5821 and 6415, Stanford Res. Inst. Internat., Menlo Park, CA, 1978 (145).

o Gaschnig, J. Development of Uranium Exploration Models for the Prospector Consultant System. Final Rep., SRI Project 7856, Stanford Res. Inst. Internat., Menlo Park, CA, 1980 (148).

ROCKVAL

ROCKVAL (149) is currently being developed but has been used in one or more tests. For areas in which the use of traditional assessment techniques is limited, ROCKVAL and similar methods may represent the only available options. It must be noted, however, that ROCKVAL was designed for application to large areas (hundreds of thousands of hectares and larger), and some aspects of the methodology depend on the equivalent of the "law of large numbers." Thus, ROCKVAL and similar approaches are not, in their current form, appropriate tools for assessing HLW repository sites; however, they could be modified, if it were deemed necessary, to make the resource estimates required by 10 CFR Part 60.

The ROCKVAL approach to natural resource evaluation includes assessment of background data, field observations, and geochemical and geophysical analyses. Subjective probability judgments are applied to the collected data to estimate the likelihood of prospects, tonnages, grades, etc. The overall approach is illustrated in Figure 11.

The conceptual framework for the assessment of undiscovered but potentially valuable mineral deposit types predicted to exist within a region consists of four components: (1) A geologic model of endowment (that quantity of resource in deposits meeting specified physical characteristics such as quality, size, and depth); (2) a set of engineering screens (constraints); (3) a set of economic constraints; and (4) a statistical process to express the major geologic and economic results as probability distributions.

The geologic model of endowment divides the geologic characteristics of a particular deposit type into the following physical factors: endowment thresholds, regional parameters, deposit parameters, and commodity parameters. These are described in Table 14.

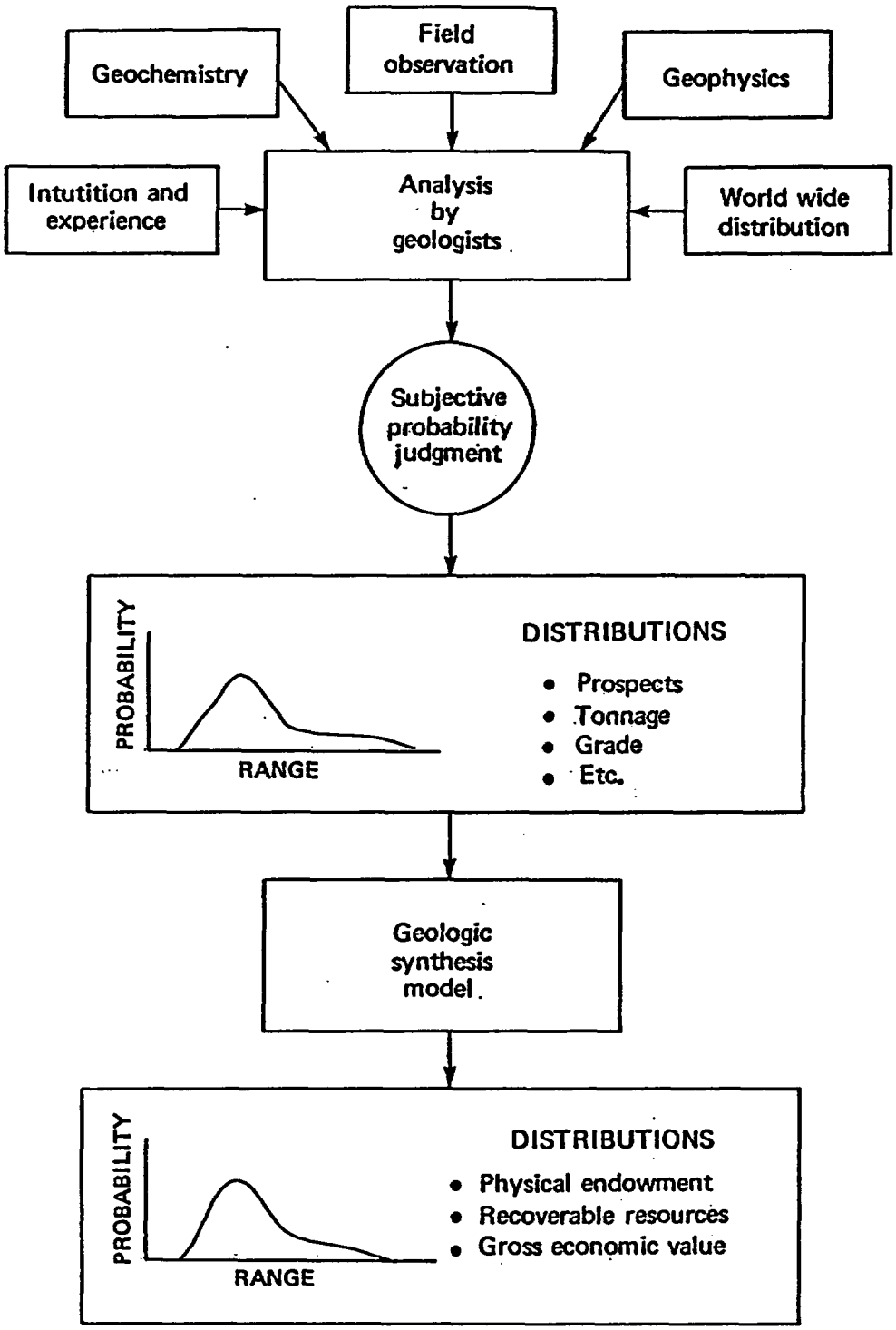


FIGURE 11.— Rockval approach to mineral resource assessment

TABLE 14. ROCKVAL - Geologic Parameter Definitions

Endowment Thresholds	
Cutoff Tonnage:	A threshold tonnage level arbitrarily set to distinguish between anomalies and deposits to be included in estimates of resource endowment. This threshold should be set well below the current economic cutoff level.
Cutoff Depth:	A threshold depth level arbitrarily set to distinguish between deposits to be included in estimates of resource endowment. This threshold should be set well below the current engineering cutoff level.
Cutoff Grade:	A threshold grade level associated with each mineral contained in a deposit arbitrarily set to distinguish between anomalies and deposits to be included in estimates of resource endowment This threshold should be set well below the current economic cutoff level.
Regional Parameters	
Regional Favorability:	A point estimate of the likelihood that all the geologic controls necessary for the formation of deposits of a specific type are regionally present.
Significant Prospect:	A prospect, occurrence, or anomaly of sufficient interest to cause a prudent exploration geologist to commit to a drilling program.
Deposit Parameters	
Deposit:	A mineral prospect exceeding a specified (cut-off) ore tonnage, grade, and depth.
Deposit Likelihood:	A point probability estimate of the likelihood that a randomly selected prospect will contain ore in excess of the cutoff tonnage, grade, and depth.
Deposit Size:	The estimated range in deposit sizes for the terrane.
Commodity Parameters	
Commodity:	A mineral of potential economic interest that may be present in a deposit.
Occurrence Probability:	A point probability estimate of the likelihood that the particular commodity is present in a deposit above the cutoff grade level.
Average Grade:	The estimated range in average grade for each commodity present in a deposit, above its cut-off grade.

Two engineering screens are employed to incorporate current technological limitations on the proportion of the mineral endowment that may be reasonably exploited. The first is a recovery factor estimated as the percent of a contained commodity in a deposit that may be efficiently recovered from the ore, and the second is a recoverable depth cutoff, below which current mining technology is unfeasible.

Two economic screens are employed to directly incorporate current (or projected) economic limitations on the proportion of the mineral endowment that may be reasonably exploited. The first is an economic cutoff on the gross value of the ore in a deposit, and the second is an economic cutoff on the unit value of ore in a deposit. The economic cutoff considers the variable costs and rate of return necessary to produce a unit of the resource. For the resources in a deposit to be considered potentially economically recoverable, rather than just part of the endowment, both the gross and the unit cutoff values for the deposit must be equaled or exceeded.

The final step in the application of ROCKVAL is to use the geologic factors and the engineering and economic screens by synthesizing them into a Monte Carlo simulation model to provide probabilistic estimates of mineral endowment and recoverable resources in terms of both physical quantities and values measured in dollars.

The model simulates one possible state of geologic nature by sampling from the probabilities assessed for each of the basic geologic factors and uses the resulting values to compute an amount of ore and contained commodities for deposits of a particular type.

The characteristics of each simulated deposit are then compared against the engineering and economic screens to determine if this deposit's resources may be considered economically recoverable. This process of simulating a particular state of nature (a Monte Carlo "pass") is repeated many times and the results stored, aggregated, and used to build a probability distribution for each of the desired products. The model also aggregates the results across all deposit types being assessed in a region, to provide total estimates for each commodity possible in the region.

2.3. Resource Evaluation

Pursuant to 10 CFR Section 60.21(c)(13), resources with current markets require estimation of gross and net value. Gross value is defined as the total dollar value of the commodity (at current prices) in the ground. Net value, on the other hand, is gross value less the cost of producing a marketable product; thus, it requires estimates of capital and operating costs necessary for recovery of the commodity. The process used to estimate resource net values uses many of the methodologies that would be employed by industry in making the decision to exploit or abandon a resource. By using these methods, sufficient data can be obtained to estimate the costs involved in extracting and marketing the resource, thus determining net value.

2.3.1 Capital and Operating Costs

Capital and operating cost estimates are necessary in order to determine the net value of a mineral resource. Capital costs represent those expenditures (exploration, development, mine and mine plant equipment purchase and installation, etc.) required to bring a resource into production; operating costs, on the other hand, represent labor, equipment and supply costs required to sustain day to day production. Major components of capital and operating costs are described in the following section.

2.3.2 Cost Components

Estimating capital and operating costs requires an estimate for each of the general cost categories shown below:

Capital Costs

o Acquisition - cost of purchase, lease, or rental of any fee lands and/or surface or mineral rights.

o Exploration - costs involved in defining the resource (costs related to methods discussed in Sec. 2.1).

o Development - costs required to prepare a mine for production (e.g., driving drifts, sinking shafts, preparing stopes, preproduction stripping, etc.).

o Extraction system equipment and plant facilities - expenditures for mining equipment and mine communications, water, or electrical systems.

o Processing system - costs associated with purchase and installation of process equipment.

o Ancillary requirements - costs of associated infrastructure.

o Engineering, design, and management costs - costs associated with the design and construction of a mine.

o Environmental costs - costs associated with measures to determine significant environmental damage and mitigation measures imposed.

Operating Costs

o Labor requirements - cost of labor needed to sustain production (e.g., miners, truck drivers, drillers, plant operators, mechanics, electricians).

o Supplies - cost of supplies needed to sustain production (e.g., fuel, electricity, explosives, reagents, water).

o Equipment operations - cost to maintain extraction and processing equipment (e.g., repair parts, tires, lube).

o Administration - cost associated with management and administrative functions (e.g., administrative personnel such as plant manager, security guards, purchasing agent.

Detailed information on cost estimation procedures and cost components may be found in the following references:

Base Line Studies, Environmental Assessment/Environmental Impact Statement (EA/EIS) Preparation, and Permitting

o Bureau of Mines Cost Estimating Handbook (150)

Underground Mines
o Cummins and Given, 1973 (151).
o Eshbach and Souders, 1975 (152).
o Hustrulid (ed.), 1982 (153).
o Peele and Church, 1941 (154).

Surface Mines
o Cummins and Given, 1973 (151).
o Caterpillar Tractor Co., 1984 (155).
o Pfleider, 1973 (156).
o Church, 1981 (157).
o Crawford and Hustrulid, 1979 (158).

Placer Mines
o Griffith, 1960 (159).
o Stebbins, 1986 (160).

Plant Design and Cost Estimating
o Currie, 1973 (161).
o Gilchrist, 1969 (162).
o Heady and K. G. Broadhead, 1976 (163).
o Pickett, 1978 (164).
o Pryor, 1965 (165).
o Richardson Engineering Services, 1984 (166).
o Taggart, 1945 (167).

2.3.3 Systems for Cost Estimating and Cost Data Sources

The following section discusses applications, advantages, and disadvantages of available systems used for estimating capital and operating costs.

BOM Cost Estimating System (CES) (150)

CES was first developed in 1975 to assist in the preparation of prefeasibility type (± 25 percent) estimates for capital and operating costs. The system is applicable for cost estimations of mining and beneficiation of various types of mineral occurrences. Recently, it was updated to reflect changes in cost and technology as of January 1984. The Handbook consists of a series of sections, each corresponding to a specific mining or mineral processing step. Costs are typically presented on a logarithmic scale of cost versus capacity.

Canadian Institute of Mining and Metallurgy (CIM) Mining and Mineral Processing and Equipment Cost and Preliminary Capital Cost Estimations (168)

The CIM estimating Handbook is useful in determining capital costs for many types of mining and processing equipment. The Handbook contains data in the form of graphs, tables, and equations to rapidly estimate the cost of individual equipment items. The Handbook cannot be used to estimate mining or processing operating costs.

BOM Cost Estimation Handbook for Small Placer Mines (160)

This Handbook was written specifically to aid in estimating capital and operating costs of placer mining operations and in designing placer mines and plants. It consists of a series of costing sections corresponding to specific components of a placer operation: exploration, mining, processing, supplemental systems, and environmental considerations. Each section contains the methodology to design a unit process or to estimate associated capital or operating cost. Costs are typically presented on a logarithmic scale of cost versus capacity. The system is designed to produce prefeasibility estimates in July 1985 dollars accurate to within 25 percent. The Handbook contains methods for updating base costs derived from the equations (July 1985 dollars) to current dollars.

Mining Cost Service (169)

Mining Cost Service is a subscription service published by Western Mine Engineering, Spokane, WA. The Handbook provides sections on electric power and natural gas rates, transportation routes and rates, labor rates, cost indices, supplies, equipment, smelting, taxes, and cost models. Data contained in the various sections allow the user to estimate capital and operating costs for most mining and processing systems; sections are updated annually negating the need to escalate costs to current dollars. The service provides information pertaining to most infrastructure requirements applicable to mining systems.

Green Guide (170)

The Green Guide, published by Dataquest, Inc., is a handbook that lists costs for new and used construction equipment. The Guide is a subscription service that provides detailed descriptions and costs for nearly all major construction equipment such as trucks, excavators, crushing equipment, air equipment, loaders, graders, pumps, and generators. The various sections are updated periodically (every few years); however, generally some escalation of dollar values is required to achieve current costs. The service is limited to capital cost estimates only.

Cost Reference Guide for Construction Equipment (171)

The Cost Reference Guide is a subscription service published by Equipment Guide-Book Co., Palo Alto, CA. The Handbook provides operational costs for nearly all the equipment contained in the Green Guides and is used to estimate operating costs for specific pieces of equipment. Costs are broken down into operating and overhaul labor, repair and overhaul parts, fuel, electricity, lubrication, tires, ground engaging components, etc. Like the Green Guide, this service is updated on a periodic basis (every few years) and requires some escalation of values to current dollars. It is limited to operating costs for specific construction equipment only.

2.3.4 Economic Analysis

The purpose of economic analysis is to determine net resource value. This is accomplished by using cost estimates of the proposed extraction and processing systems in addition to other costs deemed necessary to achieve production (e.g., environmental and infrastructure costs). Economics are normally measured in terms of net cash flow, on an annual basis. Cash flow has two components; positive cash flow (sales revenue, royalty income, interest income, tax credits, etc.) and negative cash flow (purchase of assets, purchase of materials, labor, supplies, royalty payments, interest expenses, debt repayment, local and Federal taxes, etc.).

The actual measure of profitability can be accomplished using the BOM MINSIM4. This computer program determines the discounted-cash-flow-rate-of return (DCFROR) for a profitable commodity. A complete description of the MINSIM4 package is available in Bureau of Mines IC 8820, 1980, "Supply Analyses Model (SAM): A Minerals Availability System Methodology" by R. L. Davidoff (172).

Alternative software is available for conducting economic analyses include SEE (Software for Economic Evaluation), available from Investment Evaluations Corp., 23715 Waynes Way, Golden, CO 80401 (173).

In addition to computer software, "hand calculation" methods are also available. Methodologies for calculating present worth, annual worth, future worth, rate of return, and breakeven analysis are described in detail in Economic Evaluation and Investment Decision Methods by F. J. Stermole (174).

2.4 Economic/Extraction Models

The purpose for the inclusion of economic/extraction models (EEM) in this document is to demonstrate the effort and level of detail necessary to determine the gross and net value of resources that may exist at Yucca Mountain in order to fulfill the requirements of 10 CFR Section 60.21(c)(13).

The following section discusses typical mining and processing scenarios for three deposit models (tungsten skarn, carbonate-hosted gold-silver, and hot-springs gold) selected from those discussed in Section 2.1.4.2. The three models represent those deposits, in the opinion of the authors, most likely to occur in the Paleozoic rocks underlying Yucca Mountain. For each EEM, the mining and processing system most applicable is described, an average deposit size based on other U.S. deposits has been selected, and capital and operating costs for mining and processing estimated.

Each EEM is based on the following assumptions:

1. Exploitation of the hypothetical resource(s) assumed in the models will employ underground mining methods in Paleozoic rocks underlying Yucca Mountain.

2. The mine portal and ancillary installations such as leach pads, tailings disposal areas, and shops and other buildings are located in Solitario Canyon (elevation, 4,000 feet) approximately 3,300 feet due west of drill hole USW H-3 10/. The Solitario Canyon site was selected based primarily on its proximity to a large fault/breccia zone that may host mineralized material and the possibility of metasomatic deposits along the east margin of the Crater Flat/Prospector Pass caldera complex.

3. The vertical distance from the portal to the top of the Paleozoic rocks is inferred as 4,100 feet. This inference is based on information from Robinson (15), plate 1) and Scott and Bonk (175, plates 1, 2).

10/See Scott and Bonk, 175, plate 1, for drillhole locations.

4. A 2,500-foot, 8-degree decline (for the main haulageway) bearing north-south to south 45 east 11/ is driven to a point about 350 feet lower than the portal elevation of decline terminus (3,650 feet).
5. At the terminus of the decline, a 4,000-foot shaft is sunk to the production levels (elevation, -350 feet). The shaft may require extension as production goes forward.

Detailed capital and operating cost estimates for the EEM were made using methods and references discussed in the preceding Section (2.3). Cost summaries are included with each model; costing backup data are included in Appendices C, D, and E.

Capital and operating cost estimates for each EEM were used as input for the SEE (Software for Economic Evaluation, 173) program that calculates the market price necessary to achieve a desired discounted cash flow rate of return (DCFROR). The software takes into consideration such factors as Federal, State, and local taxes, depletion allowance, commodity prices, and other cost-related variables that may affect the DCFROR. Program calculations for the selected EE models indicate that for a 15 percent DCFROR the following commodity prices are required:

1. Tungsten skarn EEM--$143 per short ton unit (stu, 12/) tungsten trioxide (WO_3);

2. Carbonate-hosted gold-silver EEM--$396 per troy ounce gold;

3. Hot-springs gold EEM--$470 per troy ounce gold.

SEE software is also capable of producing sensitivity analyses that calculates price determinations as input parameters are varied. For example, the tungsten skarn EEM assumes 2.7 million tons of ore at an average grade of 0.65 percent WO_3. For a DCFROR of 15 percent, this tonnage and grade requires a market price of $143 per stu. By varying either tonnage, grade, or desired DCFROR, the program will calculate the new commodity price. Since tonnage and grades used in the following EEM represent typical values, sensitivity analyses were deemed unnecessary for inclusion here.

11/Robinson (15, plate 1) suggests that the Paleozoic rocks beneath the hypothetical minesite are synclinal with a northeast plunge that could place the rocks at greater depth than the inferred 4,100 feet. The actual bearing of the decline would ultimately depend on more complete structural information gained during exploratory drilling.

12/One stu is 1 percent of a ton contained WO3 or 20 pounds. One stu contains 15.86 pounds W metal.

2.4.1 Tungsten Skarns

2.4.1.1 Deposit Description

The tungsten skarn model assumes a nearly vertical deposit, with a granitic footwall and limestone hanging wall, that is 2,000 feet long, 30 feet wide, and extends 500 feet downdip . Ore averages 11 cubic feet per short ton for a total resource of 2.7 million tons containing an average of 0.65 percent WO_3.

2.4.1.2 Mining Systems

Historically, tungsten mining in the United States has employed a variety of mine systems. A combination of blasthole stoping and sublevel caving was used at the Pine Creek/Adamson Mines in Inyo County, CA, and a combination of shrinkage stoping and open-pit mining was used at the Emerson Mine in Lincoln County, NV. The tungsten model developed for Yucca Mountain, based on the assumed dimensions, would be amenable to any of the three underground methods listed above. The model is based on blasthole stoping.

2.4.1.3 Processing Systems

Processing of tungsten ores in the United States is by either flotation or gravity concentration methods. Generally, low-grade deposits (0.3 up to 1 percent WO_3) are concentrated using flotation, the method employed at both the Pine Creek and Emerson Mines. High-grade deposits (generally greater than 1 percent WO_3) are concentrated using gravity separation. This method was employed at the Nevada Scheelite Mine in Mineral County, NV, and is currently in use at the Andrew Mine in Los Angeles County, CA.

2.4.1.4 Mine and Process System Description

The mine and process system model includes a 1,000 ton per day blasthole stope mine operating 2 shifts per day, 260 days per year. Processing uses a 722 ton per day flotation plant operating 3 shifts per day, 360 days per year.

2.4.1.4.1 Infrastructure

Infrastructure, not presently on site, includes upgrading 15 miles of access road from U.S. 95 to the proposed minesite, construction of 12 miles of transmission lines for electric power needs, and sinking a 300 foot (estimated) water well for process and mine water requirements.

2.4.1.4.2 Mine Development

Mine development includes driving a 14- by 12- by 2,500-foot main haulageway decline, sinking a 22- by 7- by 4,000-foot four-compartment vertical shaft, driving a 14- by 12- by 1,000-foot lower haulageway, driving three 10- by 8- by 500-foot development headings in ore, driving four 10- by 8- by 20-foot crosscuts to draw points, and raising four 6- by 6- by 24-foot ore chutes.

2.4.1.4.3 Mine Operations

Following development, mining commences at a rate of 1,000 tons per 2-shift day, 260 days per year. On a daily basis, development during production requires 0.34 feet of advance on the lower haulageway, 0.06 feet of advance on crosscuts, 3.03 feet of advance on development headings, 0.33 feet of advance on crosscuts to draw points, and 0.40 feet of advance on ore chutes. In the stopes, 3,950 feet of drilling is required daily; drill holes are loaded with 1,780 pounds of ammonium nitrate and fuel oil (ANFO) and blasted. Broken ore is drawn from ore chutes by front-end loader, hauled to an ore pocket at the base of the shaft, hoisted to the main haulage decline, loaded on 27-ton diesel haul trucks, transported to the surface, and delivered to the coarse ore stockpile.

2.4.1.4.4 Mill Operations

Mine-run ore is drawn from the coarse ore stockpile at a rate of 722 tons per day, 1 shift per day, 360 days per year. Ore drops through a hopper with 42-inch by 8-foot openings onto a 48-inch by 14-foot apron feeder which discharges onto a wobbler; this allows minus 4-inch ore to bypass the jaw crusher. A permanent magnet located at the discharge of the apron feed removes tramp metal. Crushing occurs in three stages using a 42- by 48-inch jaw crusher, a 6- by 20-foot rod deck screen, a 5.5-foot-diameter cone crusher, a 4- by 10-foot trash screen, and a 40- by 24-inch roll crusher.

Crushed ore, at 100 percent minus 3/4 inch, is conveyed to the fine ore stockpile. From there, ore is conveyed to the rod mill on a 24-inch by 240-foot belt conveyor, 3 shifts per day, 360 days per year. First stage grinding, at a maximum capacity of 42 tons per hour, occurs in an 8- by 12-foot rod mill, in open circuit, averaging 77 percent solids in the mill discharge. Rod consumption averages 0.704 lbs per ton. Rod and ball mill discharge flows to a common sump and is pumped to a 20-inch cyclone classifier. Classifier underflow is pumped to an 8- by 8-foot ball mill for further grinding. Ball consumption averages 0.778 lbs per ton; liner consumption for both mills averages 0.234 lbs per ton.

Classifier overflow, averaging 38 percent solids, is pumped to the flotation conditioning circuit for three-stage conditioning. The first conditioning introduces lime (CaO) at a rate of 12.2 lbs per ton. Second-stage conditioning adds sodium carbonate (Na_2CO_3) or sodium hydroxide (NaOH) at a rate of 10.05 lbs per ton. Final conditioning adds sodium silicate (Na_2SiO_3) at a rate of 15.08 lbs per ton and the fatty acid, EPG Acintol FA-1, at a rate of 1.1 lbs per ton. Once conditioned, ore is pumped to a bank of twelve 60-cubic foot float cells for rougher concentration. The scheelite rougher tail at this point should average 642 tons per day at 0.07 percent WO_3 and the rougher concentrate should average 80 tons per day at 5.29 percent WO_3. The rougher concentrate is then pumped to a bank of eight 10-cubic foot cleaner float cells where sodium silicate is added to the first and second cells. The final cleaned concentrate should average 27.5 tons per day at 15.00 percent WO_3. Cleaner tails are combined with rougher tails for a total tail product of 694.7 tons per day at 0.08 percent WO_3. Tails are concentrated in an 80-foot-diameter thickener and pumped to the tailing pond for disposal. Concentrates are thickened in a 10-foot-diameter thickener, filtered on a belt filter to approximately 15 percent moisture, and conveyed to a stockpile for loadout. Overall tungsten recovery is estimated at 88 percent. A generalized material balance is shown in Table 15.

2.4.1.4.5 Product Transportation

Scheelite concentrates produced from a tungsten mine located at Yucca Mountain are transported to U.S. Tungsten's ammonium paratungstate (APT) plant located at the Pine Creek Mine in Inyo County, CA. There, scheelite concentrates would either be sold to U.S. tungsten end-users or converted to APT on a custom basis. Transportation requires loading concentrates on a 20-ton rear-dump truck, hauling 15 miles to Rte. 95, 108 miles via Rte. 95 to Tonopah, 117 miles via Rte. 6 to Bishop, CA, and then 21 miles on Rte. 168 to the chemical plant. The total cycle time, including returning to the minesite would take approximately 11 hours.

2.4.1.5 Capital and Operating Cost Estimates

All capital and operating cost estimates for the underground tungsten mine and associated flotation plant are estimated in July 1989 dollars. Details of capital and operating cost estimates are presented in Appendix C.

2.4.1.5.1 Mine Costs

Mine capital and operating costs are summarized in Tables 16 and 17, respectively.

TABLE 15. Generalized Material Balance, Hypothetical Yucca Mountain Tungsten Deposit

Item	Solids, tons/day	WO_3, wt pct	WO_3, tons/day	WO_3, Recovery
Feed	722.22	0.65	4.69	100.00
Rough concentrate	80.31	5.29	4.25	90.43
Rough tail	641.91	.07	0.45	9.57
Clean concentrate	27.54	15.00	4.13	88.00
Clean tail	694.68	.08	.56	12.00

TABLE 16. Mine Capital Costs, Hypothetical Yucca Mountain Tungsten Deposit

Item	Total Cost
Infrastructure:	
Mine road upgrade	$1,313,000
Powerline	3,536,400
Water system	488,100
Exploration:	
Drilling and sampling program	1,108,200
Mine Development:	
Main haulage decline	489,300
Vertical shaft	1,484,600
Lower haulageway	201,100
Crosscuts	77,000
Development headings	293,300
Ore chutes	9,100
Underground mine equipment	8,439,400
Mine facilities, surface and underground	1,454,300
Engineering and design fees	3,778,800
Working capital	1,533,200
Total mine capital	24,205,800

TABLE 17. Mine Operating Costs, Hypothetical Yucca Mountain Tungsten Deposit

Item	Cost/day
Administrative labor	$2,946
Mine labor	14,497
Steel, bits, and rods	1,523
Steel, bolts, and mats	167
Explosives, caps, boosters	2,249
Pipe, hangers, valves	471
Ventilation tubing	137
Timber	19
Fuel	132
Electricity	1,307
Lubricants	116
Repair parts	716
Tires	69
Sales and use tax	397
Total mine operating cost per day	24,745
Total mine operating cost per ton ore	24.75

2.4.1.5.2 Mill and Product Transport Costs

Mill capital and operating costs are summarized in Tables 18 and 19, respectively. Transport costs are summarized in Table 20.

TABLE 18. Mill Capital Costs, Hypothetical Yucca Mountain Tungsten Deposit

Item	Total Cost
Process facilities:	
Mill equipment	$3,019,000
Concrete foundations	491,200
Process piping	297,100
Structural steel	308,300
Instrumentation	171,600
Insulation	17,400
Electrical system	515,100
Construction labor	1,817,400
Mill buildings	1,402,500
Tailings impoundment	1,725,300
Engineering and design fees	2,538,900
Permitting	1,230,400
Reclamation bonds	120,000
Working capital	1,370,100
Total mill capital	15,024,300

TABLE 19. Mill Operating Costs, Hypothetical Yucca Mountain Tungsten Deposit

Item	Cost/day
Mill labor	$6,350
Electrical power	1,671
Steel, balls, rods, liners	583
Reagents	4,231
Repair parts	1,258
Lubricants	63
Sales and use tax	449
Total mill operating cost per day	14,604
Total mill operating cost per ton ore	20.22

TABLE 20. Product Transport Costs, Hypothetical Yucca Mountain Tungsten Deposit

Item	Cost/trip
Labor	$159
Maintenance labor	91
Repair parts	97
Fuel	66
Lubricants	25
Tires	45
Depreciation and overhead	290
Sales and use tax	13
Total Transport cost per trip	786
Total cost per ton concentrate	22.46
Total cost per day	618
Total transport cost per ton ore	0.86

2.4.2 Carbonate-Hosted Gold-Silver Deposits

2.4.2.1 Deposit Description

The carbonate-hosted gold-silver model assumes a tabular deposit measuring 2,000- by 800- by 100-feet thick. The ore is contained in a dolomitic siltstone bounded above and below by dolomitic limestones. Ore averages 12.5 cubic feet per short ton for a total resource of 12,800,000 tons containing 0.08 oz gold per ton and 0.50 oz silver per ton.

2.4.2.2 Mining Systems

Typically, mining of large, low-grade gold deposits uses open-pit mining systems. However, due to the depth of carbonate-hosted deposits that may be found at Yucca Mountain, an underground system is required. Based on the deposit dimensions defined above, underground mining could be accomplished using a room and pillar system.

2.4.2.3 Processing Systems

Processing of refractory gold ores in the United States generally requires roasting or autoclave pressure-oxidation prior to cyanide leaching. Processing of refractory ores at the Mercur Mine, UT, incorporates a pressure-oxidation autoclave followed by a carbon-in-leach (CIL) recovery circuit. Proposed operations at the Pine Tree Mine, CA, include bulk sulfide flotation, fluid-bed roasting, and CIL recovery. The model included here is based on a system similar to that proposed at the Pine Tree.

2.4.2.4 Mine and Process System Description

The mine and process system integrates a 3,000-ton per day room-and-pillar mine, bulk sulfide flotation plant, 110-ton per day fluid-bed roaster, and 95-ton per day carbon-in-pulp (CIP) leach recovery plant, all operating 3 shifts per day, 360 days per year.

2.4.2.4.1 Infrastructure

Infrastructure, not presently on site, includes upgrading 15 miles of access road from U.S. 95 to the proposed minesite, construction of 12 miles of transmission lines for electric power needs, and sinking two 300-foot (est) water wells for process and mine water requirements.

2.4.2.4.2 Mine Development

Mine development includes driving a 14- by 12- by 2,500-foot main haulageway decline, sinking a 22- by 7- by 4,000-foot four-compartment vertical shaft, and driving three 10- by 12- by 600-foot crosscuts.

2.4.2.4.3 Mine Operations

Following preproduction, room-and-pillar mining begins at a rate of 3,000 tons per day, two production and one maintenance shift per day, 360 days per year. Ore is developed on three levels, each separated by a 20-foot sill pillar. Mining panels are 240 feet wide, 1,000 feet long and separated by 40-foot pillars. Ore is drilled using 2-boom jumbos and blasted using ANFO emulsion. Broken ore is loaded using 5.2 cubic yard front-end loaders, hauled to the shaft, hoisted to the main haulage decline, loaded in 27-ton articulated haul trucks, and transported to surface.

2.4.2.4.4 Mill Operations

Crushing and Flotation:

Primary crushing of mine-run ore uses a 48- by 60-inch jaw crusher; crushed ore is conveyed to a 10,000-ton fine ore stockpile. From the stockpile, a feed conveyor delivers ore to a semiautogenous grinding (SAG) mill. Ground ore is delivered to duplex mineral jigs for removal of any free gold. Free gold is estimated to comprise about 10 percent of the total recovered gold. Jig circuit tailing flows to a pump/cyclone circuit where two products are made: an overflow containing 80 percent minus 150 mesh and an underflow product. The underflow is delivered to a regrind ball mill which discharges back to the pump/cyclone circuit before discharging as cyclone overflow. Cyclone overflow reports to a bulk sulfide flotation circuit where gold, silver, and pyrite are removed. The bulk concentrate is cleaned to make a final concentrate averaging 109 tons per day containing 1.94 ounces of gold per ton. The concentrate is thickened to 60 percent solids, filtered to 90 percent solids, and delivered to the fluid-bed roaster. Flotation tails, averaging 2,891 tons per day, are thickened and pumped to the tailings impoundment for disposal.

Roasting:

Filtered concentrates are roasted in two stages using 35-foot fluid-bed roasters. The roasters are equipped with emission control equipment including primary and secondary high temperature cyclones, electrostatic precipitators, and an arsenic trioxide baghouse. The cyclones and electrostatic precipitators will remove 99.5 percent of the particulates. Arsenic trioxide is removed by cooling the gas stream in a cooling tower to a temperature where arsenic trioxide will sublime and form particles. A carbate cooler and mist precipitator removes excess water, weak acid, and any remaining mercury or arsenic. Sulfur dioxide in the roaster flue gas is removed by a four-stage catalytic conversion acid plant. Overall conversion of SO_2 to SO_3 and SO_3 to H_2SO_4 would be about 99.8 percent. Atmospheric emissions include 0.07 tons per day SO_2; 24.7 tons per day CO_2; and 4.8 tons per day NO_2. Roasted concentrates, averaging 92 tons per day and containing 2.2 ounces of gold per ton are then delivered to a CIP recovery plant.

Gold Recovery:

Roasted concentrates are slurried to 35 percent solids and sent to leach agitators where sodium cyanide (NaCN) and lime (CaO) are added. After 40 hours retention, 98 percent of the gold and 97 percent of the silver is dissolved from the solids in a NaCN solution. The leach solution then flows to a CIP extraction circuit. In the CIP circuit, gold and silver are adsorbed onto small granules of carbon in a series of countercurrent tanks (five). Carbon is normally kept in each tank for approximately 1 hour in contact with the pulp then pumped upstream (countercurrently) to the next tank until maximum gold loading is achieved. Pulp density is maintained at 48 percent solids. Loaded carbon is transferred to acid washing where a 3 percent hydrochloric acid (HCL) solution is added to remove lime scale and base metal impurities. This is followed by a 1 percent sodium hydroxide (NaOH) caustic wash to remove traces of acid.

Carbon Stripping:

Following washing, the carbon is transferred to a stripping column. A strip solution of 0.2 percent NaCN and 1.0 percent NaOH is circulated through a heat exchanger to maintain a solution temperature of 66° C and pumped into the bottom of the column until it overflows at the top. The stripping column is steam pressurized and heated to 135° C. Most of the gold and silver is removed from the carbon after about 9 hours of stripping. Overflow solution is then cooled in a preheat exchanger prior to electrowinning. Stripped carbon is removed from the column and transferred to a carbon reactivation kiln where the carbon is regenerated at about 700° C.

Electrowinning and Dore Production:

Solution from the stripping column and preheat exchanger passes through electrowinning cells where gold and silver are deposited on steel wool. The gold-plated steel wool is removed from the cells and melted. A flux is added to remove steel wool and impurities as a slag. The slag is skimmed off and the remaining melt poured into dore bullion molds. Most of the gold and silver is removed from the carbon after about 9 hours of stripping. Overall gold recovery (free gold plus dore) is estimated at 92 percent; a generalized material balance is shown in Table 21.

2.4.2.4.5 Product Transportation

Dore bullion and furnace slag produced from a gold mine on or near Yucca Mountain would probably be transported by air to the Handy and Harman refinery in El Monte, CA.

2.4.2.5 Capital and Operating Cost Estimates

All capital and operating cost estimates for an underground carbonate-hosted gold mine, bulk sulfide flotation plant, sulfide roasting plant, and gold leaching and recovery plant are estimated in July 1989 dollars. Details of capital and operating cost estimates are presented in

TABLE 21. Generalized Material Balance, Hypothetical Yucca Mountain Carbonate-Hosted Gold Deposit

Item	Solids tons/day	Gold tr oz/t	Gold tr oz/d	Gold recovery
Feed	3,000.00	0.080	240.00	100.00
Jig circuit:				
Free gold	-	-	24.00	10.00
Tail	3,000.00	.072	216.00	90.00
Flotation:				
Concentrate	109.00	1.944	211.90	88.29
Tail	2,891.00	.001	4.10	1.71
Roaster:				
Matte	92.36	2.179	201.26	82.86
Gases	11.78	.004	0.04	0.02
Dust	4.86	2.179	10.59	4.41
Carbon-in-pulp:				
Feed	97.22	2.179	211.85	88.27
Solids	97.22	.109	10.59	4.41
Solution	180.15	-	201.26	83.86
Metal production:				
Dore	-	-	196.23	81.76
Slag	-	-	5.03	2.10

2.4.2.5.1 Mine Costs

Mine capital and operating costs are summarized in Tables 22 and 23, respectively.

TABLE 22. Mine Capital Costs, Hypothetical Yucca Mountain Carbonate-Hosted Gold Deposit

Item	Total cost
Infrastructure:	
Mine road upgrade	$1,313,000
Powerline	3,536,400
Water system	976,200
Exploration:	
Drilling and sampling program	1,773,100
Mine Development:	
Main haulage decline	489,300
Vertical shaft	2,969,600
Crosscuts	348,100
Underground mine equipment	13,965,900
Mine facilities, surface and underground	1,454,300
Engineering and design fees	5,365,200
Working capital	2,400,900
Total mine capital	34,592,100

TABLE 23. Mine Operating Costs, Hypothetical Yucca Mountain carbonate-Hosted Gold deposit

Item	Cost/day
Administrative labor	$1,752
Mine labor	11,706
Steel, bits and rods	1,811
Explosives, caps, boosters	3,646
Pipe, hangers, valves	22
Ventilation tubing	26
Timber	15
Fuel	1,369
Electricity	2,157
Lubricants	547
Repair parts	2,422
Tires	485
Sales and use tax	719
Total mine operating cost per day	26,676
Total mine operating cost per ton ore	8.89
Total mine operating cost per ounce gold	121.13

2.4.2.5.2 Mill Costs

Mill capital and operating costs are summarized in Tables 24 and 25, respectively. Transport costs would be relatively insignificant; averaging about $0.04 per ton of ore mined.

TABLE 24. Mill Capital Costs, Hypothetical Yucca Mountain Carbonate-Hosted Gold Deposit

Item	Total Cost
Process facilities:	
Mill equipment	$9,320,200
Concrete foundations	982,200
Process piping	931,300
Structural steel	782,400
Instrumentation	479,600
Insulation	58,100
Electrical system	1,171,400
Construction labor	5,201,200
Mill buildings	2,846,000
Tailings impoundment	3,311,200
Engineering and design fees	6,521,700
Permitting	3,160,500
Reclamation bonds	252,000
Working capital	1,752,000
Total mill capital	36,769,800

TABLE 25. Mill Operating Costs, Hypothetical Yucca Mountain Carbonate-Hosted Gold Deposit

Item	Cost/day
Mill labor	$1,969
Electrical power	1,969
Steel, balls, rods, liners	1,090
Fuel oil	2,479
Reagents	3,736
Repair parts	3,430
Lubricants	172
Sales and use tax	740
Total mill operating cost per day	21,468
Total mill operating cost per ton ore	7.16
Total mill operating cost per ounce gold	97.48

2.4.3 Hot-Springs Gold

2.4.3.1 Deposit Description

The hot-springs gold model assumes an irregular deposit that measures 1,800 by 1,200 and up to 750 feet thick. The gold is disseminated in both welded tuff and in underlying Paleozoic sediments and metasediments. Ore averages 12.5 cubic feet per short ton for a total resource of 129,600,000 tons containing 0.05 oz of gold per ton.

2.4.3.2 Mining Systems

As with the carbonated-hosted gold deposits, mining typically uses open pit extraction systems. However, due to the deposit depth, underground mining would be required. Based on the deposit dimensions, this deposit could also be mined using room-and-pillar on several levels. This type of mining would permit recovery of approximately 75 pct of the ore; 25 pct would remain as pillars.

2.4.3.3 Processing Systems

Processing of large-tonnage low-grade gold ores in the United States is typically done utilizing cyanide heap leaching followed by either carbon adsorption-electrowinning-smelting, or carbon adsorption-zinc dust precipitation (Merrill-Crowe). The Round Mountain, NV, mine treats 10,000 tons of ore per day using heap leach, carbon adsorption, electrowinning and smelting. The Mesquite Mine, CA, treats over 12,000 tons in a similar manner. The following model is for a cyanide heap leach with a carbon adsorption, electrowinning and smelting recovery plant.

2.4.3.4 Mine and Process System Description

The mine and process system model is for a 10,000 ton per day room-and-pillar mine and cyanide heap leach operation. Both mining and leaching will operate 3 shifts per day, 360 days per year.

2.4.3.4.1 Infrastructure

Infrastructure, not presently on site, includes upgrading 15 miles of access road from U.S. 95 to the proposed minesite, construction of 12 miles of transmission lines for electric power needs, and sinking two-300 foot (est) water wells for process and mine water requirements.

2.4.3.4.2 Mine Development

Mine development includes driving a 14-by 12-by 2,500-foot conveyor haulage decline paralleled by a 15-by 18- by 2,500-foot main access decline, sinking a 22- by 12- by 4,000-foot four-compartment vertical shaft, driving a 20- by 20- by 1,800-foot main haulage drift, and excavating a 20,000 ton coarse ore storage raise.

2.4.3.4.3 Mine Operations

Following preproduction, room-and-pillar mining would commence at a rate of 10,000 tons per day, 3 production shifts per day, 360 days per year. Ore is developed on several levels, each separated by a 40-foot sill pillar. Mining panels are 240 feet wide, 1,800 feet long, and up to 80 feet high, separated by 40-foot pillars. For panels up to 80 feet thick, ore is breast drilled to a 16 foot height and then bench drilled the remaining 64 feet. Breast drilling uses jumbos equipped with 2.5-inch drills and bench drilling uses 3.0-inch bench drills. To maintain daily production, 5,263 feet using jumbos and 4,732 feet using bench drills is required. Holes are loaded with 16,200 pounds of ANFO emulsion and blasted. Broken ore is loaded using 5.2- and 7.0-yard front-end loaders and an 8.0-yard scoop tram. Ore is loaded in 33-ton articulated haul trucks and transported to the shaft for hoisting to the coarse ore storage pocket.

2.4.3.4.4 Mill Operations

Crushing:

Broken ore is drawn from the coarse ore storage pocket and conveyed to a 48- by 60-inch jaw crusher. Crushed ore is then conveyed to vibratory feeders which feed a 48-inch by 3,000-foot conveyor; this conveyor moves the ore out of the mine to a secondary crushing plant at the surface. At the surface, the ore is screened, crushed in a 7-foot cone crusher, screened again and crushed in two additional 7 foot cones to achieve a 90 percent minus 1-inch product. The material is then delivered to a 250-ton fine ore load-out bin.

Leach Pads:

Leach pads are constructed by grading and compacting the existing substrate followed by placement of a 40-mil PVC (polyvinyl chloride) membrane on the compacted surface. Once completed, each pad is about 4,000 feet in length and 375 feet wide; height varies between 30 and 75 feet depending on permeability and percolation properties of the ore. Each pad contains 1 year's production.

Crushed ore from the fine ore bin is loaded into 85-ton haul trucks for transport to the pads. Ore is placed on the pads and spread using dozers and front-end loaders in layers (lifts) approximately 15 feet thick; the surface of the heap is scarified by a dozer between successive lifts. Lift height, as with overall height, is a function of permeability and solution percolation rates.

Solution collection ditches along the sides of the pads are single-lined with 60-mil hypalon. Collection ditches feed main ditches which are double-lined with PVC and hypalon. The main ditches, in turn, feed pregnant solution ponds which provide 340,000 cubic yards of total storage capacity. Ponds are lined with a PVC underliner and a hypalon overliner. Once the ore has been placed on the pads, an alkaline drip solution is applied to the head at a rate of 4,690 gallons per minute and is maintained at a concentration of 0.1 percent NaCN and a pH of 11. Pregnant solution collected in the ponds averages 3,750 gallons per minute (allowing for approximately 940 gallons per minute of evaporation loss).

Gold Recovery:

The leach solution in the pregnant solution ponds is pumped to a CIP extraction circuit. In the CIP circuit, gold and silver are adsorbed onto small granules of carbon in a series of countercurrent tanks (five). The carbon is normally kept in each tank for approximately 1 hour of contact with the pulp and then pumped upstream (countercurrently) to the next tank until maximum gold loading is achieved. Pulp density is maintained at 48 percent solids. Loaded carbon would then be transferred to acid washing where 3 percent hydrochloric acid (HCL) is added to remove lime scale and base metal impurities followed by a 1 percent sodium hydroxide (NaOH) caustic wash to remove traces of acid.

Following washing, the carbon is transferred to a stripping column. A strip solution of 0.2 percent NaCN and 1.0 percent NaOH is circulated through a heat exchanger to maintain a temperature of 66° C and pumped into the bottom of the column until it overflows at the top. The stripping column is steam pressurized and heated to 135° C. Most of the gold and silver is removed from the carbon after about 9 hours of stripping. Overflow solution is then cooled in a preheat exchanger prior to electrowinning. Stripped carbon is removed from the column and transferred to a carbon reactivation kiln where the carbon is regenerated at about 700° C.

Electrowinning and Dore Production:

Solution from the stripping column and preheat exchanger passes through electrowinning cells where gold and silver are deposited on steel wool. The gold- and silver-plated steel wool is removed from the cells and melted. A flux is added to remove steel and other impurities as a slag. The slag is skimmed off the top and saved; the melt is poured into dore bullion. Overall gold recovery should be 70 percent; a generalized material balance is shown in Table 26.

TABLE 26. Generalized Material Balance, Hypothetical Yucca Mountain Hot-Springs Gold Deposit

Item	Solids tons/day	Gold tr oz/t	Gold tr oz/d	Gold Recovery
Cyanide leach:				
Feed	10,000.00	0.050	500.00	100.00
Drip solution[1]	12,763.00	.001	6.00	1.20
Recycle[2]	-	-	6.00	1.20
Evaporation	2,552.60	-	-	-
Makeup water	2,552.60	-	-	-
Pregnant solution	10,210.40	.035	360.00	72.00
Heap tailings	10,000.00	.814	140.00	28.00
Carbon adsorption:				
Pregnant solution	10,210.40	.035	360.00	72.00
Loaded carbon	2.04	176.291	360.00	72.00
Barren solution[2]	10,210.40	.001	6.00	1.20
Carbon desorption:				
Loaded carbon	2.04	176.291	360.00	72.00
Strip solution	298.36	1.207	360.00	72.00
Strip carbon[2]	2.04	3.428	7.00	1.40
Electrowinning:				
Strip solution	298.36	1.207	360.00	72.00
Strip electrodes[2]	-	-	0.40	0.10
Fe/Au cathode	-	-	360.00	72.00
Smelting:				
Dore	-	-	352.50	70.50
Slag	-	-	7.50	1.50

[1]0.004 gallons per minute per square foot. Metal content in barren solution assumed constant.
[2]These products are continually in recycle.

2.4.3.4.5 Product Transportation

Dore bullion and furnace slag produced from a gold mine near Yucca Mountain would probably be transported by air to the Handy and Harman refinery in El Monte, CA.

2.4.3.5 Capital and Operating Cost Estimates

All capital and operating cost estimates for an underground hot-springs gold mine, heap leach, and gold leaching and recovery plant are estimated in July 1989 dollars. Details of capital and operating cost estimates are contained in Appendix E.

2.4.3.5.1 Mine Costs

Mine capital and operating costs are summarized in Tables 27 and 28, respectively.

TABLE 27. Mine Capital Costs, Hypothetical Yucca Mountain Hot-Springs Gold Deposit

Item	Total cost
Infrastructure:	
Mine road upgrade	$1,313,000
Powerline	3,536,400
Water system	976,200
Exploration:	
Drilling and sampling program	4,029,800
Mine development:	
Conveyor haulage decline	513,200
Main access decline	568,500
Vertical shaft	5,953,600
Main haulage drift	461,700
Coarse ore storage	218,700
Underground mine equipment	18,888,300
Mine facilities, surface and underground	1,454,300
Engineering and design fees	7,582,700
Working capital	5,720,000
Total mine capital	51,216,500

TABLE 28. Mine Operating Costs, Hypothetical Yucca Mountain Hot-Springs Gold Deposit

Item	Cost/day
Administrative labor	$3,212
Mine labor	28,772
Steel, bits and rods	6,138
Explosives, caps, boosters	12,154
Pipe, hangers, valves	73
Ventilation tubing	85
Timber	17
Fuel	2,302
Electricity	3,531
Propane	241
Lubricants	990
Repair parts	3,830
Tires	495
Sales and use tax	1,717
Total mine operating cost per day	63,557
Total mine operating cost per ton ore	6.36
Total mine operating cost per ounce gold	190.29

2.4.3.5.2 Mill Costs

Mill capital and operating costs are summarized in Tables 29 and 30, respectively. Transport costs would be relatively insignificant; averaging about $0.04 per ton of ore mined.

TABLE 29. Mill Capital Costs, Hypothetical Yucca Mountain Hot-Springs Gold Deposit

Item	Total cost
Process facilities:	
Mill equipment	$11,085,700
Concrete foundations	802,100
Process piping	73,800
Structural steel	683,000
Instrumentation	320,800
Insulation	6,800
Electrical system	520,400
Construction labor	5,164,000
Mill buildings	2,846,000
Pad and pond development	6,047,500
Engineering and design fees	7,163,000
Permitting	3,471,300
Reclamation bonds	252,000
Working capital	4,898,700
Total mill capital	43,335,100

TABLE 30. Mill Operating Costs, Hypothetical Yucca Mountain Hot-Springs Gold Deposit

Item	Cost/day
Mill labor	$13,465
Electrical power	931
Propane	2,310
Fuel	1,782
Plastic liners	11,747
Plastic pipe	3,815
Repair parts	2,175
Reagents	13,345
Lubricants	1,144
Steel items	32
Tires	1,455
Sales and use tax	2,227
Total mill operating cost per day	54,428
Total mill operating cost per ton ore	5.44
Total mill operating cost per ounce gold	162.96

2.5 References

Except where otherwise noted, references listed below are available at larger public, geologic, or technical libraries. Photocopies of USGS open-file reports may be obtained for a fee through the Open-File Services Section, Branch of Distribution, U.S. Geological Survey, Box 25425, Denver, CO 80225. Doctoral dissertations may be obtained through University Microfilms, Inc., University of Michigan, Ann Arbor, MI.

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3. SUMMARY

This report was prepared to help the NRC provide guidance to DOE on accepted methodologies for assessing natural resources, as required by 10 CFR Part 60. It is generally applicable to the area on and around Yucca Mountain, Nye County, NV and applies to metalllic minerals currently recoverable or that may become recoverable in the future as the result of likely advances in technology.

Resource assessments are mandated by 10 CFR Section 60.21(c)(13) to accompany repository license applications submitted to NRC. The goal of resource assessment at Yucca Mountain is to ensure that the likelihood of mineral extraction is considered when evaluating post-closure human activity that may compromise the ability of the proposed high-level waste repository to isolate radionuclides from the accessible environment. This goal is partially achieved by identifying and evaluating those locations within the geologic repository operations area or adjacent controlled area that may have resource potential.

The resource assessment process is a three-step, logical sequence of events in which potential resources are identified, quantified and qualified (tonnage and grade estimates), and evaluated (gross and net value estimates).

Resource identification involves extensive literature and database research, resource identification, deposit modeling, field investigations, and geomathematical studies. Information gained through such research may identify areas that in the past have been the objects of exploratory drilling or resource extraction, as required by 10 CFR Section 60.122(c). Further, deposit modeling and geomathematical studies may alert researchers involved in site characterization activities other than resource assessment to possible resource indicators.

Accepted geological, geochemical, and geophysical resource identification methods that may be employed during site characterization include (but are not limited to): geological mapping and sampling, soil and water analyses, and seismic, magnetic, electrical, and gravity surveys.

Geomathematical methods of resource assessment allow estimates to be made of an area's resource potential at varying levels of certainty, without extensive exploratory drilling and concomitant expenditure of time, effort, and funds. Two methods, simple subjective and complex subjective, and the advantages, disadvantages, and uncertainties associated with their use, are considered. It may be that none of the current methodologies (including subjective methods) can adequately address the unique resource assessment problems encountered at Yucca Mountain.

It will be necessary to expend the time and funds necessary to develop a resource assessment program that specifically addresses the requirements of 10 CFR Section 60.21(c)(13).

Quantification and qualification of existing resources encountered during site characterization, as well as of undiscovered resources thought to exist in or near the proposed HLW repository, are required. Tonnage and grade estimates may be made by the employment of one or more geomathematical resource assessment methods. These methods, by nature, contain significant uncertainties. The use of geomathematical resource assessment methods largely stems from the regulatory restrictions that have been placed on more reliable (and verifiable) methods that involve borehole drilling or other piercement procedures.

Gross and net resource value estimates (resource evaluation), as required by 10 CFR Section 60.21(c)(13), are accomplished by using one or more of the many methods, systems, models, and procedures in common use by BOM and the private sector. In addition to gross and net value, these methodologies provide for estimating capital and operating costs, extraction systems design, and environmental, ancillary and infrastructural requirements. Economic/extraction models for three selected deposit types that may possibly exist on Yucca Mountain are presented.

The primary purpose of resource assessment at Yucca Mountain is to identify those potentially adverse conditions listed in 10 CFR Section 60.122(c)(17-19). This can be accomplished by application of methods discussed and/or referenced here.

4. ACRONYMS

AI	artificial intelligence
AIME	American Institute of Mining, Metallurgical, and Petroleum Engineers
BLM	Bureau of Land Management
BOM	Bureau of Mines
CES	Bureau of Mines' Cost Estimation System
CIM	Canadian Institute of Mining and Metallurgy
CNWRA	Center for Nuclear Waste Regulatory Analyses
CRIB	Computerized Resource Information Bank
DCFROR	discounted cash flow rate of return
DMEA	Defense Minerals Exploration Administration
DOC	(U.S.) Department of Commerce
DOD	(U.S.) Department of Defense
DOE	(U.S.) Department of Energy
DOL	(U.S.) Department of Labor
DST	drill stem test
EA	Environmental Assessment
EIS	Environmental Impact Statement
ERTS	environmental resources technology satellite
GROA	geological repository operations area
GSA	Geological Society of America
HLW	high-level waste
IRS	(U.S.) Internal Revenue Service
LC	Library of Congress
MAS	Minerals Availability System
MILS	Mineral Industry Location System
MLA	Mineral Land Assessment
MDRS	Mineral Resources Data System
MSHA	Mine Safety and Health Administration
NA	National Archives
NRC	(U.S.) Nuclear Regulatory Commission
NWPA	Nuclear Waste Policy Act
OSM	Office of Surface Mining
SEE	Software for Economic Evaluation
SPOT	Systeme Probatoire d'Observation de la Terre
USFS	U.S. Forest Service
USGS	U.S. Geological Survey

5. GLOSSARY

Definitions pertaining to site suitability and site characterization such as "accessible environment," "controlled area," and "site characterization" were taken from DOE Site Characterization Plan, Yucca Mountain Site, Nevada Research and Development Area, Nevada. Vol. 8, Part B,, Glossary and Acronyms. USDOE, December 1988.

All other definitions were taken from either A Dictionary of Mining, Mineral, and Related Terms, BuMines 1968 or Glossary of Geology, 2nd ed. Am. Geol. Inst., 1980.

accessible environment -- includes the atmosphere, land surfaces, surface waters, oceans, and parts of the lithosphere containing ground water that are more than 10 kilometers (6.7 miles) in any direction from the edge of the original location of the radioactive wastes in a disposal system.

adit -- a horizontal or nearly horizontal passage driven from the surface for the purpose of resource exploration, working, or dewatering of a mine.

advance -- the work of excavating as mining goes forward in an entry and in driving rooms. The linear distance (in feet or meters) driven over a period of time in tunnelling, drifting, or in raising or sinking a shaft.

aeromagnetic survey (aeromagnetic prospecting) -- a technique of resource exploration using an aerial magnetometer.

agglomerate -- contemporaneous pyroclastic rock containing a predominance of rounded or subangular fragments greater than 32 mm in diameter.

alteration -- change in the mineralogical composition of a rock, typically brought about by the action of hydrothermal solutions. Also applies to secondary (supergene) changes in rocks or minerals.

amorphous -- having no form; applied to rocks and minerals having no definite crystalline structure.

analogy -- inference that if two or more aspects agree with another in some respects, they will probably agree in others.

anastomosing -- having a netlike or braided appearance, as in an anastomosing stream.

andesitic tuff -- a rock composed of andesite fragments, generally smaller than 4 mm in diameter.

ANFO -- a blasting agent; ammonium nitrate and fuel oil.

anomaly -- a deviation from uniformity; a local feature distinguishable in a geophysical, geochemical, or geobotanical measurement over a larger area; a feature considered capable of being associated with economically valuable hydrocarbon or mineral resources.

anoxic -- containing no oxygen.

apical zone -- zone surrounding the apex of a mineral deposit, intrusion, etc.

argentian tetrahedrite -- a silver-bearing, copper-antimony sulfide mineral.

argillic alteration -- alteration characterized by the presence of clay minerals.

ash-flow tuffs -- a pyroclastic volcanic rock composed of welded or non-welded shards of glass and rock formed as the result of a nuee ardente ("glowing avalanche").

beryllian tactite -- beryllium-bearing skarn.

biogeochemical prospecting -- the chemical analysis of plants or animals as a resource exploration method.

bimodal volcanism -- characterized by the presence of both basaltic and rhyolitic rocks.

bulk sample -- large samples of a few hundredweight or more taken at regular but widely spaced intervals.

caldera -- a large basin-shaped volcanic depression, more or less circular or cirque-like in form, the diameter of which is many times greater than that of the included volcanic vent or vents, no matter what the steepness of the walls or form of the floor. Three major types: collapse, explosion, and erosion.

caldera complexes -- the diverse rock assemblage underlying a caldera comprising dikes, sills, stocks, and vent breccias; craterfills of lava; talus beds of tuff, cinder, and agglomerate; fault gouge and fault breccias; talus fans along fault escarpments; cinder cones; and other products laid down in a caldera. Also used in reference to a number of succeeding, coalescing, or overlapping calderas in complex structural and/or lithological relationships.

channel sample -- material from a level groove cut across an exposure in order to obtain a true cross section of mineralized material exposed.

chip sample -- a regular series of ore chips or rock chips taken either in a continuous line across an exposure or at uniformly spaced intervals.

collar -- (1) the mouth or opening of a borehole or shaft. (2) Surface area at the top of a shaft; the area is usually reinforced with concrete.

commodity -- a transportable resource product with commercial value; all resource products which are articles of commerce.

controlled area (as used by NRC) -- a surface location extending horizontally no more than 10 kilometers (6.7 miles) in any direction from the edge of the disturbed rock zone and the underlying subsurface, which area has been committed to use as a geologic repository and from which incompatible activities would be restricted following permanent closure (NRC, 1981). The outer edge of the controlled area marks the inner edge of the accessible environment.

construction materials -- those common-variety rocks and minerals used in essentially their native form for construction purposes, such as sand and gravel, stone, marble, and limestone. Their value is overwhelmingly dependent on the cost of transportation to the point of use.

core drill -- a mechanism designed to rotate and cause an annular-shaped rock cutting bit to penetrate rock formations, produce cylindrical cores of the formations penetrated, and lift such cores to the surface where they may be collected and examined.

critical minerals -- minerals essential to the national defense, but whose procurement, while difficult in case of war, is less serious than those of strategic minerals.

crosscut -- a small passageway driven at right angles to the main entry to connect it with a parallel entry or air course.

cross section -- a profile portraying an interpretation of a vertical section of the earth explored by geophysical and/or geological methods.

crystalline rock -- an inexact but convenient term designating an igneous or metamorphic rock, as opposed to a sedimentary rock. Such rock consists almost wholly of mineral crystals or fragments of crystals.

demonstrated resource -- a term for the sum of measured plus indicated.

density log -- a gamma-gamma log used to indicate the varying bulk densities of rocks penetrated in drilling by recording the amount of back-scattering of gamma rays.

deposit -- used in reference to the physical occurrence of a resource and includes metallic and nonmetallic ore bodies, peat bogs, and coal beds.

deposit model -- a concept or an analog that represents in text, tables, and diagrams the essential characteristics or attributes of a deposit.

detachment fault -- low-angle normal fault; decollement.

economic (as pertains to resources) -- this term implies that profitable extraction or production under defined investment assumptions has been established, analytically demonstrated, or assumed with reasonable certainty.

electromagnetic methods -- a group of electrical exploration methods in which one determines the magnetic field that is associated with the electrical current through the ground.

empirical deposit model -- a geologic deposit model based on known resource deposits or occurrences, containing data but no interpretation.

energy minerals -- minerals that are a source of energy, including uranium, thorium, coal, peat, etc. Petroleum, natural gas, and geothermal sources are not considered in this report.

exploitation -- the process of winning or producing from the earth the oil, gas, minerals, or rocks that have been found as the result of exploration; the extraction and utilization of ore.

exploration -- the search for naturally occurring solid, liquid, or gaseous material on or in the earth's crust; also called "prospecting."

extraction -- the process of mining and removal of coal or ore from a mine.

fair market value -- the amount in cash, or on terms reasonably equivalent to cash, for which in all probability the property would be sold by a knowledgeable owner who desired but is not obligated to sell to a knowledgeable purchaser who desired but is not obligated to buy. In ascertaining that figure, consideration should be given to all matters that might be brought forward and reasonably be given substantial weight in bargaining by persons of ordinary prudence, but no consideration whatever should be given to matters not affecting market value.

favorable geologic environment -- areas where the geologic setting, i.e., lithology (rock types), structure, location, mineral occurrences, and/or any other forms of direct or indirect evidence, indicates potential for mineral deposition. The classification system makes a distinction between mineral occurrences and favorable geologic environments without known occurrences.

fixed cost -- a cost that is committed for the time horizon of planning or the decision being considered. Fixed costs include fixed ownership requiremenets, fixed protection, short-term maintenance, and long-term planning and inventory costs.

flotation -- a method of mineral separation in which a froth created in water by a variety of reagents floats some finely-crushed minerals, whereas other minerals sink.

flotation cell -- appliance in which froth flotation of ores is performed.

fuel resource -- oil, gas, coal (including lignite and peat), or uranium resources.

genetic deposit model --an explanation of an analysis that divides an ore deposit or other resource occurrence into its primary genetic components and explains their interactions; an expansion of the straight line data listing of the empirical model.

geochemical survey -- a survey involving the chemical analysis of systematically collected samples of rock, soil, plants, fish, or water.

geophysical log -- a graphic record of measured or computed geophysical data. Types of geophysical logs include, among others, sonic, density, natural gamma, neutron, and porosity logs.

geophysical survey -- the use of one or more geophysical techniques such as earth currents, electrical, gravity, magnetic, and seismic methods to gather information on subsurface geology.

geotechnics -- the engineering behavior of all cuttings and slopes in the ground; term is gradually replacing "soil mechanics."

gravity concentration -- separating grains of minerals by a concentration method operating by virtue of the differences in density of various minerals.

gravity survey -- the systematic measurement of the earth's gravitational field in a specified area.

ground magnetic survey -- a determination of the magnetic field at the surface of the earth by means of ground-based instruments.

haulageway -- the gangway, entry, or tunnel through which loaded or empty ore cars are hauled by animal or mechanical power.

host rock -- (1) the medium within which radioactive waste is emplaced for disposal. (2) Sometimes used as the particular horizon in which the waste is emplaced in a repository. (3) Major constituent geologic formation in a mine.

hypothetical resources -- undiscovered resources that are similar to known mineral bodies and that may be reasonably expected to exist in the same producing district or region under analogous geologic conditions. If exploration confirms their existence and reveals enough information about their quality, grade, and quantity, they will be reclassified as identified resources.

identified resources -- resources whose location, grade, quality, and quantity are known or estimated from specific geologic evidence. Identified resources include economic, marginally economic, and subeconomic components. To reflect varying degrees of geologic certainty, these economic divisions can be subdivided into measured, indicated, and inferred.

indicated resources -- quantity and grade and/or quality are computed from information similar to that used for measured resources, but the sites for inspection, sampling, and measurement are farther apart or are otherwise less adequately spaced. The degree of assurance, although lower than that for measured resources, is high enough to assume continuity between points of observation.

inferred reserve base -- the in-place part of an identified resource from which inferred reserves are estimated. Quantitative estimates are based largely on knowledge of the geologic character of a deposit for which there may be no samples or measurements. The estimates are based on an assumed continuity beyond the reserve base, for which there is geologic evidence.

inferred resources -- estimates are based on an assumed continuity beyond measured and/or indicated resources, for which there is geologic evidence. Inferred resources may or may not be supported by samples or measurements.

infrastructure -- ancillary facilities such as roads, power and water lines, offices, and shops in support of a mining operation.

LHD -- a vehicle used in load-haul-dump operations in underground mining activities.

lode mining -- the mining of a valuable mineral which occurs as a tabular deposit between definite, contrasting mineral or rock boundaries.

marginal reserve -- that part of the reserve base which, at the time of determination, borders on being economically producible. Its essential characteristic is economic uncertainty. Included are resources that would be producible, given postulated changes in economic or technologic factors.

market -- the process of exchanging goods or services for money or other goods or services according to a customary procedure. A market may occur in a specific place or throughout an area by individual transactions.

measured resource -- quantity is computed from dimensions revealed in outcrops, trenches, workings, or drill holes; grade and/or quality are computed from the results of detailed sampling. The sites for inspection, sampling, and measurements are spaced so closely and the geologic character is so well defined that size, shape, depth, and mineral content of the resource are well established.

methodology -- a body of methods, rules, and postulates employed by a discipline; a particular procedure or set of procedures.

mine plan, plan of operation -- a written plan describing mining and mineral processing activities. The plan is prepared by those engaged in mining activities such as prospecting or exploration.

mineral entry -- the filing of a mining claim for public land to obtain the right to a valuable mineral.

mineral exploration -- see "exploration."

mineral withdrawal -- the exclusion of the right of possession of locatable mineral deposits by the locator on areas required for administrative sites and other areas highly valued by the public.

nonmetallic mineral -- those minerals valued primarily for their mineralogical properties (e.g., refractory nature, density, insulation value) or as sources of chemicals (e.g., borates, chlorides, strontium compounds).

occurrence -- a showing of mineral, or geological indication of the presence of a mineral, in potentially economic amounts.

ore -- a mineral of sufficient value as to quantity and quality that can be mined at a profit.

ore controls -- mechanism(s) that determines or controls the physical deposition or emplacement of ore bodies.

ore deposit -- a mineral deposit that is currently mined or that could be mined at a profit.

original resource -- the quantity of a resource before production.

piercement methods (exploration geology) -- (1) resource exploration methods including borehole drilling, deep pits or trenches, shaft sinking, or driving test adits, declines, etc. (2) any subsurface exploration method that may compromise the integrity of a geologic HLW repository.

placer mining -- a method of mining in which the surface material is washed for gold or other valuable minerals. When water under pressure is employed to break down the gravel, the term hydraulic mining is generally used.

ppm -- parts per million (grams per metric ton).

present net value (PNV) -- discounted benefits less discounted costs. The difference between the discounted value (benefits) of all outputs to which monetary value or established market prices are assigned and the total discounted costs of operating a mine.

raise -- a vertical or inclined opening driven upward from a level to connect with the level above, or to explore the ground for a limited distance above one level.

real dollar value -- a monetary value which compensates for the effects of inflation.

resources (as used here)-- a collective term for all metallic minerals and ores.

resource assessment -- the determination of mineral potential, including the process for making that determination. Assessment by definition; determine rate or amount of; determine importance, size or value.

reserve base -- that part of an identified resource that meets specified minimum physical and chemical criteria related to current mining and production practices, including those for grade, quality, thickness, and depth. The reserve base is the in-place demonstrated (measured plus indicated) resource from which reserves are estimated. It may encompass those parts of the resources that have a reasonable potential for becoming economically available within planning horizons beyond those that assume proven technology and current economics. The reserve base includes those resources that are currently economic (reserves), marginally economic (marginal reserves), and some of those that are currently subeconomic (subeconomic resources). The term "geologic reserve" has been applied by others generally to the reserve-base category, but it also may include the inferred-reserve base category; it is not a part of this classification system.

reserves -- that part of the reserve base that could be economically extracted or produced at the time of determination. The term "reserves" need not signify that extraction facilities are in place and operative. Reserves include only recoverable materials; thus, terms such as "extractable reserves" and "recoverable reserves" are redundant and are not a part of this classification system.

restricted resources/reserves -- that part of any resource/reserve category that is restricted from extraction by laws or regulations. For example, restricted reserves meet all the requirements of reserves except that they are restricted from extraction by laws or regulations.

site characterization (as defined by 10 CFR Section 60.2) -- the program of exploration and research, both in the laboratory and in the field, undertaken to establish the geologic conditions and the ranges of those parameters of a particular site relevant to the procedures in 10 CFR Part 60. Site characterization includes borings, surface excavations, excavation of exploratory shafts, limited lateral excavations and borings, and in situ testing at depth needed to determine the suitability of the site for a geologic repository, but does not include preliminary borings and geophysical testing needed to decide whether site characterization should be undertaken.

skarn -- term generally reserved for rocks composed of nearly entirely lime-bearing silicates and derived from nearly pure limestones or dolomites into which large amounts of Si, Al, Fe, and Mg have been introduced. May host economic quantities of W, Cu, Mo, Au, etc.; tactite.

speculative resources -- undiscovered resources that may occur either in known types of deposits in favorable geologic settings where mineral discoveries have not been made, or in types of deposits as yet unrecognized for their economic potential. If exploration confirms their existence and reveals enough information about their quality, grade, and quantity, they will be reclassified as identified resources.

stope -- (1) an excavation from which the ore has been extracted, either above or below a level, in a series of steps. (2) an underground excavation from which ore has been extracted, either above (overhand) or below (underhand) a level.

strategic minerals -- those mineral resources included on a list of minerals and other commodities stockpiled by the Federal government. The list is compiled annually by the Federal Emergency Management Agency.

subeconomic resources -- the part of identified resources that does not meet the economic criteria of reserves and marginal reserves.

undiscovered resources -- resources, the existence of which are only postulated, comprising deposits that are separate from identified resources. Undiscovered resources may be postulated in deposits of such grade and physical location as to render them economic, marginally economic, or subeconomic. To reflect varying degrees of geologic certainty, undiscovered resources may be divided into two parts: hypothetical and speculative.

variable cost -- a cost that varies with the level of controlled outputs in the time horizon covered by the planning period or decisions being considered. Variable costs include investment, operational, and variable general administration.

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APPENDIX A. LOCALITY ABBREVIATIONS OF DEPOSITS REFERENCED IN SECTION 2.1.4.2

ASTR	Austria
AUQL	Australia, Queensland
AUTS	Australia, Tasmania
BLVA	Bolivia
CILE	Chile
CINA	China
CNBC	Canada, British Columbia
GRMY	West Germany
ITLY	Italy
JAPN	Japan
MXCO	Mexico
THLD	Thailand
USAR	U.S., Arkansas
USAZ	U.S., Arizona
USCA	U.S., California
USCO	U.S., Colorado
USID	U.S., Idaho
USMT	U.S., Montana
USNM	U.S., New Mexico
USNV	U.S., Nevada
USPA	U.S., Pennsylvania
USUT	U.S., Utah

APPENDIX B. ANNOTATED BIBLIOGRAPHY--CASE HISTORIES AND PAPERS PERTAINING TO RESOURCE DISCOVERIES IN WHICH GEOCHEMICAL AND/OR GEOPHYSICAL EXPLORATION METHODS PLAYED A MAJOR ROLE

References listed below cite instances in which geochemical and/or geophysical methods were extensively employed in the discovery of a mineral deposit. In all cases, the deposits were further evaluated by borehole drilling. The level of detail in the references ranges from complete prospecting case histories to a passing statement of fact.

Geochemical Methods

1. Archer, A. R. and C. A. Mann. Casino, Yukon--A Geochemical Discovery of an Unglaciated Arizona-Type Porphyry. Can. Inst. Min. and Metall. Spec. v. 11, 1971, pp. 67-77. **** Cu-Mo porphyry deposit discovered primarily by the use of stream-sediment and soil geochemical techniques.

2. Brooks, R. R. Geobotany and Biogeochemistry. New York: Harper and Row, 1972, pp. 190-206. **** Cu-Mo deposit in New Zealand delineated by geochemistry and extended by biogeochemistry.

3. _____. Biological Methods of Prospecting for Minerals. New York: John Wiley and Sons, 1983, pp. 93-97. **** Geologists in Finland use dogs to locate Cu-Ni ore bodies. References to other geochemical successes are found throughout the text and in the bibliography.

4. Diehl, P., and H. Kern. Geology, Mineralogy, and Geochemistry of Some Carbonate-Hosted Lead-Zinc Deposits in Kanchanabari Province, Western Thailand. Econ. Geol. and Bull. Soc. Econ. Geol., v. 76, No. 8, 1981, pp. 2128-2146. **** Geochemical soil sampling, geological mapping, and drilling delineate exploration targets. One target, Song Tho North, commenced underground operations in the fall of 1976.

5. Economic Geology. Ore Deposits in Finland, Norway, and Sweden--A Review. Econ. Geol. and Bull. Soc. Econ. Geol., v. 74, No. 5, 1979, p. 976, fig. 1. **** Vuones Copper Mine (Finland) discovered by lithogeochemical (bedrock) surveys.

6. Mining Magazine (London). Viscaria--A New Copper Mine in Northern Sweden. Min. Mag., Oct. 1983, pp. 226-233. **** Although details are lacking, it appears that the Viscaria Cu-Zn ore body was first identified on the basis of the existence of a plant, Viscaria Alpina, that has a high affinity for copper. See Brooks (1983, No. 3 above, pp. 41 and 251) for further discussions on Viscaria Alpina as a nickel as well as a copper indicator plant.

7. Muller, D. W., and P. R. Donovan. Stream-Sediment Reconnaissance for Zinc Silicate (Willemite) in the Flinders Ranges, Southern Australia. Can. Inst. Min. and Metall. Spec. v. 11, 1971, pp. 231-234. **** Stream-sediment sampling led to the discovery of two willemite ore bodies.

8. Rodriguez, S. E. Geochemical Investigations for Base Metals and Silver in the Coast Geosyncline, Venezuela. Can. Inst. Min. and Metall. Spec. v. 11, 1971, pp. 237-246. **** Stream-sediment sampling program led to the discovery of two base metal/silver zones.

9. Rugman, G. M. Perseverance Mine--A Prospecting Case History. Min. Magazine (London), May 1982, pp. 381-391. **** The Perseverance Mine (Zimbabwe) was discovered exclusively by geochemical exploration methods.

10. Shannon, S. S., Jr. Evaluation of Copper and Molybdenum Geochemical Anomalies at the Cumo Prospect, Boise County, Idaho. Can. Inst. Min. and Metall. Spec. v. 11, 1971, pp. 247-250. **** Limonitic discoloration found during air reconnaissance was explored using soil sampling methods; anomalous Cu-Mo led to discovery of Cumo Prospect.

11. Sinclair, W. D., R. J. Cathro, and E. M. Jansen. The Cash Porphyry Copper-Molybdenum Deposit, Dawson Range, Yukon Territory. CIM Bull., v. 74, No. 833, 1981, pp. 67-76. **** One of the largest Cu-Mo porphyries in the Yukon was discovered using a combination of soil sampling and analysis of rock fragments collected from small test pits.

12. Skillings Mining Review. MicroMin Announces Highlights of 1987 Exploration Program. Skillings Min. Rev., Feb. 20, 1988, p. 13. **** Stream-sediment and bedrock sampling led to discovery of strong, consistent gold anomaly on the Pacific island of Yap (Micronesia).

13. Stevens, D. N., G. E. Rouse, and R. H. De Voto. Radon-222 in Soil Gas: Three Uranium Case Histories in the Western United States. Can. Inst. Min. and Metall. Spec. v. 11, 1971, pp. 258-264. **** Describes one success and two failures using radon-in-soil-gas surveys.

Geophysical Methods

14. Brock, J. S. Geophysical Exploration Leading to the Discovery of the Faro Deposit. CIM Bull., v. 66, No. 738, 1973, pp. 73-116. **** Airborne and ground geophysical methods (magnetic, electromagnetic, gravimetric) followed by rotary and diamond core drilling were used to discover and delineate the 63 million metric ton Faro Pb-Zn ore body.

15. Donaldson, M. J. and G. T. Bromley. The Honeymoon Well Nickel Sulfide Deposits, Western Australia. Econ. Geol. and Bull. Soc. Econ. Geol., v. 76, No. 6, 1981, pp. 1550-1564. **** Detailed ground magnetic survey followed by reverse-circulation rotary drilling, diamond drilling, and bedrock geochemistry delineated 2 major Ni-Fe sulfide zones.

16. Engineering and Mining Journal. Muscocho Explored Grenville Gneiss, Found Gold Near Quebec City. Eng. and Min. J., Exploration Roundup, Apr. 1982, pp. 29-31. **** VLF and EM used to locate anomaly. Subsequent drilling delineated ore body consisting of 2 million metric tons at 0.1 oz Au/mt.

17. _____. O'okiep Copper Company Exploration Department Uses Downhole and Other Geophysics. Eng. and Min. J., Exploration Roundup, Feb. 1983, pp. 23-25. **** Airborne magnetic, surface magnetic and gravity, surface IP and EM, and downhole IP and magnetic methods used to locate new ore bodies in O'okiep Copper District, South Africa.

18. _____. Geophysics Favored by French Comparison of Regional Methods. Eng. and Min. J., Exploration Roundup, June, 1983, pp. 23-25. **** Variety of airborne and surface geophysical methods employed to locate the Rouez Au-Ag-Cu-Pb-Zn anomaly northwest of Le Mans, France.

19. Ewers, G. R., J. Ferguson, and T. H. Donnelly. The Nabarlek Uranium Deposit, Northern Territory, Australia--Some Petrologic and Geochemical Constraints on Genesis. Econ. Geol. and Bull. Soc. Econ. Geol., v. 78, No. 8, 1983, pp. 823-837. **** Airborne gamma-ray spectrometry survey located uranium anomaly; deposit subsequently confirmed by ground survey and diamond drilling.

20. Harvey, J. D., and J. B. Hinzer. Geology of the Lyon Lake Deposits, Noranda Mines Limited, Sturgeon Lake, Ontario. CIM Bull., v. 74, No. 833, 1981, pp. 77-83. **** Three ore zones discovered and delineated by airborne magnetic surveys, ground geophysical surveys (VLF, EM, and gravity), and diamond core drilling.

21. Lundberg, B., and J. A. T. Smellie. Painirova and Mertainen Iron Ores: Two Deposits of the Kiruna Iron Ore Type in Northern Sweden. Econ. Geol. and Bull. Soc. Econ. Geol., v. 74, No. 5, 1979, pp. 1131-1152. **** These deposits were discovered in 1897 by the use of a dip needle.

22. Matthews, P. F. P. Tin Mineralisation in Central Goias, Brazil. Min. Magazine (London), June 1982, pp. 461-467. **** Airborne radiometric surveys followed up by ground geophysical surveys are credited for the discovery of the Novo Roma tin deposits.

23. Mining Magazine (London). Rautuvaara and Hannukainen Mines. Min. Magazine, Aug. 1982, pp. 101-111. **** The Rautuvaara ore body (magnetite) was located by airborne magnetic surveys and examined in detail by surface magnetic methods and diamond drilling.

24. _____. Polaris Mine. Min. Magazine, Sept. 1982, pp. 180-193. **** Ore body discovered in 1970 by gravity survey followed by diamond drilling.

25. Mining Magazine (London). Malanjkhand Copper Project. Min. Magazine, Nov. 1983, pp. 234-253. **** Resistivity surveys followed up by unspecified geophysical methods and diamond drilling led to the discovery of the deposit.

26. Mining Magazine (London). The Elura Mine, New South Wales. Min. Mag., Dec. 1983, pp. 436-443. **** Airborne magnetics followed up by unspecified ground work and diamond drilling is credited for the discovery of the Elura Zn-Pb-Ag deposit.

27. Orajaka, I. P., B. C. E. Egboka, and E. A. Emenike. Geoelectric Exploration for Lead-Zinc Sulphide Deposits in Nigeria. Min. Magazine (London), Jan. 1988, pp. 38-41. **** Use of self-potential (SP) method to outline Pb/Zn sulfide ore bodies.

28. Roberts, D. E., and G. R. T. Hudson. The Olympic Dam Copper-Uranium-Gold Deposit, Roxby Downs, South Australia. Econ. Geol. and Bull. Soc. Econ. Geol., v. 78, No. 5, 1983, pp. 799-822. **** Anomalies detected by gravity and magnetic surveys were further tested and drilled leading to the discovery of the Olympic Dam deposit.

Combined Geochemical and Geophysical Methods

29. Engineering and Mining Journal. Midway and Pinson Discoveries Reviewed at PDA March Meeting. Eng. and Min. J., Exploration Roundup, May 1982, pp. 29-31. **** Airborne EM and magnetic methods, surface EM and gravity methods and geochemical soil sampling led to discovery of Midway Pb-Zn-Ag ore body.

30. Huhtala, T. The Geology and Zinc-Copper Deposits of the Pyhasalmi-Piela vesi District, Finland. Econ. Geol. and Bull. Soc. Econ. Geol., v. 74, No. 5, 1979, pp. 1069-1083. **** Several deposits are described in which airborne and ground geophysical methods and various geochemical methods were used in discovery.

31. Lowe, N. T., R. G. Raney, and J. R. Norberg. Principal Deposits of Strategic and Critical Minerals in Nevada. BuMines IC 9035, 1985, pp. 66-184. **** The following deposits were discovered by use of geochemical and/or geophysical methods and subsequent drilling:

1. Ann Mason--Cu, p. 68
2. B & C Springs--Mo, p. 74
3. Bald Mt.--Au, p.75
4. Battle Mtn. Copper Canyon--Au, p. 78
5. Bootstrap--Au, p. 85
6. Borealis--Au, p. 86
7. Calico Hills--Fe, p. 94
8. Carlin--Au, p. 96
9. Dee--Au, p. 101
10. Enfield Bell--Au, p. 107
11. Manhattan--Au, p. 131
12. Mt. Hope--Mo, p. 138
13. Northumberland--Au, p. 143
14. Piute--Fe, p. 150
15. Preble--Au, p. 151
16. Pumpkin Hollow--Fe, p. 153
17. Rain--Au, p. 155
18. Relief Canyon--Au, p. 157
19. Tonkin Springs--Au, p. 174
20. Windfall--Au, p. 183

32. Hawkes, H. E. and J. S. Webb. "Case Histories of Integrated Exploration Programs." Chapter in Geochemistry in Mineral Exploration. New York: Harper and Row, 1962, pp. 331-347. **** Three case histories in which geochemical, geophysical, and geological methods were integrated leading to the discovery and delineation of mineral deposits.

33. Reid, K. O., and M. D. Meares. Exploration for Volcanic-Hosted Sulfide Deposits in Western Tasmania. Econ. Geol. and Bull. Soc. Econ. Geol., v. 76, No. 2, 1981, pp. 350-364. **** Application of geophysical and geochemical exploration methods led to the discovery of the Que River massive sulfide deposit.

APPENDIX C. COSTING BACKUP DATA, TUNGSTEN SKARN ECONOMIC/EXTRACTION MODEL

YUCCA MOUNTAIN TUNGSTEN MINE, CAPITAL COST ESTIMATES
INFRASTRUCTURE YUCCA1

Item	Units	Cost/unit	Total Cost
Access Roads, upgrade, 78,600 ft, gravel last 3 miles			
Rough grade, 873,330 square yards, $0.56/sy			
Labor	873330	$0.16	$139,733
Parts	873330	$0.13	$113,533
Fuel	873330	$0.19	$165,933
Lube	873330	$0.05	$43,667
GEC	873330	$0.03	$26,200
Scarify, Grade, Compact, 873,330 square yards, $0.70/sy			
Labor	873330	$0.20	$174,666
Parts	873330	$0.16	$141,916
Fuel	873330	$0.24	$207,416
Lube	873330	$0.06	$54,583
GEC	873330	$0.04	$32,750
Gravel surface, 6" x 3", 26,250 cubic yards, $8.10/cy			
Labor	26250	$0.43	$11,288
Parts	26250	$0.19	$4,988
Fuel	26250	$0.27	$7,088
Lube	26250	$0.07	$1,838
Gravel	26250	$7.14	$187,425
Access road upgrade summary			
Labor			$325,686
Parts			$260,437
Fuel			$380,436
Lube			$100,087
Gravel			$187,425
Steel			$58,950
Total Access road upgrade			$1,313,021

Item	Units	Cost/unit	Total Cost
Power line, 33 kv, 12 miles			
Poles, 312 @ 30' high			
Poles	312	$500.00	$156,000
Labor	312	$285.00	$88,920
Fuel	312	$40.00	$12,480
Lube	312	$10.00	$3,120
Transmission line, 70,404 linear feet			
Power line	70404	$35.97	$2,532,432
Labor	70404	$10.56	$743,466
Power line summary			
Labor			$832,386
Transmission line			$2,532,432
Lumber			$156,000
Fuel			$12,480
Lube			$3,120
Total Power line			$3,536,418

Item	Units	Cost/unit	Total Cost
Water well, 300' deep, 12" diameter			
Labor, drilling, 12 hours	12	$52.83	$634
Labor, maintenance	12	$66.97	$804
Parts	12	$62.84	$754
Fuel	12	$22.33	$268
Lube	12	$8.78	$105
GEC	12	$3.85	$46
Cement, 3 yards	3	$310.00	$930
Casing, 12", 600 feet	300	$20.31	$6,093
Gravel, 209 cu.yds	104	$7.14	$743
Pump, 750 gpm, 295 hp	1	$75,000	$75,000
Pump motor, 295 hp	1	$52,271	$52,271
Pipeline, 5,000', 4" schedule 40	5000	$4.09	$20,450
Water tank, 500,000 gallon	1	$282,192	$282,192
Water tank/pipline installation	1992	$24.00	$47,808
Water system summary			
Labor			$49,246
Parts			$754
Fuel			$268
Lube			$105
Steel, mobile equipment			$46
Cement			$930
Construction gravel			$743
Steel pipe			$26,543
Process equipment, tanks, pumps, motors			$409,463
Total, water system			$488,098

EXPLORATION YUCCA1

Item	Units	Cost/unit	Total Cost
Diamond drilling, 25 holes (100 foot centers) 3,000' deep			
Labor, 50'/shift			
Drillers, 2 - 12.5'/hr=6,000 hr/man	24000	$17.17	$412,080
Maintenance labor	12000	$4.16	$49,920
Geologist	12000	$18.08	$216,960
Helper	12000	$12.41	$148,920
Repair parts, drill, mud, water serv.	12000	$3.52	$42,240
Fuel, drill, mud, water service	12000	$4.10	$49,200
Lube, drill, mud, water service	12000	$0.85	$10,200
GEC, drill	12000	$0.33	$3,960
Drill bits, NW, soft rock - 2/hole	150.00	$362.00	$54,300
Drill rods, NW, 1/hole	75.00	$148.00	$11,100
Drill mud, 4.4 pct total	1005210	$0.04	$44,229
Cement, 60 lb sacks, 1/shift	1500	$4.22	$6,330
Exploration drilling summary			
Labor			$827,880
Parts			$42,240
Fuel			$49,200
Lube			$10,200
Steel, mobile equipment			$3,960
Steel, bits and rods			$65,400
Drill mud			$44,229
Cement			$6,330
Sales and use tax			$12,740
Total exploration drilling cost			$1,062,179

Item	Units	Cost/unit	Total Cost
Contracted exploration expenses			
Assaying, 1,650 samples			
Sample preparation	1650	$3.04	$5,016
Assays	1650	$16.90	$27,885
Petrographic work	375	$35.00	$13,125
Contracted exploration expenses			$46,026

Main haulage decline, 14' x 12' x 2,500'

Item	Units	Cost/unit	Total Cost
Labor, hours			
Miners	6000	$17.03	$102,180
Laborors	5500	$10.48	$57,640
Supervision	588	$19.65	$11,554
Maintenance	1412	$17.23	$24,329
Repair parts			
Two boom jumbos	298	$5.50	$1,636
Overshot mucker	162	$3.75	$608
27 ton diesel	220	$10.90	$2,398
Compressor	500	$2.44	$1,220
Ventilation fan	2000	$1.27	$2,540
Electricity			
Compressor	500	$8.70	$4,350
Ventilation fan	2000	$2.74	$5,480
Fuel			
Two boom jumbos	298	$1.98	$589
27 ton diesel	220	$7.29	$1,604
Rock bolter	903	$0.33	$298
Tires			
Two boom jumbos	298	$1.82	$541
27 ton diesel	220	$3.60	$792
Overshot mucker	162	$1.24	$201
Lubricants			
Two boom jumbos	298	$0.73	$217
Rock bolter	903	$0.03	$27
Overshot mucker	162	$0.28	$45
27 ton diesel	220	$2.15	$473
Compressor	500	$0.22	$110
Ventilation fan	2000	$0.08	$160
Drill bits, 363.3 feet/bit	253	$58.70	$14,822
Drill rods, 720.9 feet/rod	128	$170.00	$21,675
Explosives, 2.4 lbs/ton	77537	$0.25	$19,384
Blasting caps	8000	$1.61	$12,880
Air pipe, sch 40, 8" w/couplings	2500	$18.78	$46,950
Mine water pipe, sch 40, 6" w/couplings	2500	$11.92	$29,800
Potable water pipe, sch 40, 2" w/coup.	2500	$2.39	$5,975
Pipe hangers (chain)	2500	$4.11	$10,275
Vent tubing, spiral wound, 20"	2500	$9.96	$24,900
Rock bolts, 10 bolt pattern, 4' centers	6250	$6.07	$37,938
Rock bolt mat, 11", 14 gauge	6750	$3.83	$25,853
Bolter bits, 346.8 feet/bit	118	$16.05	$1,886
Bolter rods, 688.2 feet/rod	60	$75.60	$4,536

Main access decline cost summary	
Labor	$195,703
Repair parts	$8,402
Electricity	$9,830
Lubricants	$1,033
Tires	$1,534
Steel, bits and rods	$42,919
Steel, pipe and chain	$93,000
Steel, bolts and mats	$63,790
Explosives	$32,264
Vent tubing	$24,900
Sales and use tax	$15,966
Total main access decline capital	$489,341

Vertical shaft, 22' x 7' x 4,000'

Item	Units	Cost/unit	Total Cost
Labor			
Miners	52084	$17.23	$897,407
Laborors	34666	$10.48	$363,300
Supervision	1958	$19.65	$38,475
Hoistmen, waste haulage	19000	$14.61	$277,590
Repair parts			
Sinker	12916	$0.17	$2,196
Cryderman	3166	$8.46	$26,784
Hoist	13000	$6.30	$81,900
27 ton diesel	658	$10.90	$7,172
Ventilation fan	17334	$1.27	$22,014
Electricity			
Hoist	13000	$5.78	$75,140
Ventilation fan	17334	$2.74	$47,495
Lubricants			
Sinker	12916	$0.01	$129
Cryderman	3166	$1.10	$3,483
Hoist	13000	$0.82	$10,660
27 ton diesel	658	$2.15	$1,415
Ventilation fan	17334	$0.08	$1,387
Timber	1110834	$0.48	$533,200
Drill bits, 363.3 feet/bit; 67.6 ft/foot	934	$58.70	$54,826
Drill rods, 720.9 feet/rod; 67.6 ft/foot	466	$170.00	$79,220
Explosives, 1.4 lbs/ton	89834	$1.18	$106,004
Blasting caps	45808	$1.64	$75,125
Air pipe, sch 40, 8" w/couplings	4000	$18.78	$75,120
Mine water pipe, sch 40, 6" w/couplings	4000	$11.92	$47,680
Potable water pipe, sch 40, 2" w/coup.	4000	$2.39	$9,560
Pipe hangers (chain)	4000	$4.11	$16,440
Vent tubing, spiral wound, 20"	4000	$9.96	$39,840

Vertical shaft cost summary	
Labor	$1,576,772
Repair parts	$140,066
Electricity	$122,635
Lubricants	$17,073
Timber	$533,200
Steel, bits and rods	$134,046
Steel, pipe and chain	$148,800
Explosives	$181,129
Vent tubing	$39,840
Sales and use tax	$75,715
Total vertical shaft capital	$2,969,277

Lower haulageway, 14' x 12' x 1,000'

Item	Units	Cost/unit	Total Cost
Labor, hours			
Miners	2587	$17.03	$44,057
Laborors	2200	$10.48	$23,056
Supervision	235	$19.65	$4,618
Maintenance	565	$17.23	$9,735
Repair parts			
Two boom jumbos	123	$5.50	$677
Overshot mucker	68	$3.75	$255
27 ton diesel	187	$10.90	$2,038
Hoist	269	$6.30	$1,695
Compressor	200	$2.44	$488
Ventilation fan	800	$1.27	$1,016
Electricity			
Hoist	269	$5.78	$1,555
Compressor	200	$8.70	$1,740
Ventilation fan	800	$2.74	$2,192
Fuel			
Two boom jumbos	123	$1.98	$244
27 ton diesel	187	$7.29	$1,363
Rock bolter	361	$0.33	$119
Tires			
Two boom jumbos	298	$1.82	$541
27 ton diesel	220	$3.60	$792
Overshot mucker	162	$1.24	$201
Lubricants			
Two boom jumbos	123	$0.73	$90
Rock bolter	361	$0.03	$11
Overshot mucker	162	$0.28	$45
Hoist	269	$0.82	$221
27 ton diesel	187	$2.15	$402
Compressor	200	$0.22	$44
Ventilation fan	800	$0.08	$64
Drill bits, 363.3 feet/bit	105	$58.70	$6,164
Drill rods, 720.9 feet/rod	53	$170.00	$9,010
Explosives, 2.4 lbs/ton	32256	$0.25	$8,064
Blasting caps	334	$1.61	$538
Air pipe, sch 40, 8" w/couplings	1000	$18.78	$18,780
Mine water pipe, sch 40, 6" w/couplings	1000	$11.92	$11,920
Potable water pipe, sch 40, 2" w/coup.	1000	$2.39	$2,390
Pipe hangers (chain)	1000	$4.11	$4,110
Vent tubing, spiral wound, 20"	1000	$9.96	$9,960
Rock bolts, 10 bolt pattern, 4' centers	2500	$6.07	$15,175
Rock bolt mat, 11", 14 gauge	2700	$3.83	$10,341
Bolter bits, 346.8 feet/bit	47	$16.05	$754
Bolter rods, 688.2 feet/rod	24	$75.60	$1,814

Lower Haulageway cost summary	
Labor	$81,465
Repair parts	$6,169
Electricity	$5,487
Lubricants	$877
Tires	$1,534
Steel, bits and rods	$17,742
Steel, pipe and chain	$37,200
Steel, bolts and mats	$25,516
Explosives	$8,602
Vent tubing	$9,960
Sales and use tax	$6,502
Total lower haulageway capital	$201,054

Crosscuts, 4 @ 100' each, 10' x 8'

Item	Units	Cost/unit	Total Cost
Labor			
Miners	1280	$17.23	$22,054
Laborors	852	$10.48	$8,929
Supervision	48	$19.65	$943
Hoistmen, waste haulage	88	$14.61	$1,286
Repair parts			
Drifter	236	$0.33	$78
Overshot mucker	13	$3.75	$49
27 ton diesel	36	$10.90	$392
Hoist	51	$6.30	$323
Compressor	80	$2.44	$195
Ventilation fan	320	$1.27	$406
Electricity			
Hoist	51	$5.78	$296
Compressor	80	$8.70	$696
Ventilation fan	320	$2.74	$877
Fuel			
27 ton diesel	36	$7.29	$262
Rock bolter	144	$0.33	$48
Lubricants			
Drifter	236	$0.03	$7
Rock bolter	144	$0.30	$43
Overshot mucker	13	$0.28	$4
27 ton diesel	36	$2.15	$77
Hoist	51	$0.82	$42
Compressor	80	$0.22	$18
Ventilation fan	320	$0.08	$26
Tires			
Overshot mucker	13	$1.24	$16
27 ton diesel	36	$3.60	$130
Drill bits, 363.3 feet/bit	29	$58.70	$1,702
Drill rods, 720.9 feet/rod	15	$170.00	$2,550
Rock bolts, 10 bolt pattern, 4 ft center	1000	$6.07	$6,070
Rock bolt mat, 11", 14 gauge	1080	$3.83	$4,136
Rock bolt bits	19	$16.05	$305
Rock bolt rods	10	$75.60	$756
Explosives, 2.4 lbs/ton	6144	$0.25	$1,536
Blasting caps	892	$1.64	$1,463
Air pipe, sch 40, 8" w/couplings	400	$18.78	$7,512
Mine water pipe, sch 40, 6" w/couplings	400	$11.92	$4,768
Potable water pipe, sch 40, 2" w/coup.	400	$2.39	$956
Pipe hangers (chain)	400	$4.11	$1,644
Vent tubing, spiral wound, 20"	400	$9.96	$3,984

Crosscuts cost summary	
Labor	$33,212
Repair parts	$1,443
Electricity	$1,869
Fuel	$310
Lubricants	$216
Tires	$146
Steel, bits, rods, bolts, mats	$15,520
Steel, pipe and chain	$14,880
Explosives	$2,999
Vent tubing	$3,984
Sales and use tax	$2,379
Total crosscut capital	$76,957

Development headings, 3 @ 500' each, 10' x 8'

Item	Units	Cost/unit	Total Cost
Labor			
Miners	4800	$17.23	$82,704
Laborors	3195	$10.48	$33,484
Supervision	180	$19.65	$3,537
Hoistmen, waste haulage	330	$14.61	$4,821
Repair parts			
Drifter	1006	$0.33	$332
Overshot mucker	56	$3.75	$210
27 ton diesel	152	$10.90	$1,657
Hoist	218	$6.30	$1,373
Compressor	300	$2.44	$732
Ventilation fan	1200	$1.27	$1,524
Electricity			
Hoist	218	$5.78	$1,260
Compressor	300	$8.70	$2,610
Ventilation fan	1200	$2.74	$3,288
Fuel			
27 ton diesel	152	$7.29	$1,108
Rock bolter	542	$0.33	$179
Lubricants			
Drifter	1006	$0.03	$30
Rock bolter	542	$0.30	$163
Overshot mucker	56	$0.28	$16
27 ton diesel	152	$2.15	$327
Hoist	218	$0.82	$179
Compressor	300	$0.22	$66
Ventilation fan	1200	$0.08	$96
Tires			
Overshot mucker	56	$1.24	$69
27 ton diesel	152	$3.60	$547
Drill bits, 363.3 feet/bit	125	$58.70	$7,338
Drill rods, 720.9 feet/rod	63	$170.00	$10,710
Rock bolts, 10 bolt pattern, 4 ft center	3750	$6.07	$22,763
Rock bolt mat, 11", 14 gauge	4050	$3.83	$15,512
Rock bolt bits	71	$16.05	$1,132
Rock bolt rods	36	$75.60	$2,722
Explosives, 2.4 lbs/ton	26183	$0.25	$6,546
Blasting caps	3861	$1.64	$6,332
Air pipe, sch 40, 8" w/couplings	1500	$18.78	$28,170
Mine water pipe, sch 40, 6" w/couplings	1500	$11.92	$17,880
Potable water pipe, sch 40, 2" w/coup.	1500	$2.39	$3,585
Pipe hangers (chain)	1500	$4.11	$6,165
Vent tubing, spiral wound, 20"	1500	$9.96	$14,940

Development headings cost summary	
Labor	$124,546
Repair parts	$5,828
Electricity	$7,158
Fuel	$1,287
Lubricants	$876
Tires	$617
Steel, bits, rods, bolts, mats	$60,175
Steel, pipe and chain	$55,800
Explosives	$12,878
Vent tubing	$14,940
Sales and use tax	$9,175
Total development headings capital	$293,279

Ore chutes, 4 @ 6' x 6' x 24'

Item	Units	Cost/unit	Total Cost
Labor			
Miners	384	$17.23	$6,616
Laborors	26	$10.48	$268
Supervision	1	$19.65	$28
Hoistmen, waste haulage	9	$14.61	$131
Repair parts			
Stoper	24	$0.33	$8
Overshot mucker	1	$3.75	$5
27 ton diesel	4	$10.90	$42
Hoist	6	$6.30	$35
Compressor	24	$2.44	$59
Ventilation fan	176	$1.27	$224
Electricity			
Hoist	6	$5.78	$32
Compressor	24	$8.70	$209
Ventilation fan	176	$2.74	$482
Fuel			
27 ton diesel	4	$7.29	$28
Lubricants			
Stoper	24	$0.03	$1
Overshot mucker	1	$0.28	$0
27 ton diesel	4	$2.15	$8
Hoist	6	$0.82	$5
Compressor	24	$0.22	$5
Ventilation fan	176	$0.08	$14
Tires			
Overshot mucker	1	$1.24	$2
27 ton diesel	4	$3.60	$14
Drill bits, 363.3 feet/bit	3	$58.70	$183
Drill rods, 720.9 feet/rod	2	$170.00	$265
Explosives, 2.4 lbs/ton	664	$0.25	$166
Blasting caps	73	$1.64	$120

Ore chutes cost summary	
Labor	$7,044
Repair parts	$372
Electricity	$723
Fuel	$28
Lubricants	$33
Tires	$16
Steel, bits, rods	$448
Explosives	$286
Sales and use tax	$110
Total ore chute capital	$9,060

MINE EQUIPMENT

YUCCA1

Item	No.	Cost/unit	Total cost
Mine Equipment			
Front end loaders, 3.5 cu.yard	4	$127,518	$510,072
Articulated haul trucks, 25 ton	3	$226,610	$679,830
Jumbos, 2.5 inch	2	$642,430	$1,284,860
Rock bolter	1	$282,900	$282,900
Production drill rigs	4	$213,800	$855,200
Service truck, 5 ton, 82 hp diesel	1	$56,160	$56,160
Lube truck	1	$75,000	$75,000
Scissor lift truck, 8,000 lb cap.	1	$63,440	$63,440
ANFO loader truck	1	$71,760	$71,760
Personnel carrier, 12 person	1	$61,360	$61,360
Water truck, 900 gallon	1	$60,000	$60,000
Grader, 150 hp	1	$133,190	$133,190
Dozer, 200 hp	1	$172,500	$172,500
Ventilation fans, 800 hp	2	$235,152	$470,304
Mine hoist, 120 inch, 1000 hp drive	1	$950,000	$950,000
Utility hoist, 60 inch, 250 hp drive	1	$425,000	$425,000
Hoist cable, 2"	8000	$15	$121,280
Misc. mine equipment			$1,254,571
Mine Equipment Total			$7,527,427
Sales and use tax @ 5.75%			$432,827
Freight @ 7.46%			$561,546
Total Mine equipment			$8,521,800

FACILITIES

Concrete	Units	Cost/Unit	Total cost
Shop, 441 cubic yards	400	$310	$124,000
Warehouse, 267 cubic yards	267	$310	$82,667
Dry, 154 cubic yards	140	$310	$43,400
Services, 153 cubic yards	153	$140	$21,467
Structures			
Shop, 12,000 sq.ft.	12000	$8	$96,000
Warehouse, 8,000 sq.ft.	8000	$12	$96,000
Dry, 4,200 sq.ft.	4200	$12	$50,400
Services, 4,600 sq.ft.	4600	$18	$82,800
Construction labor			
Concrete, $140/cubic yard	960	$140	$134,400
Structures, $23/sq.ft.	28800	$23	$662,400
Mine facilities total			$1,454,336

YUCCA MOUNTAIN TUNGSTEN MINE, CAPITAL COST SUMMARY YUCCA1

Infrastructure	
Mine road upgrade	$1,313,021
Powerline	$3,536,418
Water system	$488,098
Exploration	
Drilling program	$1,108,205
Development	
Main haulage decline	$489,341
Vertical shaft	$2,969,277
Lower haulageway	$201,054
Crosscuts	$76,957
Development headings	$293,279
Ore chutes	$9,060
Undgerground mine equipment	$8,521,800
Mine facilities, surface and underground	$1,454,336
Engineering and design fees	$4,092,169
Working capital	$1,610,219
Total mine capital	$26,163,234

YUCCA MOUNTAIN TUNGSTEN MINE, OPERATING COST ESTIMATES

LABOR YUCCA2

	No.	Cost/year	Cost/day
Adminsitration-salaried			
Operations manager	1	$65,900	$253.46
Mine superintendent	1	$56,751	$218.27
Maintenance superintendent	1	$56,751	$218.27
Development foreman	1	$54,900	$211.15
Maintenance foreman	1	$54,900	$211.15
Mine engineer	1	$44,716	$171.98
Mine geologists	1	$40,651	$156.35
Underground engineers	2	$40,651	$312.70
Underground geologists	2	$36,956	$284.28
Drafting	1	$27,456	$105.60
Safety officer	1	$36,818	$141.61
Ventilation engineer	1	$36,818	$141.61
Clerks	2	$30,283	$232.95
Typists	2	$23,338	$179.52
Receptionist	1	$23,338	$89.76
Accountants	2	$35,143	$270.33
Subtotal, Administrative labor	21		$2,945.54

Mine labor	No.	Cost/hour	Cost/day
Mine formen	4	$19.65	$628.80
Maintenance foremen	1	$19.65	$157.20
Miners, production	24	$17.23	$3,308.16
Miners, development	18	$17.23	$2,481.12
Haulage crew	12	$18.02	$1,729.92
Helpers, production	16	$10.68	$1,367.04
Helpers, development	12	$10.68	$1,025.28
Hoistmen/Cage tenders	4	$14.51	$464.32
Chief mechanic	1	$18.68	$149.44
Maintenance	16	$17.03	$2,179.84
Utility men	12	$10.48	$1,006.08
Subtotal, direct labor	120		$20,641.75
Total labor cost per day	141		$23,587.29
Total cost per ton ore	1000		$23.59

Development, lower haulageway	Cost/ft	Rate/Advance	Cost/day
Bits	$6.18	0.3365	$2.08
Rods	$7.79	0.3365	$2.62
Explosives	$8.06	0.3365	$2.71
Caps	$5.38	0.3365	$1.81
Air pipe	$18.78	0.3365	$6.32
Mine water pipe	$11.92	0.3365	$4.01
Potable water pipe	$2.39	0.3365	$0.80
Pipe hangers	$4.11	0.3365	$1.38
Vent tubing	$9.96	0.3365	$3.35
Rock bolts	$15.18	0.3365	$5.11
Rock bolt mats	$10.34	0.3365	$3.48
Bolter bits	$0.75	0.3365	$0.25
Bolter rods	$1.79	0.3365	$0.60
Fuel	$1.72	0.3365	$0.58
Electricity	$6.52	0.3365	$2.19
Lube	$1.38	0.3365	$0.46
Parts	$7.31	0.3365	$2.46
Tires	$0.97	0.3365	$0.33
Subtotal, lower haulageway			$40.56

Development, crosscuts	Cost/ft	Rate/Advance	Cost/day
Bits	$4.29	0.3885	$1.67
Rods	$5.42	0.3885	$2.11
Explosives	$3.84	0.3885	$1.49
Caps	$3.59	0.3885	$1.39
Air pipe	$18.78	0.3885	$7.30
Mine water pipe	$11.92	0.3885	$4.63
Potable water pipe	$2.39	0.3885	$0.93
Pipe hangers	$4.11	0.3885	$1.60
Vent tubing	$9.96	0.3885	$3.87
Rock bolts	$15.18	0.3885	$5.90
Rock bolt mats	$10.34	0.3885	$4.02
Bolter bits	$0.75	0.3885	$0.29
Bolter rods	$1.79	0.3885	$0.70
Fuel	$0.77	0.3885	$0.30
Electricity	$5.16	0.3885	$2.00
Lube	$0.50	0.3885	$0.19
Parts	$4.13	0.3885	$1.60
Tires	$0.36	0.3885	$0.14
Subtotal, crosscuts			$40.12

Development, development headings	Cost/ft	Rate/Advance	Cost/day
Bits	$4.88	3.0288	$14.78
Rods	$6.15	3.0288	$18.63
Explosives	$4.36	3.0288	$13.21
Caps	$4.14	3.0288	$12.54
Air pipe	$18.78	3.0288	$56.88
Mine water pipe	$11.92	3.0288	$36.10
Potable water pipe	$2.39	3.0288	$7.24
Pipe hangers	$4.11	3.0288	$12.45
Vent tubing	$9.96	3.0288	$30.17
Rock bolts	$15.18	3.0288	$45.98
Rock bolt mats	$10.34	3.0288	$31.32
Bolter bits	$0.75	3.0288	$2.27
Bolter rods	$1.79	3.0288	$5.42
Fuel	$0.86	3.0288	$2.60
Electricity	$5.33	3.0288	$16.14
Lube	$0.56	3.0288	$1.70
Parts	$4.50	3.0288	$13.63
Tires	$0.41	3.0288	$1.24
Subtotal, development headings			$322.29

Development, ore chutes	Cost/ft	Rate/Advance	Cost/day
Bits	$1.54	0.3969	$0.61
Rods	$1.95	0.3969	$0.77
Explosives	$1.38	0.3969	$0.55
Caps	$0.98	0.3969	$0.39
Fuel	$0.23	0.3969	$0.09
Electricity	$4.37	0.3969	$1.73
Lube	$0.23	0.3969	$0.09
Parts	$2.45	0.3969	$0.97
Tires	$0.13	0.3969	$0.05
Subtotal, ore chutes			$5.26
Development summary			$408.24

Development summary	Cost/day
Steel, bits/rods	$52.80
Steel, bolts/mats	$95.80
Explosives, caps/boosters	$34.09
Pipe, hangers/valves	$139.64
Vent tubing	$37.39
Timber	$0.00
Fuel	$3.57
Electricity	$22.08
Lube	$2.45
Parts	$18.67
Tires	$1.76
Development supplies summary	$408.24

Production requirements	Units	Cost/unit	Cost/day
Drill bits	10.87	$58.70	$638.07
Drill rods	5.48	$147.00	$805.56
Explosives	1780.00	$1.18	$2,100.40
Boosters	39.50	$2.90	$114.55
Mucking, hours/day	5.07		
Lube	5.07	$0.28	$1.42
Parts	5.07	$3.75	$19.01
Tires	5.07	$1.24	$6.29
Diesel truck haulage	16.80		
Fuel	16.80	$7.29	$122.47
Lube	16.80	$2.15	$36.12
Parts	16.80	$10.90	$183.12
Tires	16.80	$3.60	$60.48
Hoisting	22.00		
Electricity	22.00	$5.78	$127.16
Lube	22.00	$0.82	$18.04
Parts	22.00	$6.30	$138.60
Ventilation	48.00		
Electricity	48.00	$2.74	$131.52
Lube	48.00	$0.08	$3.84
Parts	48.00	$1.27	$60.96
Compressor	88.00		
Electricity	88.00	$8.70	$765.60
Lube	88.00	$0.22	$19.36
Parts	88.00	$2.44	$214.72
Subtotal, Production			$5,567.29

Production summary	
Steel, bits/rods	$1,443.63
Steel, bolts/mats	$0.00
Explosives, caps/boosters	$2,214.95
Pipe, hangers/valves	$0.00
Vent tubing	$0.00
Timber	$0.00
Fuel	$122.47
Electricity	$1,024.28
Lube	$78.78
Parts	$616.41
Tires	$66.77
Production supplies summary	$5,567.29

Mine services	Units	Cost/unit	Cost/day
Timber, board feet	40	$0.48	$19.20
Pipe, 8", linear feet	10	$18.78	$187.80
Pipe, 4", linear feet	10	$11.92	$119.20
Pipe, 2" linear feet	10	$2.39	$23.90
Vent tubing, 20" diameter, linear feet	10	$9.96	$99.60
Rock bolts	6	$6.07	$36.42
Rock bolt mats	9	$3.83	$34.47
Drill bits	0.2	$59.38	$11.88
Drill steel	0.2	$74.94	$14.99
Auxiliary ventilation			
Electricity	8.00	$2.74	$21.92
Lube	8.00	$0.08	$0.64
Parts	8.00	$1.27	$10.16
Compressed air			
Electricity	8.00	$8.70	$69.60
Lube	8.00	$0.22	$1.76
Parts	8.00	$2.44	$19.52
Utility trucks			
Fuel	8.00	$0.77	$6.16
Lube	8.00	$0.17	$1.36
Parts	8.00	$0.58	$4.64
Tires	8.00	$0.11	$0.88
Mine water pumps			
Electricity	24.00	$7.52	$180.48
Lube	24.00	$1.34	$32.16
Parts	24.00	$2.46	$59.04
Subtotal, mine services			$955.77

Mine services summary	
Steel, bits/rods	$26.86
Steel, bolts/mats	$70.89
Explosives, caps/boosters	$0.00
Pipe, hangers/valves	$330.90
Vent tubing	$99.60
Timber	$19.20
Fuel	$6.16
Electricity	$272.00
Lube	$35.92
Parts	$93.36
Tires	$0.88
Mine services supply summary	$955.77

YUCCA MOUNTAIN TUNGSTEN MINE OPERATING COSTS SUMMARY

		Cost/day
Administrative labor		$2,945.54
Mine labor		$14,497.20
Steel, bits/rods		$1,523.29
Steel, bolts/mats		$166.69
Explosives, caps/boosters		$2,249.04
Pipe, hangers/valves		$470.54
Vent tubing		$136.99
Timber		$19.20
Fuel		$132.21
Electricity		$1,318.36
Lube		$117.15
Parts		$728.44
Tires		$69.41
Sales and use tax		$398.55
Total mine operating cost		$24,772.60
Mine operating cost per ton	1000	$24.77

YUCCA MOUNTAIN TUNGSTEN MINE, MILL CAPITAL COSTS

MILL EQUIPMENT	HP		YUCCA3 Total cost
Apron feeder, 4' x 14'	2		$11,272
42" x 48" jaw crusher			$197,250
Jaw motor, 200 hp	200		$13,761
Baghouse, 20,000 cfm - collection system	60		$35,280
Baghouse, 20,000 cfm - ductwork			$51,800
Permenant magnet	5	36	$5,515
Wobbler feeder	2		$11,272
36" x 120' crusher belt conv.	25		$86,140
Belt magnet	2	36	$5,515
6' x 20' rod deck screen			$34,900
Rod deck motor, 25 hp	25		$3,014
30" x 90' o'size return belt	20		$76,600
Cone crusher, 5.5' diameter	250		$291,000
4' x 10' trash screen			$16,600
Trash screen motor, 10 hp	10		$1,921
Crushed ore sampler	1		$14,800
40" x 24" roll crusher			$91,916
Roll crusher motor, 150 hp	150		$10,536
Fine ore sampler	1		$14,800
Vibratory feeders, 2 req., 42st/hr	4		$15,146
24" x 280' rod mill feed belt	20		$76,600
Lime hydrate feeder	1		$1,000
Rod mill, 8' x 12'			$165,000
Rod mill motor, 300 hp	300		$104,966
Ball mill, 8' x 8'			$270,000
Ball mill motor, 300 hp	300		$104,966
Rod/Ball mill sump, 6'x6'x7', 1500 gpm	30		$8,235
Cyclone feed pump, 8", 965 gpm	25		$10,694
Cyclone classifier, 20", 965 gpm			$8,100
WO3 conditioning pump, 2 req. 400 gpm	12		$4,800
Lime mix tank, 1500 gallon w/agitator	5		$4,488
Lime pump, 1-1/4" x 1-1/4", 5 gpm	1	5	$2,562
Lime hold tank, 500 gallon w/agitator	5		$3,573
WO3 conditioning tanks, 2 req. 2,000 gal	6		$8,844
Na2CO3 storage bin, 45 ton, 1,500 cu.ft.			$7,907
Na2CO3 mix tank, 4,500 gallon w/agitator	5		$7,394
Na2CO3 pumps, 1-1/2" x 1-1/2", 20 gpm, 2	1	20	$2,755
Na2CO3 hold tank, 1500 gallon			$1,365
Na2CO3 head tank, 100 gallon			$179
Na2SiO3 unload pump, 100 gpm, 2"x2"	1		$1,120
Na2SiO3 storage tank, 50 ton, 1200 cu.ft			$10,176
Na2SiO3 transfer pump, 20 gpm, 1-1/2"	1	20	$2,755
Na2SiO3 mix tank, 3000 gallon w/agitator	5		$5,092
Na2SiO3 pumps, 20 gpm, 1-1/2", 2 req.	1	20	$2,755
Na2SiO3 hold tank, 1000 gallon			$854
Na2SiO3 head tank, 100 gallon			$179
Mill equipment subtotal			$1,805,396

MILL EQUIPMENT, cont'd	HP		YUCCA3 Total cost
Caustic starch mix tank, 3000 gallon	5		$5,092
Caustic Startch pumps, 20 gpm, 1-1/2".	1	20	$2,755
Caustic Startch head tank, 100 gallon			$179
Float cells, 60 cu.ft., 12 req.			$87,708
Float cell motors, 6 @ 20 hp each	120		$18,246
Float cells, 10 cu.ft., 8 req.			$32,120
Float cell motors, 4 @ 5 hp ea.	12		$5,096
Flotation blower, 1,500 cfm w/motor	350		$70,000
Cleaner tail pumps, 2 req, 74 gpm	4		$2,240
10' concentrate thickener	2		$25,541
80' tailings thickener	10		$126,225
Belt filter, 40 sq.ft.			$115,000
Filterate reciever pump	10	2100	$77,976
Vacuum pump, 5000 cmf		5000	$24,395
Vacuum motor, 100 hp	100	100	$5,617
Tailings sump/pump, 500 gpm,	10		$2,978
Mill equipment subtotal	2100		$601,167

Subtotal, flotation plant equipment	$2,406,564
Miscellaneous plant equipment	
Analytical lab equipment	$22,381
Assay lab equipment	$14,921
Maintenance tools and equipment	$16,846
Sample preparation equipment	$13,477
Vehicles	$192,525
Total flotation plant equipment	$2,666,713
Sales and use tax @ 5.75%	$153,336
Freight @ 7.46%	$198,937
Total delivered equipment cost	$3,018,986

MILL CONCRETE FOUNDATIONS	YUCCA3 Total cost
Apron feeder, 4' x 14'	$451
42" x 48" jaw crusher	$67,065
Jaw motor, 200 hp	$550
Baghouse, 20,000 cfm - collection system	$7,762
Baghouse, 20,000 cfm - ductwork	$0
Permenant magnet	$0
Wobbler feeder	$451
36" x 120' crusher belt conv.	$10,337
Belt magnet	$0
6' x 20' rod deck screen	$3,141
Rod deck motor, 25 hp	$121
30" x 90' o'size return belt	$9,192
Cone crusher, 5.5' diameter	$98,940
4' x 10' trash screen	$1,494
Trash screen motor, 10 hp	$77
Crushed ore sampler	$0
40" x 24" roll crusher	$31,251
Roll crusher motor, 150 hp	$421
Fine ore sampler	$0
Vibratory feeders, 2 req., 42st/hr	$606
24" x 280' rod mill feed belt	$9,192
Lime hydrate feeder	$40
Rod mill, 8' x 12'	$56,100
Rod mill motor, 300 hp	$4,199
Ball mill, 8' x 8'	$91,800
Ball mill motor, 300 hp	$4,199
Rod/Ball mill sump, 6'x6'x7', 1500 gpm	$329
Cyclone feed pump, 8", 965 gpm	$428
Cyclone classifier, 20", 965 gpm	$162
WO3 conditioning pump, 2 req. 400 gpm	$192
Lime mix tank, 1500 gallon w/agitator	$404
Lime pump, 1-1/4" x 1-1/4", 5 gpm	$102
Lime hold tank, 500 gallon w/agitator	$322
WO3 conditioning tanks, 2 req. 2,000 gal	$796
Na2CO3 storage bin, 45 ton, 1,500 cu.ft.	$712
Na2CO3 mix tank, 4,500 gallon w/agitator	$665
Na2CO3 pumps, 1-1/2" x 1-1/2", 20 gpm, 2	$110
Na2CO3 hold tank, 1500 gallon	$123
Na2CO3 head tank, 100 gallon	$16
Na2SiO3 unload pump, 100 gpm, 2"x2"	$45
Na2SiO3 storage tank, 50 ton, 1200 cu.ft.	$916
Na2SiO3 transfer pump, 20 gpm, 1-1/2"	$110
Na2SiO3 mix tank, 3000 gallon w/agitator	$458
Na2SiO3 pumps, 20 gpm, 1-1/2", 2 req.	$110
Na2SiO3 hold tank, 1000 gallon	$77
Na2SiO3 head tank, 100 gallon	$16
Mill concrete foundations, subtotal	$403,482

MILL CONCRETE FOUNDATIONS, cont'd	YUCCA3 Total cost
Caustic starch mix tank, 3000 gallon	$458
Caustic Startch pumps, 20 gpm, 1-1/2".	$110
Caustic Startch head tank, 100 gallon	$16
Float cells, 60 cu.ft., 12 req.	$5,262
Float cell motors, 6 @ 20 hp each	$730
Float cells, 10 cu.ft., 8 req.	$1,927
Float cell motors, 4 @ 5 hp ea.	$204
Flotation blower, 1,500 cfm w/motor	$4,200
Cleaner tail pumps, 2 req, 74 gpm	$90
10' concentrate thickener	$3,576
80' tailings thickener	$51,752
Belt filter, 40 sq.ft.	$14,950
Filterate reciever pump	$3,119
Vacuum pump, 5000 cmf	$976
Vacuum motor, 100 hp	$225
Tailings sump/pump, 500 gpm,	$119
Mill concrete foundations, subtotal	$87,714
Total concrete foundations	$491,196

MILL PROCESS PIPING	YUCCA3 Total cost
Lime hydrate feeder	$280
Rod mill, 8' x 12'	$14,850
Ball mill, 8' x 8'	$24,300
Rod/Ball mill sump, 6'x6'x7', 1500 gpm	$2,306
Cyclone feed pump, 8", 965 gpm	$2,994
Cyclone classifier, 20", 965 gpm	$729
WO3 conditioning pump, 2 req. 400 gpm	$1,344
Lime mix tank, 1500 gallon w/agitator	$2,154
Lime pump, 1-1/4" x 1-1/4", 5 gpm	$717
Lime hold tank, 500 gallon w/agitator	$1,715
WO3 conditioning tanks, 2 req. 2,000 gal	$4,245
Na2CO3 mix tank, 4,500 gallon w/agitator	$3,549
Na2CO3 pumps, 1-1/2" x 1-1/2", 20 gpm, 2	$771
Na2CO3 hold tank, 1500 gallon	$655
Na2CO3 head tank, 100 gallon	$86
Na2SiO3 unload pump, 100 gpm, 2"x2"	$314
Na2SiO3 storage tank, 50 ton, 1200 cu.ft.	$4,884
Na2SiO3 transfer pump, 20 gpm, 1-1/2"	$771
Na2SiO3 mix tank, 3000 gallon w/agitator	$2,444
Na2SiO3 pumps, 20 gpm, 1-1/2", 2 req.	$771
Na2SiO3 hold tank, 1000 gallon	$410
Na2SiO3 head tank, 100 gallon	$86
Caustic starch mix tank, 3000 gallon	$2,444
Caustic Startch pumps, 20 gpm, 1-1/2".	$771
Caustic Startch head tank, 100 gallon	$86
Float cells, 60 cu.ft., 12 req.	$53,940
Float cells, 10 cu.ft., 8 req.	$19,754
Flotation blower, 1,500 cfm w/motor	$7,700
Cleaner tail pumps, 2 req, 74 gpm	$627
10' concentrate thickener	$7,407
80' tailings thickener	$36,605
Belt filter, 40 sq.ft.	$67,850
Filterate reciever pump	$21,833
Vacuum pump, 5000 cmf	$6,831
Tailings sump/pump, 500 gpm,	$834
Mill process piping	$297,060

MILL STEEL SUPPORTS	YUCCA3 Total cost
Apron feeder, 4' x 14'	$2,254
42" x 48" jaw crusher	$29,588
Jaw motor, 200 hp	$963
Baghouse, 20,000 cfm - collection system	$4,586
Baghouse, 20,000 cfm - ductwork	$0
Wobbler feeder	$2,254
36" x 120' crusher belt conv.	$21,535
6' x 20' rod deck screen	$349
Rod deck motor, 25 hp	$211
30" x 90' o'size return belt	$19,150
Cone crusher, 5.5' diameter	$43,650
Trash screen motor, 10 hp	$134
40" x 24" roll crusher	$13,787
Roll crusher motor, 150 hp	$738
Vibratory feeders, 2 req., 42st/hr	$3,029
24" x 280' rod mill feed belt	$19,150
Lime hydrate feeder	$200
Rod mill, 8' x 12'	$24,750
Rod mill motor, 300 hp	$7,348
Ball mill, 8' x 8'	$40,500
Ball mill motor, 300 hp	$7,348
Cyclone classifier, 20", 965 gpm	$1,782
Lime mix tank, 1500 gallon w/agitator	$314
Lime hold tank, 500 gallon w/agitator	$250
WO3 conditioning tanks, 2 req. 2,000 gal	$619
Na2CO3 storage bin, 45 ton, 1,500 cu.ft.	$553
Na2CO3 mix tank, 4,500 gallon w/agitator	$518
Na2CO3 hold tank, 1500 gallon	$96
Na2CO3 head tank, 100 gallon	$13
Na2SiO3 storage tank, 50 ton, 1200 cu.ft.	$712
Na2SiO3 mix tank, 3000 gallon w/agitator	$356
Na2SiO3 hold tank, 1000 gallon	$60
Na2SiO3 head tank, 100 gallon	$13
Caustic starch mix tank, 3000 gallon	$356
Caustic Startch head tank, 100 gallon	$13
Float cells, 60 cu.ft., 12 req.	$8,771
Float cell motors, 6 @ 20 hp each	$1,277
Float cells, 10 cu.ft., 8 req.	$3,212
Float cell motors, 4 @ 5 hp ea.	$357
Flotation blower, 1,500 cfm w/motor	$10,500
10' concentrate thickener	$2,299
80' tailings thickener	$11,360
Belt filter, 40 sq.ft.	$23,000
Vacuum motor, 100 hp	$393
Mill structural steel	$308,348

MILL INSTRUMENTATION	YUCCA3 Total cost
Apron feeder, 4' x 14'	$1,465
42" x 48" jaw crusher	$19,725
Jaw motor, 200 hp	$413
Baghouse, 20,000 cfm - collection system	$3,175
Baghouse, 20,000 cfm - ductwork	$0
Permenant magnet	$165
Wobbler feeder	$1,465
36" x 120' crusher belt conv.	$5,168
Belt magnet	$165
6' x 20' rod deck screen	$2,792
Rod deck motor, 25 hp	$90
30" x 90' o'size return belt	$4,596
Cone crusher, 5.5' diameter	$29,100
4' x 10' trash screen	$498
Trash screen motor, 10 hp	$154
Crushed ore sampler	$444
40" x 24" roll crusher	$9,192
Roll crusher motor, 150 hp	$316
Fine ore sampler	$444
Vibratory feeders, 2 req., 42st/hr	$1,969
24" x 280' rod mill feed belt	$4,596
Lime hydrate feeder	$130
Rod mill, 8' x 12'	$16,500
Rod mill motor, 300 hp	$3,149
Ball mill, 8' x 8'	$27,000
Ball mill motor, 300 hp	$3,149
Rod/Ball mill sump, 6'x6'x7', 1500 gpm	$247
Cyclone feed pump, 8", 965 gpm	$321
Cyclone classifier, 20", 965 gpm	$324
WO3 conditioning pump, 2 req. 400 gpm	$144
Lime mix tank, 1500 gallon w/agitator	$359
Lime pump, 1-1/4" x 1-1/4", 5 gpm	$77
Lime hold tank, 500 gallon w/agitator	$286
WO3 conditioning tanks, 2 req. 2,000 gal	$708
Na2CO3 storage bin, 45 ton, 1,500 cu.ft.	$633
Na2CO3 mix tank, 4,500 gallon w/agitator	$592
Na2CO3 pumps, 1-1/2" x 1-1/2", 20 gpm, 2	$83
Na2CO3 hold tank, 1500 gallon	$109
Na2CO3 head tank, 100 gallon	$14
Na2SiO3 unload pump, 100 gpm, 2"x2"	$34
Na2SiO3 storage tank, 50 ton, 1200 cu.ft.	$814
Na2SiO3 transfer pump, 20 gpm, 1-1/2"	$83
Na2SiO3 mix tank, 3000 gallon w/agitator	$407
Na2SiO3 pumps, 20 gpm, 1-1/2", 2 req.	$83
Na2SiO3 hold tank, 1000 gallon	$68
Na2SiO3 head tank, 100 gallon	$14
Mill instrumentation, subtotal	$141,260

MILL INSTRUMENTATION, cont'd

	YUCCA3 Total cost
Caustic starch mix tank, 3000 gallon	$407
Caustic Startch pumps, 20 gpm, 1-1/2".	$83
Caustic Startch head tank, 100 gallon	$14
Float cells, 60 cu.ft., 12 req.	$8,771
Float cell motors, 6 @ 20 hp each	$547
Float cells, 10 cu.ft., 8 req.	$3,212
Float cell motors, 4 @ 5 hp ea.	$153
Flotation blower, 1,500 cfm w/motor	$3,500
Cleaner tail pumps, 2 req, 74 gpm	$67
10' concentrate thickener	$766
80' tailings thickener	$3,787
Belt filter, 40 sq.ft.	$5,750
Filterate reciever pump	$2,339
Vacuum pump, 5000 cmf	$732
Vacuum motor, 100 hp	$169
Tailings sump/pump, 500 gpm,	$89
Mill instrumentation, subtotal	$30,387
Total mill instrumentation	$171,647

MILL INSULATION

	Total cost
Baghouse, 20,000 cfm - collection system	$3,528
Baghouse, 20,000 cfm - ductwork	$5,180
Cyclone classifier, 20", 965 gpm	$810
Lime mix tank, 1500 gallon w/agitator	$224
Lime hold tank, 500 gallon w/agitator	$179
WO3 conditioning tanks, 2 req. 2,000 gal	$442
Na2CO3 storage bin, 45 ton, 1,500 cu.ft.	$395
Na2CO3 mix tank, 4,500 gallon w/agitator	$370
Na2CO3 hold tank, 1500 gallon	$68
Na2SiO3 storage tank, 50 ton, 1200 cu.ft.	$509
Na2SiO3 mix tank, 3000 gallon w/agitator	$255
Na2SiO3 hold tank, 1000 gallon	$43
Na2SiO3 head tank, 100 gallon	$9
Caustic starch mix tank, 3000 gallon	$255
Flotation blower, 1,500 cfm w/motor	$2,800
Belt filter, 40 sq.ft.	$2,300
Total mill insulation	$17,366

MILL ELECTRICAL SYSTEM	YUCCA3 Total cost
Apron feeder, 4' x 14'	$2,818
42" x 48" jaw crusher	$49,313
Jaw motor, 200 hp	$2,752
Baghouse, 20,000 cfm - collection system	$12,701
Baghouse, 20,000 cfm - ductwork	$0
Permenant magnet	$1,103
Wobbler feeder	$2,818
36" x 120' crusher belt conv.	$17,228
Belt magnet	$1,103
6' x 20' rod deck screen	$6,806
Rod deck motor, 25 hp	$603
30" x 90' o'size return belt	$15,320
Cone crusher, 5.5' diameter	$72,750
4' x 10' trash screen	$3,237
Trash screen motor, 10 hp	$384
Crushed ore sampler	$2,960
40" x 24" roll crusher	$22,979
Roll crusher motor, 150 hp	$2,107
Fine ore sampler	$2,960
Vibratory feeders, 2 req., 42st/hr	$3,787
24" x 280' rod mill feed belt	$19,150
Lime hydrate feeder	$250
Rod mill, 8' x 12'	$41,250
Rod mill motor, 300 hp	$20,993
Ball mill, 8' x 8'	$67,500
Ball mill motor, 300 hp	$20,993
Rod/Ball mill sump, 6'x6'x7', 1500 gpm	$2,388
Cyclone feed pump, 8", 965 gpm	$3,101
Cyclone classifier, 20", 965 gpm	$3,807
WO3 conditioning pump, 2 req. 400 gpm	$1,392
Lime mix tank, 1500 gallon w/agitator	$180
Lime pump, 1-1/4" x 1-1/4", 5 gpm	$743
Lime hold tank, 500 gallon w/agitator	$143
WO3 conditioning tanks, 2 req. 2,000 gal	$354
Na2CO3 storage bin, 45 ton, 1,500 cu.ft.	$316
Na2CO3 mix tank, 4,500 gallon w/agitator	$296
Na2CO3 pumps, 1-1/2" x 1-1/2", 20 gpm, 2	$799
Na2CO3 hold tank, 1500 gallon	$55
Na2CO3 head tank, 100 gallon	$7
Na2SiO3 unload pump, 100 gpm, 2"x2"	$325
Na2SiO3 storage tank, 50 ton, 1200 cu.ft.	$407
Na2SiO3 transfer pump, 20 gpm, 1-1/2"	$799
Na2SiO3 mix tank, 3000 gallon w/agitator	$204
Na2SiO3 pumps, 20 gpm, 1-1/2", 2 req.	$799
Na2SiO3 hold tank, 1000 gallon	$34
Na2SiO3 head tank, 100 gallon	$7
Mill electrical system	$410,019

MILL ELECTRICAL SYSTEM, cont'd	YUCCA3 Total cost
Caustic starch mix tank, 3000 gallon	$204
Caustic Startch pumps, 20 gpm, 1-1/2".	$799
Caustic Startch head tank, 100 gallon	$7
Float cells, 60 cu.ft., 12 req.	$17,542
Float cell motors, 6 @ 20 hp each	$3,649
Float cells, 10 cu.ft., 8 req.	$6,424
Float cell motors, 4 @ 5 hp ea.	$1,019
Flotation blower, 1,500 cfm w/motor	$21,000
Cleaner tail pumps, 2 req, 74 gpm	$650
10' concentrate thickener	$1,788
80' tailings thickener	$8,836
Belt filter, 40 sq.ft.	$11,500
Filterate reciever pump	$22,613
Vacuum pump, 5000 cmf	$7,075
Vacuum motor, 100 hp	$1,123
Tailings sump/pump, 500 gpm,	$864
Mill electrical system	$105,091
Total mill electrical system	$515,111

MILL CONSTRUCTION LABOR	YUCCA3 Total cost
Apron feeder, 4' x 14'	$5,501
42" x 48" jaw crusher	$156,025
Jaw motor, 200 hp	$6,922
Baghouse, 20,000 cfm - collection system	$34,539
Baghouse, 20,000 cfm - ductwork	$50,712
Permenant magnet	$3,441
Wobbler feeder	$5,501
36" x 120' crusher belt conv.	$65,553
Belt magnet	$3,441
6' x 20' rod deck screen	$15,182
Rod deck motor, 25 hp	$1,516
30" x 90' o'size return belt	$58,293
Cone crusher, 5.5' diameter	$230,181
4' x 10' trash screen	$7,221
Trash screen motor, 10 hp	$966
Crushed ore sampler	$9,235
40" x 24" roll crusher	$72,706
Roll crusher motor, 150 hp	$5,300
Fine ore sampler	$9,235
Vibratory feeders, 2 req., 42st/hr	$7,391
24" x 280' rod mill feed belt	$60,591
Lime hydrate feeder	$488
Rod mill, 8' x 12'	$130,515
Rod mill motor, 300 hp	$52,798
Ball mill, 8' x 8'	$213,570
Ball mill motor, 300 hp	$52,798
Rod/Ball mill sump, 6'x6'x7', 1500 gpm	$4,521
Cyclone feed pump, 8", 965 gpm	$5,871
Cyclone classifier, 20", 965 gpm	$4,390
WO3 conditioning pump, 2 req. 400 gpm	$2,635
Lime mix tank, 1500 gallon w/agitator	$2,940
Lime pump, 1-1/4" x 1-1/4", 5 gpm	$1,407
Lime hold tank, 500 gallon w/agitator	$2,340
WO3 conditioning tanks, 2 req. 2,000 gal	$5,793
Na2CO3 storage bin, 45 ton, 1,500 cu.ft.	$5,179
Na2CO3 mix tank, 4,500 gallon w/agitator	$4,843
Na2CO3 pumps, 1-1/2" x 1-1/2", 20 gpm, 2	$1,512
Na2CO3 hold tank, 1500 gallon	$894
Na2CO3 head tank, 100 gallon	$117
Na2SiO3 unload pump, 100 gpm, 2"x2"	$615
Na2SiO3 storage tank, 50 ton, 1200 cu.ft.	$6,665
Na2SiO3 transfer pump, 20 gpm, 1-1/2"	$1,512
Na2SiO3 mix tank, 3000 gallon w/agitator	$3,335
Na2SiO3 pumps, 20 gpm, 1-1/2", 2 req.	$1,512
Na2SiO3 hold tank, 1000 gallon	$559
Na2SiO3 head tank, 100 gallon	$117
Mill construction labor	$1,316,378

MILL CONSTRUCTION LABOR, cont'd	YUCCA3 Total cost
Caustic starch mix tank, 3000 gallon	$3,335
Caustic Startch pumps, 20 gpm, 1-1/2".	$1,512
Caustic Startch head tank, 100 gallon	$117
Float cells, 60 cu.ft., 12 req.	$44,293
Float cell motors, 6 @ 20 hp each	$9,178
Float cells, 10 cu.ft., 8 req.	$16,221
Float cell motors, 4 @ 5 hp ea.	$2,563
Flotation blower, 1,500 cfm w/motor	$24,220
Cleaner tail pumps, 2 req, 74 gpm	$1,230
10' concentrate thickener	$41,274
80' tailings thickener	$203,980
Belt filter, 40 sq.ft.	$92,460
Filterate reciever pump	$42,809
Vacuum pump, 5000 cmf	$13,393
Vacuum motor, 100 hp	$2,825
Tailings sump/pump, 500 gpm,	$1,635
Mill construction labor, subtotal	$501,044
Total mill construction labor	$1,817,423

MILL STRUCTURES	Units	Cost/Unit	YUCCA3 Total cost
Structures			
Mill building, 22,000 sq.ft.	22000	$12.00	$264,000
Office, 9,000 sq.ft.	9000	$8.00	$72,000
Concrete foundations			
Mill building, 275 cubic yards	275	$310.00	$85,250
Office, 180 cubic yards	180	$310.00	$55,800
Steel items			
Floor gratings, 3,092 sq.ft.	3092	$5.00	$15,460
Stairways, 5.1 tons	5	$2,500.00	$12,750
Handrails, 4.1 tons	4	$4,400.00	$18,040
Furnishings			
Administration			$60,000
Mine			$30,000
Labor			
Buildings, 31,000 sq.ft.	31000	$23.00	$713,000
Concrete, 455 cubic yards	455	$140.00	$63,700
Steel, gratings, 341 hours	341	$23.00	$7,843
Steel, stairways, 92 hours	92	$23.00	$2,116
Steel, handrails, 111 hours	111	$23.00	$2,553
Mill buildings summary			
Structures			$336,000
Concrete			$141,050
Steel			$46,250
Furnishings			$90,000
Construction labor			$789,212
Total, Mill buildings			$1,402,512

TAILINGS IMPOUNDMENT YUCCA3

	Units	Cost/Unit	Total cost
Dike and dam construction, 346,000 cubic yards, $1.78/yard			
Labor	346000	$0.51	$176,460
Parts	346000	$0.41	$141,860
Fuel	346000	$0.61	$211,060
Lube	346000	$0.15	$51,900
GEC	346000	$0.10	$34,600
Reclaim ponds, 500 square yards, $1.75/yard			
Labor	500	$0.51	$255
Parts	500	$0.41	$205
Fuel	500	$0.61	$305
Lube	500	$0.14	$70
GEC	500	$0.08	$40
Fencing, 4,382 linear feet			
Fence, 6 foot, 3 strand barbed wire	4382	$5.20	$22,786
Fence, labor	4382	$2.36	$10,342
Slurry pipe, schedule 40, 4", 2,000 feet			
Pipe	2000	$46.40	$92,800
Labor	2000	$10.75	$21,500
Recliam pipe, Schedule 40, 1", 2,000 feet			
Pipe	2000	$8.21	$16,420
Labor	2000	$4.35	$8,700
Liners, hypalon, 1.2 million sq.ft.			
Liner	1200000	$0.57	$684,000
Labor	1200000	$0.21	$252,000
Tailing impoundment summary			
Labor			$469,257
Parts			$142,065
Fuel			$211,365
Lube			$51,970
GEC			$34,640
Steel pipe			$109,220
Plastic liners			$684,000
Metal fences			$22,786
Total, tailings impoundment			$1,725,303

YUCCA MOUNTAIN TUNGSTEN MINE, MILL CAPITAL COST SUMMARY

Process facilities	
Mill equipment	$3,018,986
Concrete foundations	$491,196
Process piping	$297,060
Structural steel	$308,348
Instrumentations	$171,647
Insulation	$17,366
Electrical system	$515,111
Construction labor	$1,817,423
Mill buildings	$1,402,512
Tailings impoundment	$1,725,303
Engineering and design fees	$2,538,887
Permitting	$1,230,384
Reclamation bonds	$120,000
Working Capital	$1,370,060
Total mill capital	$15,024,282

YUCCA MOUNTAIN TUNGSTEN MINE, MILL OPERATING COSTS

	No.	$/hr-$/ann.	YUCCA4 $/day
Supervision/Administration			
Mill op. super.	1	$54,900.00	$152.50
Mill maint. super.	1	$54,900.00	$152.50
Oper. formen	3	$23.07	$553.68
Maint. formen	3	$23.07	$553.68
Engineer	1	$17.38	$139.04
Metallurgist	1	$21.01	$168.08
Purchasing	1	$11.74	$93.92
Accountant	1	$11.74	$93.92
Clerk	1	$10.45	$83.60
Secretarial	1	$10.45	$83.60
Security	3	$13.05	$313.20
Direct mill labor			
Crushing operators	1	$16.94	$135.52
Grinding operators	1	$16.94	$135.52
Flotation operators	3	$16.94	$406.56
Electricians	2	$19.27	$308.32
Assay lab	2	$12.24	$195.84
Maintenence	11	$15.51	$1,364.88
Mechanics, millwrights	9	$16.94	$1,219.68
Support	2	$12.24	$195.84
Total Labor	48		$6,349.88

SUPPLIES

Item			$/day
Electric Power, kwh/day	37598	0.04445	$1,671.23
Steel			
Rod consumption, lbs/day	509	0.247	$125.72
Ball consumption, lbs/day	562	0.578	$324.84
Liner consumption, lbs/day	176	0.75	$132.00
Reagents			
Na_2CO_3, NaOH, lbs/day	7261	$0.12	$871.32
Lime, lbs/day	8802	$0.10	$880.20
Na_2SiO_3, lbs/day	10891	$0.16	$1,742.56
EPG Acintol FA-1, lbs/day	490	$0.89	$436.10
Aluminum Sulfate, lbs/day	792	$0.38	$300.96
Parts			$1,257.91
Lubricants			$62.90
Total supplies			$7,805.74

YUCCA MOUNTAIN TUNGSTEN MINE, OPERATING COST SUMMARY

Item	YUCCA4 $/day
Labor	$6,349.88
Electric power	$1,671.23
Steel	$582.56
Reagents	$4,231.14
Parts	$1,257.91
Lubricants	$62.90
Sales and use tax	$448.83
Total operating cost per day	$14,604.45
Total operating cost per ton	$20.22

YUCCA MOUNTAIN TUNGSTEN MINE - CONCENTRATE TRANSPORT

YUCCA4

Route/road	distance	speed	travel time
Mine road to rte 95	15	25	0.60
Rte 95 to Tonapah	108	50	2.16
Tonapah to Bishop	117	50	2.34
Bishop to Pine Creek	21	30	0.70
Pine Creek to Bishop	21	35	0.60
Bishop to Tonapah	117	55	2.13
Tonapah to Mine road	108	55	1.96
Rte 95 to mine	15	30	0.50
Total cycle time			10.99

Item	Cost/hour	Hours	Total Cost
Driver	$14.48	10.99	$159.15
Maintenance labor	$8.25	10.99	$90.68
Parts	$8.84	10.99	$97.16
Fuel	$5.98	10.99	$65.73
Lube	$2.27	10.99	$24.95
Tires	$4.10	10.99	$45.06
Depreciation and overhead	$26.37	10.99	$289.83
Sales and use tax			$13.39
Total cost per trip			$785.94
Cost per ton concentrate		35.00	$22.46
Cost per day		27.54	$618.44
Cost per ton ore		722.22	$0.86

MATERIAL BALANCE - YUCCA MOUNTAIN TUNGSTEN MINE YUCCA4

Item	Tons/day	Wt.Pct WO3	Tons WO3	Wt.Pct WO3
Feed	722.22	0.65%	4.69	100.00%
Rougher concentrate	80.31	5.29%	4.25	90.43%
Rougher tail	641.91	0.07%	0.45	9.57%
Cleaner concentrate	27.54	15.00%	4.13	88.00%
Cleaner tail	694.68	0.08%	0.56	12.00%

(All Values in Thousands)

Title : YUCCA MOUNTAIN TUNGSTEN
Run Date : 2/8/1990
Evaluation Date : 07/89
Project Start : 01/89
Evaluator : WETZEL

Period Ending	12/89	12/90	12/91	12/92	12/93	12/94	12/95	12/96	12/97	12/98	Salv.
Revenue		21,280	21,280	21,280	21,280	21,280	21,280	21,280	21,280	21,280	2,980
-Oper Costs		-11,697	-11,697	-11,697	-11,697	-11,697	-11,697	-11,697	-11,697	-11,697	
-Sever, Ad-Val		-233	-233	-233	-233	-233	-233	-233	-233	-233	
-Developaent	-6,873										
-Depreciation	-1,692	-2,989	-2,302	-1,795	-1,545	-1,479	-1,479	-592	-592	-592	-2,959
-Writeoffs											-2,980
Before Depltn	-8,565	6,360	7,047	7,554	7,805	7,870	7,870	8,758	8,758	8,758	-2,959
-50% Liait		-3,180	-3,523	-3,777	-3,902	-3,935	-3,935	-4,379	-4,379	-4,379	
-Percent Depl		4,682	4,682	4,682	4,682	4,682	4,682	4,682	4,682	4,682	
-Cost Depltn											
-Loss Forward		-8,565	-5,384	-1,861							
Taxable	-8,565	-5,384	-1,861	1,916	3,902	3,935	3,935	4,379	4,379	4,379	-2,959
-Tax @ 44%				-839	-1,708	-1,722	-1,722	-1,917	-1,917	-1,917	1,295
Net Income	-8,565	-5,384	-1,861	1,077	2,194	2,213	2,213	2,462	2,462	2,462	-1,664
+Depreciation	1,692	2,989	2,302	1,795	1,545	1,479	1,479	592	592	592	2,959
+Depletion		3,180	3,523	3,777	3,902	3,935	3,935	4,379	4,379	4,379	
+Loss Forward		8,565	5,384	1,861							
+Writeoffs											2,980
-Capitl Costs	-31,335	-2,980									
Cash Flow	-38,207	6,369	9,349	8,511	7,641	7,627	7,627	7,433	7,433	7,433	4,275

(All Values in Thousands)
Title : YUCCA MOUNTAIN TUNGSTEN
Run Date : 2/8/1990
Evaluation Date : 07/89
Project Start : 01/89
Evaluator : WETZEL

Revenue Breakeven Analysis

Iter	Revenue %	NPV	Iter	Revenue %	NPV
1	100.00000	7.28			

Minimum Rate Of Return : 15.00

Revenue at 100.0000% NPV = 7.28

Break Even $/unit at Project Start = 14308.59 Per ton = $143/stu

APPENDIX D. COSTING BACKUP DATA, CARBONATE-HOSTED GOLD ECONOMIC/EXTRACTION MODEL

YUCCA MOUNTAIN CARBONATE-HOSTED GOLD MINE, CAPITAL COST ESTIMATES
INFRASTRUCTURE YUCCA5

Item	Units	Cost/unit	Total Cost
Access Roads, upgrade, 78,600 ft, gravel last 3 miles			
Rough grade, 873,330 square yards, $0.56/sy			
Labor	873330	$0.16	$139,733
Parts	873330	$0.13	$113,533
Fuel	873330	$0.19	$165,933
Lube	873330	$0.05	$43,667
GEC	873330	$0.03	$26,200
Scarify, Grade, Compact, 873,330 square yards, $0.70/sy			
Labor	873330	$0.20	$174,666
Parts	873330	$0.16	$141,916
Fuel	873330	$0.24	$207,416
Lube	873330	$0.06	$54,583
GEC	873330	$0.04	$32,750
Gravel surface, 6" x 3", 26,250 cubic yards, $8.10/cy			
Labor	26250	$0.43	$11,288
Parts	26250	$0.19	$4,988
Fuel	26250	$0.27	$7,088
Lube	26250	$0.07	$1,838
Gravel	26250	$7.14	$187,425
Access road upgrade summary			
Labor			$325,686
Parts			$260,437
Fuel			$380,436
Lube			$100,087
Gravel			$187,425
Steel			$58,950
Total Access road upgrade			$1,313,021

Item	Units	Cost/unit	Total Cost
Power line, 33 kv, 12 miles			
Poles, 312 @ 30' high			
Poles	312	$500.00	$156,000
Labor	312	$285.00	$88,920
Fuel	312	$40.00	$12,480
Lube	312	$10.00	$3,120
Transmission line, 70,404 linear feet			
Power line	70404	$35.97	$2,532,432
Labor	70404	$10.56	$743,466
Power line summary			
Labor			$832,386
Transmission line			$2,532,432
Lumber			$156,000
Fuel			$12,480
Lube			$3,120
Total Power line			$3,536,418

Item	Units	Cost/unit	Total Cost
Water well, 2 @ 300' deep, 12" diameter			
Labor, drilling, 12 hours	12	$52.83	$634
Labor, maintenance	12	$66.97	$804
Parts	12	$62.84	$754
Fuel	12	$22.33	$268
Lube	12	$8.78	$105
GEC	12	$3.85	$46
Cement, 3 yards	3	$310.00	$930
Casing, 12", 600 feet	300	$20.31	$6,093
Gravel, 209 cu.yds	104	$7.14	$743
Pump, 750 gpm, 295 hp	1	$75,000	$75,000
Pump motor, 295 hp	1	$52,271	$52,271
Pipeline, 5,000', 4" schedule 40	5000	$4.09	$20,450
Water tank, 500,000 gallon	1	$282,192	$282,192
Water tank/pipline installation	1992	$24.00	$47,808
Water system summary			
Labor			$49,246
Parts			$754
Fuel			$268
Lube			$105
Steel, mobile equipment			$46
Cement			$930
Construction gravel			$743
Steel pipe			$26,543
Process equipment, tanks, pumps, motors			$409,463
Total, water system, two complete			$976,196

Item	Units	Cost/unit	Total Cost
Diamond drilling, 120 holes (100 foot centers) 3,000' deep			
Labor, 50'/shift			
Drillers, 2 - 12.5'/hr=6,000 hr/man	38400	$17.17	$659,328
Maintenance labor	19200	$4.16	$79,872
Geologist	19200	$18.08	$347,136
Helper	19200	$12.41	$238,272
Repair parts, drill, mud, water serv.	19200	$3.52	$67,584
Fuel, drill, mud, water service	19200	$4.10	$78,720
Lube, drill, mud, water service	19200	$0.85	$16,320
GEC, drill	19200	$0.33	$6,336
Drill bits, NW, soft rock - 2/hole	240.00	$362.00	$86,880
Drill rods, NW, 1/hole	120.00	$148.00	$17,760
Drill mud, 4.4 pct total	1608336	$0.04	$70,767
Cement, 60 lb sacks, 1/shift	2400	$4.22	$10,128
Exploration drilling summary			
Labor			$1,324,608
Parts			$67,584
Fuel			$78,720
Lube			$16,320
Steel, mobile equipment			$6,336
Steel, bits and rods			$104,640
Drill mud			$70,767
Cement			$10,128
Sales and use tax			$20,383
Total exploration drilling cost			$1,699,486

Item	Units	Cost/unit	Total Cost
Contracted exploration expenses			
Assaying, 2,640 samples			
Sample preparation	2640	$3.04	$8,026
Assays	2640	$16.90	$44,616
Petrographic work	600	$35.00	$21,000
Contracted exploration expenses			$73,642

Main haulage decline, 14′ x 12′ x 2,500′

Item	Units	Cost/unit	Total Cost
Labor, hours			
Miners	6000	$17.03	$102,180
Laborors	5500	$10.48	$57,640
Supervision	588	$19.65	$11,554
Maintenance	1412	$17.23	$24,329
Repair parts			
Two boom jumbos	298	$5.50	$1,636
Overshot mucker	162	$3.75	$608
27 ton diesel	220	$10.90	$2,398
Compressor	500	$2.44	$1,220
Ventilation fan	2000	$1.27	$2,540
Electricity			
Compressor	500	$8.70	$4,350
Ventilation fan	2000	$2.74	$5,480
Fuel			
Two boom jumbos	298	$1.98	$589
27 ton diesel	220	$7.29	$1,604
Rock bolter	903	$0.33	$298
Tires			
Two boom jumbos	298	$1.82	$541
27 ton diesel	220	$3.60	$792
Overshot mucker	162	$1.24	$201
Lubricants			
Two boom jumbos	298	$0.73	$217
Rock bolter	903	$0.03	$27
Overshot mucker	162	$0.28	$45
27 ton diesel	220	$2.15	$473
Compressor	500	$0.22	$110
Ventilation fan	2000	$0.08	$160
Drill bits, 363.3 feet/bit	253	$58.70	$14,822
Drill rods, 720.9 feet/rod	128	$170.00	$21,675
Explosives, 2.4 lbs/ton	77537	$0.25	$19,384
Blasting caps	8000	$1.61	$12,880
Air pipe, sch 40, 8" w/couplings	2500	$18.78	$46,950
Mine water pipe, sch 40, 6" w/couplings	2500	$11.92	$29,800
Potable water pipe, sch 40, 2" w/coup.	2500	$2.39	$5,975
Pipe hangers (chain)	2500	$4.11	$10,275
Vent tubing, spiral wound, 20"	2500	$9.96	$24,900
Rock bolts, 10 bolt pattern, 4′ centers	6250	$6.07	$37,938
Rock bolt mat, 11", 14 gauge	6750	$3.83	$25,853
Bolter bits, 346.8 feet/bit	118	$16.05	$1,886
Bolter rods, 688.2 feet/rod	60	$75.60	$4,536

Main access decline cost summary	
Labor	$195,703
Repair parts	$8,402
Electricity	$9,830
Lubricants	$1,033
Tires	$1,534
Steel, bits and rods	$42,919
Steel, pipe and chain	$93,000
Steel, bolts and mats	$63,790
Explosives	$32,264
Vent tubing	$24,900
Sales and use tax	$15,966
Total main access decline capital	$489,341

Vertical shaft, 22' x 7' x 4,000'

Item	Units	Cost/unit	Total Cost
Labor			
Miners	52084	$17.23	$897,407
Laborors	34668	$10.48	$363,321
Supervision	1959	$19.65	$38,494
Hoistmen, waste haulage	19000	$14.61	$277,590
Repair parts			
Sinker	12916	$0.17	$2,196
Cryderman	3167	$8.46	$26,793
Hoist	13000	$6.30	$81,900
27 ton diesel	657	$10.90	$7,161
Ventilation fan	17333	$1.27	$22,013
Electricity			
Hoist	13000	$5.78	$75,140
Ventilation fan	17333	$2.74	$47,492
Lubricants			
Sinker	12916	$0.01	$129
Cryderman	3167	$1.10	$3,484
Hoist	13000	$0.82	$10,660
27 ton diesel	657	$2.15	$1,413
Ventilation fan	17333	$0.08	$1,387
Timber	1110834	$0.48	$533,200
Drill bits, 363.3 feet/bit; 67.6 ft/foot	935	$58.70	$54,885
Drill rods, 720.9 feet/rod; 67.6 ft/foot	467	$170.00	$79,390
Explosives, 1.4 lbs/ton	89835	$1.18	$106,005
Blasting caps	45808	$1.64	$75,125
Air pipe, sch 40, 8" w/couplings	4000	$18.78	$75,120
Mine water pipe, sch 40, 6" w/couplings	4000	$11.92	$47,680
Potable water pipe, sch 40, 2" w/coup.	4000	$2.39	$9,560
Pipe hangers (chain)	4000	$4.11	$16,440
Vent tubing, spiral wound, 20"	4000	$9.96	$39,840

Vertical shaft cost summary	
Labor	$1,576,812
Repair parts	$140,063
Electricity	$122,632
Lubricants	$17,072
Timber	$533,200
Steel, bits and rods	$134,275
Steel, pipe and chain	$148,800
Explosives	$181,130
Vent tubing	$39,840
Sales and use tax	$75,728
Total vertical shaft capital	$2,969,553

Crosscuts, 3 @ 600' each, 10' x 8'

Item	Units	Cost/unit	Total Cost
Labor			
Miners	5760	$17.23	$99,245
Laborors	3834	$10.48	$40,180
Supervision	217	$19.65	$4,264
Hoistmen, waste haulage	396	$14.61	$5,786
Repair parts			
Drifter	1062	$0.33	$350
Overshot mucker	58	$3.75	$218
27 ton diesel	160	$10.90	$1,744
Hoist	230	$6.30	$1,449
Compressor	360	$2.44	$878
Ventilation fan	1440	$1.27	$1,829
Electricity			
Hoist	230	$5.78	$1,329
Compressor	360	$8.70	$3,132
Ventilation fan	1440	$2.74	$3,946
Fuel			
27 ton diesel	160	$7.29	$1,166
Rock bolter	650	$0.33	$215
Lubricants			
Drifter	1062	$0.03	$32
Rock bolter	650	$0.30	$195
Overshot mucker	58	$0.28	$16
27 ton diesel	160	$2.15	$344
Hoist	230	$0.82	$189
Compressor	360	$0.22	$79
Ventilation fan	3468	$0.08	$277
Tires			
Overshot mucker	58	$1.24	$72
27 ton diesel	160	$3.60	$576
Drill bits, 363.3 feet/bit	131	$58.70	$7,690
Drill rods, 720.9 feet/rod	67	$170.00	$11,390
Rock bolts, 10 bolt pattern, 4 ft center	4500	$6.07	$27,315
Rock bolt mat, 11", 14 gauge	4860	$3.83	$18,614
Rock bolt bits	85	$16.05	$1,364
Rock bolt rods	67	$75.60	$5,065
Explosives, 2.4 lbs/ton	27648	$0.25	$6,912
Blasting caps	4014	$1.64	$6,583
Air pipe, sch 40, 8" w/couplings	1800	$18.78	$33,804
Mine water pipe, sch 40, 6" w/couplings	1800	$11.92	$21,456
Potable water pipe, sch 40, 2" w/coup.	1800	$2.39	$4,302
Pipe hangers (chain)	1800	$4.11	$7,398
Vent tubing, spiral wound, 20"	1800	$9.96	$17,928

Crosscuts cost summary	
Labor	$149,475
Repair parts	$6,468
Electricity	$8,407
Fuel	$1,381
Lubricants	$1,132
Tires	$648
Steel, bits, rods, bolts, mats	$71,438
Steel, pipe and chain	$66,960
Explosives	$13,495
Vent tubing	$17,928
Sales and use tax	$10,802
Total crosscut capital	$348,134

MINE EQUIPMENT — YUCCA5

Item	No.	Cost/unit	Total cost
Mine Equipment			
Front end loaders, 5.2 cu.yard	9	$238,370	$2,145,330
Articulated haul trucks, 27 ton	4	$228,678	$914,712
Jumbos, 2.5 inch	3	$642,430	$1,927,290
Rock bolter	4	$282,900	$1,131,600
Kerf cutting machines	2	$750,660	$1,501,320
Service truck, 5 ton, 82 hp diesel	1	$56,160	$56,160
Lube truck	1	$75,000	$75,000
Scissor lift truck, 8,000 lb cap.	1	$63,440	$63,440
ANFO loader truck	1	$71,760	$71,760
Personnel carrier, 12 person	1	$61,360	$61,360
Water truck, 900 gallon	1	$60,000	$60,000
Grader, 150 hp	1	$133,190	$133,190
Dozer, 200 hp	1	$172,500	$172,500
Ventilation fans, 800 hp	2	$235,152	$470,304
Mine hoist, 120 inch, 1000 hp drive	1	$950,000	$950,000
Utility hoist, 60 inch, 250 hp drive	1	$425,000	$425,000
Hoist cable, 2"	8000	$15	$121,280
Misc. mine equipment			$2,056,049
Mine Equipment Total			$12,336,295
Sales and use tax @ 5.75%			$709,337
Freight @ 7.46%			$920,288
Total Mine equipment			$13,965,920

FACILITIES

Concrete	Units	Cost/Unit	Total cost
Shop, 441 cubic yards	400	$310	$124,000
Warehouse, 267 cubic yards	267	$310	$82,667
Dry, 154 cubic yards	140	$310	$43,400
Services, 153 cubic yards	153	$140	$21,467
Structures			
Shop, 12,000 sq.ft.	12000	$8	$96,000
Warehouse, 8,000 sq.ft.	8000	$12	$96,000
Dry, 4,200 sq.ft.	4200	$12	$50,400
Services, 4,600 sq.ft.	4600	$18	$82,800
Construction labor			
Concrete, $140/cubic yard	960	$140	$134,400
Structures, $23/sq.ft.	28800	$23	$662,400
Mine facilities total			$1,454,336

YUCCA MOUNTAIN CARBONATE-HOSTED GOLD MINE, CAPITAL COST ESTIMATES

Infrastructure	
Mine road upgrade	$1,313,021
Powerline	$3,536,418
Water system	$976,196
Exploration	
Drilling program	$1,773,128
Development	
Main haulage decline	$489,341
Vertical shaft	$2,969,553
Crosscuts	$348,134
Undgerground mine equipment	$13,965,920
Mine facilities, surface and underground	$1,454,336
Engineering and design fees	$5,365,209
Working capital	$2,400,856
Total mine capital	$34,592,111

YUCCA MOUNTAIN CAARBONATE-HOSTED GOLD MINE, OPERATING COST ESTIMATES
LABOR YUCCA6

	No.	Cost/year	Cost/day
Adminsitration-salaried			
Operations manager	1	$65,900	$183.06
Mine superintendent	1	$56,751	$157.64
Maintenance superintendent	1	$56,751	$157.64
Development foreman	1	$54,900	$152.50
Maintenance foreman	1	$54,900	$152.50
Mine engineer	1	$44,716	$124.21
Mine geologists	1	$40,651	$112.92
Underground engineers	2	$40,651	$225.84
Underground geologists	2	$36,956	$205.31
Drafting	1	$27,456	$76.27
Safety officer	1	$36,818	$102.27
Ventilation engineer	1	$36,818	$102.27
Subtotal, Administrative labor	14		$1,752.43

Mine labor	No.	Cost/hour	Cost/day
Mine formen	3	$19.65	$471.60
Maintenance foremen	1	$19.65	$157.20
Miners	18	$17.23	$2,481.12
Scalers	6	$17.21	$826.08
LHD operators	8	$17.21	$1,101.44
Truck drivers	6	$17.21	$826.08
Blasters	4	$17.45	$558.40
Hoistmen/Cage tenders	6	$14.51	$696.48
Utility men	3	$16.76	$402.24
Helpers	3	$16.55	$397.20
Electricians	2	$17.69	$283.04
Lubrications	2	$17.45	$279.20
Welders	2	$17.45	$279.20
Machinists	2	$17.69	$283.04
Repairmen	4	$16.98	$543.36
Surface men	2	$16.13	$258.08
Subtotal, direct labor	60		$11,705.74
Total labor cost per day	74		$13,458.17
Total cost per ton ore	3000		$4.49

	Units	Cost/unit	Cost/day
Drill bits, 2.5"	4.02	$182.00	$731.64
Drill bits, 3.0"	3.15	$266.00	$837.90
Drill rods	0.39	$126.00	$49.14
Explosives	4860.00	$0.61	$2,964.60
Boosters	151.00	$0.37	$55.87
Saftey fuse	6258.00	$0.10	$625.80
Timber, board feet	15	$0.34	$5.10
Pipe, 2", linear feet	9.6	$1.28	$12.29
Pipe, 1", linear feet	9.6	$1.00	$9.60
Vent tubing, 20" diameter, linear feet	9.6	$2.66	$25.54
Rock bolts	28.2	$6.81	$192.04
Front end loaders, 5.2 cy.yd	64.00		
Lube	64.00	$2.31	$147.84
Fuel	64.00	$8.51	$544.64
Parts	64.00	$11.40	$729.60
Tires	64.00	$3.38	$216.32
Diesel truck haulage	51.00		
Lube	51.00	$2.36	$120.36
Fuel	51.00	$8.81	$449.31
Parts	51.00	$11.37	$579.87
Tires	51.00	$4.78	$243.78
Jumbos, 2.5 inch	13.38		
Lube	13.38	$2.99	$40.01
Fuel	13.38	$11.59	$155.07
Parts	13.38	$38.29	$512.32
Tires	13.38	$1.47	$19.67
Powder buggies	0.06		
Lube	0.06	$0.45	$0.03
Fuel	0.06	$3.84	$0.23
Parts	0.06	$0.47	$0.03
Tires	0.06	$0.11	$0.01
Roof bolters	14.10		
Lube	14.10	$1.42	$20.02
Fuel	14.10	$4.77	$67.26
Parts	14.10	$6.42	$90.52
Tires	14.10	$0.00	$0.00
Scissor lift	3.99		
Lube	3.99	$0.37	$1.48
Fuel	3.99	$0.95	$3.79
Parts	3.99	$2.17	$8.66
Tires	3.99	$0.28	$1.12
Personnel carrier	1.74		
Lube	1.74	$0.45	$0.78
Fuel	1.74	$3.84	$6.68
Parts	1.74	$0.47	$0.82
Tires	1.74	$0.11	$0.19
Supply carrier	7.20		
Lube	7.20	$0.45	$3.24
Fuel	7.20	$3.84	$27.65
Parts	7.20	$0.47	$3.38
Tires	7.20	$0.11	$0.79

SUPPLIES, Cont'd YUCCA6

	Units	Cost/unit	Cost/day
Dozer, 200 hp	12.50		
Lube	12.50	$1.88	$23.50
Fuel	12.50	$7.10	$88.75
Parts	12.50	$10.42	$130.25
Tires	12.50	$0.00	$0.00
Grader, 150 hp	5.30		
Lube	5.30	$1.28	$6.78
Fuel	5.30	$4.89	$25.92
Parts	5.30	$6.58	$34.87
Tires	5.30	$0.63	$3.34
Hoist	23.00		
Electricity	23.00	$68.74	$1,581.02
Lube	23.00	$7.73	$177.79
Parts	23.00	$8.68	$199.64
Ventilation	24.00		
Electricity	24.00	$15.28	$366.72
Lube	24.00	$1.68	$40.32
Parts	24.00	$3.05	$73.20
Compressor	24.00		
Electricity	24.00	$8.70	$208.80
Lube	24.00	$0.22	$5.28
Parts	24.00	$2.44	$58.56
Subtotal, supplies			$12,529.72

Supply Summary		Cost/day
Repair Parts		$2,421.72
Electric Power		$2,156.54
Fuel		$1,369.30
Lube		$547.11
Tires		$485.21
Steel, Bits/Rods/Bolts		$1,810.72
Steel, Pipe		$21.89
Vent tubing		$25.54
Timber		$15.00
Explosives		$3,646.27
Sales and use tax		$718.71
Total supply cost		$13,218.01
Total cost per ton ore	3000	$4.41

YUCCA MOUNTAIN CARBONATE-HOSTED GOLD MINE, OPERATING COST SUMMARY

Item		YUCCA6 Cost/day
Administrative labor		$1,752.43
Mine labor		$11,705.74
Steel, bits/rods/bolts		$1,810.72
Explosives, caps/boosters		$3,646.27
Pipe, hangers/valves		$21.89
Vent tubing		$25.54
Timber		$15.00
Fuel		$1,369.30
Electricity		$2,156.54
Lube		$547.11
Parts		$2,421.72
Tires		$485.21
Sales and use tax		$718.71
Total mine operating cost		$26,676.18
Mine operating cost per ton	3000	$8.89
Mine operating cost per troy ounce	220.23	$121.13

YUCCA MOUNTAIN CARBONATE-HOSTED GOLD, MILL CAPITAL COSTS

PLANT EQUIPMENT	HP	YUCCA7 Total cost
Feeder, 60" by 15 feet	6	$11,683
42" x 48" jaw crusher		$197,250
Jaw motor, 200 hp	200	$13,761
Baghouse, 20,000 cfm - collection system	60	$35,280
Baghouse, 20,000 cfm - ductwork		$51,800
Overhead crane, 20 ton	20	$66,000
36" x 120' crusher belt conv.	25	$86,140
22' by 7' SAG mill		$954,000
SAG mill motor	1750	$261,629
6' x 16' lowhead screen		$34,900
Screen motor	25	$3,014
Baghouse, 20,000 cfm - collection system	60	$35,280
Baghouse, 20,000 cfm - ductwork		$51,800
SAG mill pumps, 2 @ 500 gpm ea.		$50,566
Pump motors	250	$14,336
Overhead crane, 5 ton	8	$20,000
Duplex jigs, 42" by 48", 2 req.	15	$70,269
Vertical sump/pump, 58 gpm	10	$26,395
Flotation blower, 4,000 cfm		$32,700
Sump/pump, 840 gpm	60	$20,201
Float cells, 4 @ 1350 cu.ft.		$138,160
Float cells, 3 @ 500 cu.ft.		$67,791
Float cells, 2 @ 300 cu.ft.		$33,060
Cell motors, 4 @ 60 hp	240	$46,380
Cell motors, 3 @ 40 hp	120	$18,549
Cell motors, 2 @ 30 hp	60	$10,734
Pump, 8" by 6"	75	$15,445
Pump, 6" by 4"	50	$5,885
Cyclones, 12", 2 required		$6,880
Regrind mill, 8' diameter	400	$360,000
Cleaner pumps, 6" by 4" 2 req.	100	$11,770
60' tailings thickener	20	$96,776
Tails pump, 2000 gpm	40	$22,711
70' concentrate thickener	25	$111,500
1-1/2" x 1-1/2", 20 gpm, 2	1	$2,755
120 by 144 surge tank		$4,271
Rotary disc filter, 400 sq.ft.	9	$136,818
Filtrate reciever pump	10	$77,976
Vacuum pump, 1,000 cfm	50	$6,400
Fluid bed roaster, 35 foot	300	$3,000,000
High temperature cyclones, 12", 2 req.		$8,022
Electrostatic precipitator, 10,000 cfm		$290,608
Aresenic trioxide baghouse	10	$11,283
Rotary feeders, 13	5	$106,211
Quench tanks, 2,000 gal, 3 req.		$11,152
Collection tank, 5,000 gal.		$13,341
Rotary disc filter, 400 sq.ft.	9	$136,818
Repulper	15	$11,710
Plant Equipment Subtotal	4028	$6,800,010

PLANT EQUIPMENT, cont'd	HP	YUCCA7 Total cost
4 x 3" pump, 500 gpm, 2 req.	50	$5,885
Filtrate reciever pump	10	$77,976
Vacuum pump, 1,000 cfm	50	$6,400
Overhead crane, 5 ton	8	$20,000
Fuel oil storage tank, 22' by 24'		$46,262
Fuel oil transfer pump	5	$1,108
Carbon columns, 5 @ 4'6" x 14'		$30,648
Pregnant solution pump	40	$3,965
Carbon column advance pump	5	$3,606
Strip solution pumps, 3 req.	3	$1,368
Barren solution return pump	60	$12,757
NaOH supply, Acid wash pumps, 2 req.	2	$912
Acid wash circ. pump	5	$3,606
Regenerated carbon pump	5	$3,606
Column carbon supply pump	5	$3,606
Strip carbon transfer pump	5	$3,606
Strip solution transfer pump	1	$456
Process floor pump	5	$3,837
Carbon column feed tank		$988
Caron strip tanks, 2 req.		$11,884
Strip solution tank		$9,383
NaOH tank		$8,881
NaCN mix tank		$2,200
Acid wash tank		$16,059
Carbon holding tank		$6,502
Carbon quench tank		$2,302
Carbon atttrition tank		$2,995
Electrowinning cell		$29,626
Bridge crane, 7.5ton	7	$31,565
Strip solution agitator	4	$3,588
Carbon attrition agitator	4	$3,588
Mecury retort	30	$41,192
Carbon regeneration kiln	10	$139,135
Induction furnace	167	$71,486
Samplers, 4 req.	4	$1,704
Exhaust fans, 3 req.	3	$2,979
Carbon screen		$7,581
Strip solution heater		$6,297
Plant equipment subtotal	488	$629,539

PLANT EQUIPMENT, cont'd		YUCCA7 Total Cost
Subtotal, flotation plant equipment	4515	$7,429,549
Miscellaneous plant equipment		
Analytical lab equipment		$69,095
Assay lab equipment		$46,063
Maintenance tools and equipment		$52,007
Sample preparation equipment		$41,605
Vehicles		$594,364
Total flotation plant equipment		$8,232,683
Sales and use tax @ 5.75%		$473,379
Freight @ 7.46%		$614,158
Total delivered equipment cost		$9,320,221

CONCRETE FOUNDATIONS	YUCCA7 Total cost
Feeder, 60" by 15 feet	$467
42" x 48" jaw crusher	$67,065
Jaw motor, 200 hp	$550
Baghouse, 20,000 cfm - collection system	$7,762
Baghouse, 20,000 cfm - ductwork	$0
Overhead crane, 20 ton	$6,600
36" x 120' crusher belt conv.	$10,337
22' by 7' SAG mill	$324,360
SAG mill motor	$10,465
6' x 16' lowhead screen	$3,141
Screen motor	$121
Baghouse, 20,000 cfm - collection system	$7,762
Baghouse, 20,000 cfm - ductwork	$0
SAG mill pumps, 2 @ 500 gpm ea.	$2,023
Pump motors	$573
Overhead crane, 5 ton	$2,000
Duplex jigs, 42" by 48", 2 req.	$4,216
Vertical sump/pump, 58 gpm	$1,056
Flotation blower, 4,000 cfm	$1,962
Sump/pump, 840 gpm	$808
Float cells, 4 @ 1350 cu.ft.	$8,290
Float cells, 3 @ 500 cu.ft.	$4,067
Float cells, 2 @ 300 cu.ft.	$1,984
Cell motors, 4 @ 60 hp	$1,855
Cell motors, 3 @ 40 hp	$742
Cell motors, 2 @ 30 hp	$429
Pump, 8" by 6"	$618
Pump, 6" by 4"	$235
Cyclones, 12", 2 required	$138
Regrind mill, 8' diameter	$122,400
Cleaner pumps, 6" by 4" 2 req.	$471
60' tailings thickener	$13,549
Tails pump, 2000 gpm	$908
70' concentrate thickener	$15,610
1-1/2" x 1-1/2", 20 gpm, 2	$110
120 by 144 surge tank	$384
Rotary disc filter, 400 sq.ft.	$17,786
Filtrate reciever pump	$3,119
Vacuum pump, 1,000 cfm	$256
Fluid bed roaster, 35 foot	$165,000
High temperature cyclones, 12", 2 req.	$160
Electrostatic precipitator, 10,000 cfm	$98,807
Aresenic trioxide baghouse	$2,482
Rotary feeders, 13	$4,248
Quench tanks, 2,000 gal, 3 req.	$1,004
Collection tank, 5,000 gal.	$1,201
Rotary disc filter, 400 sq.ft.	$17,786
Repulper	$468
Concrete foundations, subtotal	$935,376

PLANT CONCRETE FOUNDATIONS, cont'd	YUCCA7 Total cost
4 x 3" pump, 500 gpm, 2 req.	$235
Filtrate reciever pump	$3,119
Vacuum pump, 1,000 cfm	$256
Overhead crane, 5 ton	$2,000
Fuel oil storage tank, 22' by 24'	$4,164
Fuel oil transfer pump	$44
Carbon columns, 5 @ 4'6" x 14'	$2,758
Pregnant solution pump	$159
Carbon column advance pump	$144
Strip solution pumps, 3 req.	$55
Barren solution return pump	$510
NaOH supply, Acid wash pumps, 2 req.	$36
Acid wash circ. pump	$144
Regenerated carbon pump	$144
Column carbon supply pump	$144
Strip carbon transfer pump	$144
Strip solution transfer pump	$18
Process floor pump	$153
Carbon column feed tank	$89
Caron strip tanks, 2 req.	$1,070
Strip solution tank	$844
NaOH tank	$799
NaCN mix tank	$198
Acid wash tank	$1,445
Carbon holding tank	$585
Carbon quench tank	$207
Carbon atttrition tank	$270
Electrowinning cell	$1,778
Bridge crane, 7.5ton	$3,157
Strip solution agitator	$72
Carbon attrition agitator	$72
Mecury retort	$1,648
Carbon regeneration kiln	$12,522
Induction furnace	$6,434
Samplers, 4 req.	$68
Exhaust fans, 3 req.	$60
Carbon screen	$682
Strip solution heater	$567
Concrete foundations, subtotal	$46,795
Total concrete foundations	$982,171

PLANT PROCESS PIPING	YUCCA7 Total cost
Baghouse, 20,000 cfm - collection system	$3,528
22' by 7' SAG mill	$85,860
Baghouse, 20,000 cfm - collection system	$3,528
SAG mill pumps, 2 @ 500 gpm ea.	$14,158
Duplex jigs, 42" by 48", 2 req.	$19,675
Vertical sump/pump, 58 gpm	$7,391
Flotation blower, 4,000 cfm	$3,597
Sump/pump, 840 gpm	$5,656
Float cells, 4 @ 1350 cu.ft.	$16,579
Float cells, 3 @ 500 cu.ft.	$8,135
Float cells, 2 @ 300 cu.ft.	$3,967
Pump, 8" by 6"	$4,325
Pump, 6" by 4"	$1,648
Cyclones, 12", 2 required	$619
Regrind mill, 8' diameter	$32,400
Cleaner pumps, 6" by 4" 2 req.	$3,296
60' tailings thickener	$28,065
Tails pump, 2000 gpm	$6,359
70' concentrate thickener	$32,335
1-1/2" x 1-1/2", 20 gpm, 2	$771
120 by 144 surge tank	$2,050
Rotary disc filter, 400 sq.ft.	$80,723
Filtrate reciever pump	$21,833
Vacuum pump, 1,000 cfm	$1,792
Fluid bed roaster, 35 foot	$300,000
High temperature cyclones, 12", 2 req.	$722
Electrostatic precipitator, 10,000 cfm	$26,155
Aresenic trioxide baghouse	$1,015
Quench tanks, 2,000 gal, 3 req.	$5,353
Collection tank, 5,000 gal.	$6,404
Rotary disc filter, 400 sq.ft.	$80,723
Repulper	$1,054
4 x 3" pump, 500 gpm, 2 req.	$1,648
Filtrate reciever pump	$21,833
Vacuum pump, 1,000 cfm	$1,792
Fuel oil storage tank, 22' by 24'	$22,206
Fuel oil transfer pump	$310
Carbon columns, 5 @ 4'6" x 14'	$14,711
Pregnant solution pump	$1,110
Carbon column advance pump	$1,010
Strip solution pumps, 3 req.	$383
Barren solution return pump	$3,572
NaOH supply, Acid wash pumps, 2 req.	$255
Acid wash circ. pump	$1,010
Regenerated carbon pump	$1,010
Column carbon supply pump	$1,010
Strip carbon transfer pump	$1,010
Strip solution transfer pump	$128
Process floor pump	$1,074
Carbon column feed tank	$474
Process piping, subtotal	$884,261

PLANT PROCESS PIPING, cont'd	YUCCA7 Total cost
Caron strip tanks, 2 req.	$5,704
Strip solution tank	$4,504
NaOH tank	$4,263
NaCN mix tank	$1,056
Acid wash tank	$7,708
Carbon holding tank	$3,121
Carbon quench tank	$1,105
Carbon atttrition tank	$1,438
Electrowinning cell	$3,555
Carbon regeneration kiln	$13,914
Strip solution heater	$630
Process piping, subtotal	$46,997
Total process piping	$931,259

PLANT STEEL SUPPORTS	YUCCA7 Total cost
Feeder, 60" by 15 feet	$2,337
42" x 48" jaw crusher	$29,588
Baghouse, 20,000 cfm - collection system	$4,586
Overhead crane, 20 ton	$19,140
36" x 120' crusher belt conv.	$21,535
22' by 7' SAG mill	$143,100
6' x 16' lowhead screen	$3,490
Baghouse, 20,000 cfm - collection system	$4,586
Overhead crane, 5 ton	$5,800
Duplex jigs, 42" by 48", 2 req.	$10,540
Flotation blower, 4,000 cfm	$1,308
Cyclones, 12", 2 required	$1,514
Regrind mill, 8' diameter	$54,000
60' tailings thickener	$8,710
70' concentrate thickener	$10,035
120 by 144 surge tank	$299
Rotary disc filter, 400 sq.ft.	$20,523
Fluid bed roaster, 35 foot	$300,000
High temperature cyclones, 12", 2 req.	$1,765
Electrostatic precipitator, 10,000 cfm	$43,591
Aresenic trioxide baghouse	$1,467
Rotary feeders, 13	$21,242
Quench tanks, 2,000 gal, 3 req.	$781
Collection tank, 5,000 gal.	$934
Rotary disc filter, 400 sq.ft.	$20,523
Repulper	$468
Overhead crane, 5 ton	$5,800
Fuel oil storage tank, 22' by 24'	$3,238
Carbon columns, 5 @ 4'6" x 14'	$2,145
Carbon column feed tank	$69
Caron strip tanks, 2 req.	$832
Strip solution tank	$657
NaOH tank	$622
NaCN mix tank	$154
Acid wash tank	$1,124
Carbon holding tank	$455
Carbon quench tank	$161
Carbon atttrition tank	$210
Electrowinning cell	$1,185
Bridge crane, 7.5ton	$9,154
Mecury retort	$1,648
Carbon regeneration kiln	$13,914
Induction furnace	$7,149
Exhaust fans, 3 req.	$596
Carbon screen	$758
Strip solution heater	$630
Total steel supports	$782,361

PLANT INSTRUMENTATION	YUCCA7 Total cost
Feeder, 60" by 15 feet	$1,519
42" x 48" jaw crusher	$19,725
Jaw motor, 200 hp	$550
Baghouse, 20,000 cfm - collection system	$3,175
36" x 120' crusher belt conv.	$6,030
22' by 7' SAG mill	$95,400
SAG mill motor	$10,465
6' x 16' lowhead screen	$2,792
Screen motor	$121
Baghouse, 20,000 cfm - collection system	$3,175
SAG mill pumps, 2 @ 500 gpm ea.	$1,517
Pump motors	$573
Duplex jigs, 42" by 48", 2 req.	$1,405
Vertical sump/pump, 58 gpm	$792
Flotation blower, 4,000 cfm	$3,270
Sump/pump, 840 gpm	$606
Float cells, 4 @ 1350 cu.ft.	$2,763
Float cells, 3 @ 500 cu.ft.	$1,356
Float cells, 2 @ 300 cu.ft.	$661
Cell motors, 4 @ 60 hp	$1,855
Cell motors, 3 @ 40 hp	$742
Cell motors, 2 @ 30 hp	$429
Pump, 8" by 6"	$463
Pump, 6" by 4"	$177
Cyclones, 12", 2 required	$275
Regrind mill, 8' diameter	$36,000
Cleaner pumps, 6" by 4" 2 req.	$353
60' tailings thickener	$2,903
Tails pump, 2000 gpm	$681
70' concentrate thickener	$3,345
1-1/2" x 1-1/2", 20 gpm, 2	$83
120 by 144 surge tank	$342
Rotary disc filter, 400 sq.ft.	$6,841
Filtrate reciever pump	$2,339
Vacuum pump, 1,000 cfm	$192
Fluid bed roaster, 35 foot	$180,000
High temperature cyclones, 12", 2 req.	$321
Electrostatic precipitator, 10,000 cfm	$29,061
Aresenic trioxide baghouse	$1,015
Rotary feeders, 13	$13,807
Quench tanks, 2,000 gal, 3 req.	$892
Collection tank, 5,000 gal.	$1,067
Rotary disc filter, 400 sq.ft.	$6,841
Repulper	$351
Instrumentation, subtotal	$446,273

PLANT INSTRUMENTATION, cont'd	YUCCA7 Total cost
4 x 3" pump, 500 gpm, 2 req.	$177
Filtrate reciever pump	$2,339
Vacuum pump, 1,000 cfm	$192
Fuel oil storage tank, 22' by 24'	$4,164
Fuel oil transfer pump	$33
Carbon columns, 5 @ 4'6" x 14'	$2,758
Pregnant solution pump	$119
Carbon column advance pump	$108
Strip solution pumps, 3 req.	$41
Barren solution return pump	$383
NaOH supply, Acid wash pumps, 2 req.	$27
Acid wash circ. pump	$108
Regenerated carbon pump	$108
Column carbon supply pump	$108
Strip carbon transfer pump	$108
Strip solution transfer pump	$14
Process floor pump	$115
Carbon column feed tank	$79
Caron strip tanks, 2 req.	$951
Strip solution tank	$751
NaOH tank	$710
NaCN mix tank	$176
Acid wash tank	$1,285
Carbon holding tank	$520
Carbon quench tank	$184
Carbon atttrition tank	$240
Electrowinning cell	$593
Bridge crane, 7.5ton	$1,263
Strip solution agitator	$144
Carbon attrition agitator	$144
Mecury retort	$1,648
Carbon regeneration kiln	$8,348
Induction furnace	$4,289
Samplers, 4 req.	$68
Exhaust fans, 3 req.	$60
Carbon screen	$606
Strip solution heater	$378
Instrumentation, subtotal	$33,337
Total instrumentation	$479,610

PLANT INSULATION	YUCCA7 Total cost
Baghouse, 20,000 cfm - collection system	$3,528
Baghouse, 20,000 cfm - ductwork	$5,180
Baghouse, 20,000 cfm - collection system	$3,528
Baghouse, 20,000 cfm - ductwork	$5,180
Flotation blower, 4,000 cfm	$654
Cyclones, 12", 2 required	$688
120 by 144 surge tank	$214
High temperature cyclones, 12", 2 req.	$802
Electrostatic precipitator, 10,000 cfm	$29,061
Aresenic trioxide baghouse	$1,128
Quench tanks, 2,000 gal, 3 req.	$558
Collection tank, 5,000 gal.	$667
Fuel oil storage tank, 22' by 24'	$2,313
Carbon columns, 5 @ 4'6" x 14'	$1,532
Carbon column feed tank	$49
Caron strip tanks, 2 req.	$594
Strip solution tank	$469
NaOH tank	$444
NaCN mix tank	$110
Acid wash tank	$803
Carbon holding tank	$325
Carbon quench tank	$115
Carbon atttrition tank	$150
Total insulation	$58,093

PLANT ELECTRICAL	YUCCA7 Total cost
Feeder, 60" by 15 feet	$2,921
42" x 48" jaw crusher	$11,835
Jaw motor, 200 hp	$3,991
Baghouse, 20,000 cfm - collection system	$12,701
Overhead crane, 20 ton	$13,200
36" x 120' crusher belt conv.	$17,228
22' by 7' SAG mill	$57,240
SAG mill motor	$75,872
6' x 16' lowhead screen	$6,806
Screen motor	$874
Baghouse, 20,000 cfm - collection system	$12,701
SAG mill pumps, 2 @ 500 gpm ea.	$14,664
Pump motors	$4,157
Overhead crane, 5 ton	$4,000
Duplex jigs, 42" by 48", 2 req.	$4,216
Vertical sump/pump, 58 gpm	$7,655
Flotation blower, 4,000 cfm	$9,810
Sump/pump, 840 gpm	$5,858
Float cells, 4 @ 1350 cu.ft.	$8,290
Float cells, 3 @ 500 cu.ft.	$4,067
Float cells, 2 @ 300 cu.ft.	$1,984
Cell motors, 4 @ 60 hp	$13,450
Cell motors, 3 @ 40 hp	$5,379
Cell motors, 2 @ 30 hp	$3,113
Pump, 8" by 6"	$4,479
Pump, 6" by 4"	$1,707
Cyclones, 12", 2 required	$3,234
Regrind mill, 8' diameter	$21,600
Cleaner pumps, 6" by 4" 2 req.	$3,413
60' tailings thickener	$6,774
Tails pump, 2000 gpm	$6,586
70' concentrate thickener	$7,805
1-1/2" x 1-1/2", 20 gpm, 2	$799
120 by 144 surge tank	$171
Rotary disc filter, 400 sq.ft.	$13,682
Filtrate reciever pump	$22,613
Vacuum pump, 1,000 cfm	$1,856
Fluid bed roaster, 35 foot	$600,000
High temperature cyclones, 12", 2 req.	$3,770
Electrostatic precipitator, 10,000 cfm	$17,436
Aresenic trioxide baghouse	$4,062
Rotary feeders, 13	$26,553
Quench tanks, 2,000 gal, 3 req.	$446
Collection tank, 5,000 gal.	$534
Rotary disc filter, 400 sq.ft.	$13,682
Repulper	$3,396
Electrical, subtotal	$1,066,609

PLANT ELECTRICAL, cont'd	YUCCA7 Total cost
4 x 3" pump, 500 gpm, 2 req.	$1,707
Filtrate reciever pump	$22,613
Vacuum pump, 1,000 cfm	$1,856
Overhead crane, 5 ton	$4,000
Fuel oil storage tank, 22' by 24'	$1,850
Fuel oil transfer pump	$321
Carbon columns, 5 @ 4'6" x 14'	$1,226
Pregnant solution pump	$1,166
Carbon column advance pump	$1,060
Strip solution pumps, 3 req.	$402
Barren solution return pump	$3,751
NaOH supply, Acid wash pumps, 2 req.	$268
Acid wash circ. pump	$1,060
Regenerated carbon pump	$1,060
Column carbon supply pump	$1,060
Strip carbon transfer pump	$1,060
Strip solution transfer pump	$134
Process floor pump	$1,128
Carbon column feed tank	$40
Caron strip tanks, 2 req.	$475
Strip solution tank	$375
NaOH tank	$355
NaCN mix tank	$88
Acid wash tank	$642
Carbon holding tank	$260
Carbon quench tank	$92
Carbon atttrition tank	$120
Bridge crane, 7.5ton	$6,313
Strip solution agitator	$861
Carbon attrition agitator	$861
Mecury retort	$2,472
Carbon regeneration kiln	$27,827
Induction furnace	$14,297
Samplers, 4 req.	$494
Exhaust fans, 3 req.	$745
Carbon screen	$1,478
Strip solution heater	$1,259
Electrical, subtotal	$104,778
Total electrical	$1,171,387

PLANT CONSTRUCTION LABOR	YUCCA7 Total cost
Feeder, 60" by 15 feet	$5,713
42" x 48" jaw crusher	$78,111
Jaw motor, 200 hp	$7,555
Baghouse, 20,000 cfm - collection system	$34,539
Baghouse, 20,000 cfm - ductwork	$50,712
Overhead crane, 20 ton	$32,868
36" x 120' crusher belt conv.	$65,553
22' by 7' SAG mill	$377,784
SAG mill motor	$143,634
6' x 16' lowhead screen	$23,907
Screen motor	$1,655
Baghouse, 20,000 cfm - collection system	$34,539
Baghouse, 20,000 cfm - ductwork	$50,712
SAG mill pumps, 2 @ 500 gpm ea.	$27,761
Pump motors	$7,870
Overhead crane, 5 ton	$9,960
Duplex jigs, 42" by 48", 2 req.	$13,070
Vertical sump/pump, 58 gpm	$19,242
Flotation blower, 4,000 cfm	$11,314
Sump/pump, 840 gpm	$14,727
Float cells, 4 @ 1350 cu.ft.	$25,698
Float cells, 3 @ 500 cu.ft.	$12,609
Float cells, 2 @ 300 cu.ft.	$6,149
Cell motors, 4 @ 60 hp	$25,463
Cell motors, 3 @ 40 hp	$10,183
Cell motors, 2 @ 30 hp	$5,893
Pump, 8" by 6"	$8,479
Pump, 6" by 4"	$3,231
Cyclones, 12", 2 required	$3,729
Regrind mill, 8' diameter	$142,920
Cleaner pumps, 6" by 4" 2 req.	$6,462
60' tailings thickener	$156,390
Tails pump, 2000 gpm	$12,468
70' concentrate thickener	$180,184
1-1/2" x 1-1/2", 20 gpm, 2	$1,512
120 by 144 surge tank	$2,798
Rotary disc filter, 400 sq.ft.	$68,409
Filtrate reciever pump	$42,809
Vacuum pump, 1,000 cfm	$3,514
Fluid bed roaster, 35 foot	$2,778,000
High temperature cyclones, 12", 2 req.	$4,348
Electrostatic precipitator, 10,000 cfm	$115,081
Aresenic trioxide baghouse	$11,046
Rotary feeders, 13	$51,937
Quench tanks, 2,000 gal, 3 req.	$5,676
Collection tank, 5,000 gal.	$6,791
Rotary disc filter, 400 sq.ft.	$68,409
Repulper	$6,429
Construction labor, subtotal	$4,777,842

PLANT CONSTRUCTION LABOR, cont'd	YUCCA7 Total cost
4 x 3" pump, 500 gpm, 2 req.	$3,231
Filtrate reciever pump	$42,809
Vacuum pump, 1,000 cfm	$3,514
Overhead crane, 5 ton	$9,960
Fuel oil storage tank, 22' by 24'	$23,547
Fuel oil transfer pump	$608
Carbon columns, 5 @ 4'6" x 14'	$15,600
Pregnant solution pump	$2,177
Carbon column advance pump	$1,980
Strip solution pumps, 3 req.	$751
Barren solution return pump	$7,004
NaOH supply, Acid wash pumps, 2 req.	$501
Acid wash circ. pump	$1,980
Regenerated carbon pump	$1,980
Column carbon supply pump	$1,980
Strip carbon transfer pump	$1,980
Strip solution transfer pump	$250
Process floor pump	$2,107
Carbon column feed tank	$503
Caron strip tanks, 2 req.	$6,049
Strip solution tank	$4,776
NaOH tank	$4,520
NaCN mix tank	$1,120
Acid wash tank	$8,174
Carbon holding tank	$3,310
Carbon quench tank	$1,172
Carbon atttrition tank	$1,524
Electrowinning cell	$5,510
Bridge crane, 7.5ton	$15,719
Strip solution agitator	$1,145
Carbon attrition agitator	$1,145
Mecury retort	$38,144
Carbon regeneration kiln	$128,839
Induction furnace	$66,196
Samplers, 4 req.	$935
Exhaust fans, 3 req.	$1,457
Carbon screen	$5,193
Strip solution heater	$5,831
Construction labor, subtotal	$423,218
Total construction labor	$5,201,060

MILL STRUCTURES	Units	Cost/Unit	YUCCA7 Total cost
Structures			
Mill building, 46,200 sq.ft.	46200	$12.00	$554,400
Office, 18,900 sq.ft.	18900	$8.00	$151,200
Concrete foundations			
Mill building, 577 cubic yards	577	$310.00	$178,870
Office, 378 cubic yards	378	$310.00	$117,180
Steel items			
Floor gratings, 6,493sq.ft.	6493	$5.00	$32,465
Stairways, 10.7 tons	11	$2,500.00	$26,750
Handrails, 8.6 tons	9	$4,400.00	$37,840
Furnishings			
Administration			$60,000
Mine			$30,000
Labor			
Buildings, 65,100 sq.ft.	65100	$23.00	$1,497,300
Concrete, 955 cubic yards	955	$140.00	$133,700
Steel, gratings, 716 hours	716	$23.00	$16,468
Steel, stairways, 193 hours	193	$23.00	$4,439
Steel, handrails, 233 hours	233	$23.00	$5,359
Mill buildings summary			
Structures			$705,600
Concrete			$296,050
Steel			$97,055
Furnishings			$90,000
Construction labor			$1,657,266
Total, Mill buildings			$2,845,971

TAILINGS IMPOUNDMENT			YUCCA7
	Units	Cost/Unit	Total cost
Dike and dam construction, 692,000 cubic yards, $1.78/yard			
Labor	692000	$0.51	$352,920
Parts	692000	$0.41	$283,720
Fuel	692000	$0.61	$422,120
Lube	692000	$0.15	$103,800
GEC	692000	$0.10	$69,200
Reclaim ponds, 1000 square yards, $1.75/yard			
Labor	1000	$0.51	$510
Parts	1000	$0.41	$410
Fuel	1000	$0.61	$610
Lube	1000	$0.14	$140
GEC	1000	$0.08	$80
Fencing, 8,764 linear feet			
Fence, 6 foot, 3 strand barbed wire	8764	$5.20	$45,573
Fence, labor	8764	$2.36	$20,683
Slurry pipe, schedule 40, 4", 2,000 feet			
Pipe	2000	$46.40	$92,800
Labor	2000	$10.75	$21,500
Recliam pipe, Schedule 40, 1", 2,000 feet			
Pipe	2000	$8.21	$16,420
Labor	2000	$4.35	$8,700
Liners, hypalon, 2.4 million sq.ft.			
Liner	2400000	$0.57	$1,368,000
Labor	2400000	$0.21	$504,000
Tailing impoundment summary			
Labor			$908,313
Parts			$284,130
Fuel			$422,730
Lube			$103,940
GEC			$69,280
Steel pipe			$109,220
Plastic liners			$1,368,000
Metal fences			$45,573
Total, tailings impoundment			$3,311,186

YUCCA7

YUCCA MOUNTAIN CARBONATE-HOSTED GOLD, MILL CAPITAL COST SUMMARY

Process facilities	
Mill equipment	$9,320,221
Concrete foundations	$982,171
Process piping	$931,259
Structural steel	$782,361
Instrumentations	$479,610
Insulation	$58,093
Electrical system	$1,171,387
Construction labor	$5,201,060
Mill buildings	$2,845,971
Tailings impoundment	$3,311,186
Engineering and design fees	$6,521,663
Permitting	$3,160,498
Reclamation bonds	$252,000
Working Capital	$1,751,963
Total plant capital	$36,769,442

YUCCA MOUNTAIN CARBONATE-HOSTED GOLD, MILL OPERATING COSTS

	No.	$/hr-$/ann.	YUCCA8 $/day
Supervision/Administration			
Mill op. super.	1	$54,900.00	$152.50
Mill maint. super.	1	$54,900.00	$152.50
Oper. formen	3	$23.07	$553.68
Maint. formen	3	$23.07	$553.68
Engineer	2	$17.38	$278.08
Metallurgist	2	$21.01	$336.16
Purchasing	1	$11.74	$93.92
Accountant	1	$11.74	$93.92
Clerk	1	$10.45	$83.60
Secretarial	2	$10.45	$167.20
Security	3	$13.05	$313.20
Direct mill labor			
Crushing operators	2	$16.94	$271.04
Crushing helpers	1	$14.62	$116.96
Grinding operators	3	$16.94	$406.56
Jigging	3	$16.94	$406.56
Flotation operators	3	$16.94	$406.56
Roasting operators	3	$16.94	$406.56
CIL operators	3	$16.94	$406.56
Control room operators	4	$16.94	$542.08
Electricians	2	$19.27	$308.32
Assay lab	3	$12.24	$293.76
Maintenence	9	$15.51	$1,116.72
Support	4	$12.24	$391.68
Total Labor	60		$7,851.80

Item	SUPPLIES		YUCCA8 $/day
Electric Power	4515	33681.9	$1,969.38
Fuel oil			
Roasting, US gallons	3845	0.578	$2,222.41
Flotation, US gallons	444	0.578	$256.63
Steel items			
Ball consumption	1200	0.578	$693.60
Liner consumption	528	0.75	$396.00
Reagents			
Sodium cyanide, lbs/day	820	$0.98	$803.60
Sodium hydroxide, lbs/day	164	$1.15	$188.60
Hydrochloric acid, lbs/day	151	$0.10	$15.10
Liquid flocculant, lbs/day	117	$2.10	$245.70
Copper sulfate, lbs/day	292	$1.50	$438.00
Xanthate, lbs/day	584	$0.83	$484.72
Depramin, lbs/day	584	$0.83	$484.72
Aerofloat 208, lbs/day	175	$1.15	$201.25
Hydrogen peroxide, lbs/day	202	$0.25	$50.50
Lime, lbs/day	7917	$0.10	$791.70
Coconut carbon, lbs/day	29	$1.10	$31.90
Repair Parts			
Crushing and grinding equip			$786.39
Flotation equipment			$551.43
Roasting equipment			$1,495.47
CIL equipment			$262.31
Miscellaneous equipment			$334.65
Lubricants			$171.51
Total supplies			$12,875.58
Total operating cost per day			$20,727.38
Total operating cost per ton			$6.91
Total operating cost per troy ounce			$94.12

YUCCA MOUNTAIN CARBONATE-HOSTED GOLD, MILL OPERATING COST SUMMA

Item	$/day
Mill Labor	$7,851.80
Electric Power	$1,969.38
Steel items	$1,089.60
Fuel oil	$2,479.04
Reagents	$3,735.79
Repair parts	$3,430.25
Lubricants	$171.51
Sales and use tax	$740.35
Total operating cost per day	$21,467.72
Total operating cost per ton	$7.16
Total operating cost per troy ounce	$97.48

(All Values in Thousands)

Title : YUCCA MOUNTAIN, CARBONATE HOSTED GOLD
Run Date : 2/8/1990
Evaluation Date : 07/89
Project Start : 01/89
Evaluator : WETZEL

Period Ending	12/89	12/90	12/91	12/92	12/93	12/94	12/95	12/96	12/97	12/98	12/99
Revenue		31,446	31,446	31,446	31,446	31,446	31,446	31,446	31,446	31,446	31,446
-Oper Costs		-17,334	-17,334	-17,334	-17,334	-17,334	-17,334	-17,334	-17,334	-17,334	-17,334
-Sever, Ad-Val		-344	-344	-344	-344	-344	-344	-344	-344	-344	-344
-Development	-8,891										
-Depreciation	-4,022	-7,024	-5,262	-3,980	-3,388	-3,291	-3,291	-867	-867	-867	-867
-Writeoffs											
Before Depltn	-12,913	6,744	8,506	9,788	10,380	10,477	10,477	12,901	12,901	12,901	12,901
-50% Limit		-3,372	-4,253	4,894	5,190	5,238	5,238	6,451	6,451	6,451	6,451
-Percent Depl		4,717	4,717	-4,717	-4,717	-4,717	-4,717	-4,717	-4,717	-4,717	-4,717
-Cost Depltn											
-Loss Forward		-12,913	-9,541	-5,288	-216						
Taxable	-12,913	-9,541	-5,288	-216	5,447	5,760	5,760	8,184	8,184	8,184	8,184
-Tax @ 44%					-2,384	-2,521	-2,521	-3,582	-3,582	-3,582	-3,582
Net Income	-12,913	-9,541	-5,288	-216	3,063	3,239	3,239	4,602	4,602	4,602	4,602
+Depreciation	4,022	7,024	5,262	3,980	3,388	3,291	3,291	867	867	867	867
+Depletion		3,372	4,253	4,717	4,717	4,717	4,717	4,717	4,717	4,717	4,717
+Loss Forward		12,913	9,541	5,288	216						
+Writeoffs											
-Capitl Costs	-51,795	-4,153									
Cash Flow	-60,686	9,615	13,768	13,768	11,384	11,247	11,247	10,186	10,186	10,186	10,186

(All Values in Thousands)
Title : YUCCA MOUNTAIN, CARBONATE HOSTED GOLD
Run Date : 2/8/1990
Evaluation Date : 07/89
Project Start : 01/89
Evaluator : WETZEL

Period Ending	12/00	Salv.
Revenue	31,446	4,153
-Oper Costs	-17,334	
-Sever, Ad-Val	-344	
-Development		
-Depreciation	-867	-2,600
-Writeoffs		-4,153
Before Depltn	12,901	-2,600
-50% Limit	6,451	
-Percent Depl	-4,717	
-Cost Depltn		
-Loss Forward		
Taxable	8,184	-2,600
-Tax @ 44%	-3,582	1,138
Net Income	4,602	-1,462
+Depreciation	867	2,600
+Depletion	4,717	
+Loss Forward		
+Writeoffs		4,153
-Capitl Costs		
Cash Flow	10,186	5,291

(All Values in Thousands)
Title : YUCCA MOUNTAIN, CARBONATE HOSTED GOLD
Run Date : 2/8/1990
Evaluation Date : 07/89
Project Start : 01/89
Evaluator : WETZEL

Revenue Breakeven Analysis

Iter	Revenue %	NPV	Iter	Revenue %	NPV
1	100.00000	-0.10			

Minimum Rate Of Return : 15.00

Revenue at 100.0000% NPV = -0.10

Break Even $/unit at Project Start = 395.61

APPENDIX E. COSTING BACKUP DATA, HOT-SPRINGS GOLD ECONOMIC/EXTRACTION MODEL

YUCCA MOUNTAIN HOT SPRINGS GOLD MINE, CAPITAL COST ESTIMATES

INFRASTRUCTURE YUCCA9

Item	Units	Cost/unit	Total Cost
Access Roads, upgrade, 78,600 ft, gravel last 3 miles			
Rough grade, 873,330 square yards, $0.56/sy			
Labor	873330	$0.16	$139,733
Parts	873330	$0.13	$113,533
Fuel	873330	$0.19	$165,933
Lube	873330	$0.05	$43,667
GEC	873330	$0.03	$26,200
Scarify, Grade, Compact, 873,330 square yards, $0.70/sy			
Labor	873330	$0.20	$174,666
Parts	873330	$0.16	$141,916
Fuel	873330	$0.24	$207,416
Lube	873330	$0.06	$54,583
GEC	873330	$0.04	$32,750
Gravel surface, 6" x 3", 26,250 cubic yards, $8.10/cy			
Labor	26250	$0.43	$11,288
Parts	26250	$0.19	$4,988
Fuel	26250	$0.27	$7,088
Lube	26250	$0.07	$1,838
Gravel	26250	$7.14	$187,425
Access road upgrade summary			
Labor			$325,686
Parts			$260,437
Fuel			$380,436
Lube			$100,087
Gravel			$187,425
Steel			$58,950
Total Access road upgrade			$1,313,021

Item	Units	Cost/unit	Total Cost
Power line, 33 kv, 12 miles			
Poles, 312 @ 30' high			
Poles	312	$500.00	$156,000
Labor	312	$285.00	$88,920
Fuel	312	$40.00	$12,480
Lube	312	$10.00	$3,120
Transmission line, 70,404 linear feet			
Power line	70404	$35.97	$2,532,432
Labor	70404	$10.56	$743,466
Power line summary			
Labor			$832,386
Transmission line			$2,532,432
Lumber			$156,000
Fuel			$12,480
Lube			$3,120
Total Power line			$3,536,418

Item	Units	Cost/unit	Total Cost
Water well, 2 @ 300' deep, 12" diameter			
Labor, drilling, 12 hours	12	$52.83	$634
Labor, maintenance	12	$66.97	$804
Parts	12	$62.84	$754
Fuel	12	$22.33	$268
Lube	12	$8.78	$105
GEC	12	$3.85	$46
Cement, 3 yards	3	$310.00	$930
Casing, 12", 600 feet	300	$20.31	$6,093
Gravel, 209 cu.yds	104	$7.14	$743
Pump, 750 gpm, 295 hp	1	$75,000	$75,000
Pump motor, 295 hp	1	$52,271	$52,271
Pipeline, 5,000', 4" schedule 40	5000	$4.09	$20,450
Water tank, 500,000 gallon	1	$282,192	$282,192
Water tank/pipline installation	1992	$24.00	$47,808
Water system summary			
Labor			$49,246
Parts			$754
Fuel			$268
Lube			$105
Steel, mobile equipment			$46
Cement			$930
Construction gravel			$743
Steel pipe			$26,543
Process equipment, tanks, pumps, motors			$409,463
Total, water system, two complete			$976,196

Item	Units	Cost/unit	Total Cost
Diamond drilling, 260 holes (100 foot centers) 3,000′ deep			
Labor, 50′/shift			
Drillers, 2 - 12.5′/hr=6,000 hr/man	83200	$17.17	$1,428,544
Maintenance labor	41600	$4.16	$173,056
Geologist	41600	$18.08	$752,128
Helper	41600	$12.41	$516,256
Repair parts, drill, mud, water serv.	41600	$3.52	$146,432
Fuel, drill, mud, water service	41600	$4.10	$170,560
Lube, drill, mud, water service	41600	$0.85	$35,360
GEC, drill	41600	$0.33	$13,728
Drill bits, NW, soft rock - 2/hole	520.00	$362.00	$188,240
Drill rods, NW, 1/hole	260.00	$148.00	$38,480
Drill mud, 4.4 pct total	7524642	$0.04	$331,084
Cement, 60 lb sacks, 1/shift	5200	$4.22	$21,944
Exploration drilling summary			
Labor			$2,869,984
Parts			$146,432
Fuel			$170,560
Lube			$35,360
Steel, mobile equipment			$13,728
Steel, bits and rods			$226,720
Drill mud			$331,084
Cement			$21,944
Sales and use tax			$54,385
Total exploration drilling cost			$3,870,197

Item	Units	Cost/unit	Total Cost
Contracted exploration expenses			
Assaying, 5720 samples			
Sample preparation	5720	$3.04	$17,389
Assays	5720	$16.90	$96,668
Petrographic work	1300	$35.00	$45,500
Contracted exploration expenses			$159,557

Conveyor haulage decline, 14′ x 12′ x 2,500′

Item	Units	Cost/unit	Total Cost
Labor, hours			
Miners	6000	$17.03	$102,180
Laborors	5500	$10.48	$57,640
Supervision	588	$19.65	$11,554
Maintenance	1412	$17.23	$24,329
Repair parts			
2-1/2 inch jumbos	160	$38.29	$6,126
Scoop tram	297	$18.85	$5,598
Front end loader	363	$11.40	$4,138
Compressor	500	$2.44	$1,220
Ventilation fan	2000	$1.27	$2,540
Electricity			
Compressor	500	$8.70	$4,350
Ventilation fan	2000	$2.74	$5,480
Fuel			
2-1/2 inch jumbos	160	$11.59	$1,854
Front end loader	363	$8.51	$3,089
Scoop tram	297	$6.35	$1,886
1.5 inch roof bolter	165	$4.77	$787
Tires			
2-1/2 inch jumbos	160	$1.47	$235
Front end loader	363	$3.38	$1,227
Scoop tram	297	$7.94	$2,358
Lubricants			
2-1/2 inch jumbos	160	$2.99	$478
1.5 inch roof bolter	165	$1.42	$234
Scoop tram	297	$2.14	$636
Front end loader	363	$2.31	$839
Compressor	500	$0.22	$110
Ventilation fan	2000	$0.08	$160
Drill bits, 363.3 feet/bit	253	$58.70	$14,822
Drill rods, 720.9 feet/rod	128	$170.00	$21,675
Explosives, 2.4 lbs/ton	77537	$0.25	$19,384
Blasting caps	8000	$1.61	$12,880
Air pipe, sch 40, 8" w/couplings	2500	$18.78	$46,950
Mine water pipe, sch 40, 6" w/couplings	2500	$11.92	$29,800
Potable water pipe, sch 40, 2" w/coup.	2500	$2.39	$5,975
Pipe hangers (chain)	2500	$4.11	$10,275
Vent tubing, spiral wound, 20"	2500	$9.96	$24,900
Rock bolts, 10 bolt pattern, 4′ centers	6250	$6.07	$37,938
Rock bolt mat, 11", 14 gauge	6750	$3.83	$25,853
Bolter bits, 346.8 feet/bit	118	$16.05	$1,886
Bolter rods, 688.2 feet/rod	60	$75.60	$4,536

Conveyor haulage decline cost summary	
Labor	$195,703
Repair parts	$19,623
Electricity	$9,830
Fuel	$7,617
Lubricants	$2,457
Tires	$3,820
Steel, bits and rods	$42,919
Steel, pipe and chain	$93,000
Steel, bolts and mats	$63,790
Explosives	$32,264
Vent tubing	$24,900
Sales and use tax	$17,263
Total conveyor haulage decline capital	$513,185

Main access decline, 15' x 18' x 2,500'

Item	Units	Cost/unit	Total Cost
Labor, hours			
Miners	7200	$17.03	$122,616
Laborors	6600	$10.48	$69,168
Supervision	706	$19.65	$13,873
Maintenance	1694	$17.23	$29,188
Repair parts			
2-1/2 inch jumbos	228	$38.29	$8,730
Scoop tram	613	$18.85	$11,555
Front end loader	108	$11.40	$1,231
Compressor	500	$2.44	$1,220
Ventilation fan	2000	$1.27	$2,540
Electricity			
Compressor	500	$8.70	$4,350
Ventilation fan	2000	$2.74	$5,480
Fuel			
2-1/2 inch jumbos	228	$11.59	$2,643
Front end loader	108	$8.51	$919
Scoop tram	613	$6.35	$3,893
1.5 inch roof bolter	213	$4.77	$1,016
Tires			
2-1/2 inch jumbos	228	$1.47	$335
Front end loader	108	$3.38	$365
Scoop tram	613	$7.94	$4,867
Lubricants			
2-1/2 inch jumbos	228	$2.99	$682
1.5 inch roof bolter	213	$1.42	$302
Scoop tram	613	$2.14	$1,312
Front end loader	108	$2.31	$249
Compressor	500	$0.22	$110
Ventilation fan	2000	$0.08	$160
Drill bits, 363.3 feet/bit	172	$58.70	$10,096
Drill rods, 720.9 feet/rod	87	$170.00	$14,790
Explosives, 1.8 lbs/ton	97200	$0.25	$24,300
Blasting caps	3840	$1.61	$6,182
Air pipe, sch 40, 8" w/couplings	2500	$18.78	$46,950
Mine water pipe, sch 40, 6" w/couplings	2500	$11.92	$29,800
Potable water pipe, sch 40, 2" w/coup.	2500	$2.39	$5,975
Pipe hangers (chain)	2500	$4.11	$10,275
Vent tubing, spiral wound, 20"	2500	$9.96	$24,900
Rock bolts, 10 bolt pattern, 4' centers	8036	$6.07	$48,779
Rock bolt mat, 11", 14 gauge	8679	$3.83	$33,241
Bolter bits, 346.8 feet/bit	152	$16.05	$2,440
Bolter rods, 688.2 feet/rod	77	$75.60	$5,821

Main access decline cost summary	
Labor	$234,845
Repair parts	$25,276
Electricity	$9,830
Fuel	$8,470
Lubricants	$2,815
Tires	$5,567
Steel, bits and rods	$33,147
Steel, pipe and chain	$93,000
Steel, bolts and mats	$82,019
Explosives	$30,482
Vent tubing	$24,900
Sales and use tax	$18,142
Total main access decline capital	$568,494

Vertical shaft, 22' by 12' by 3,000

Item	Units	Cost/unit	Total Cost
Labor			
Miners	75338	$17.23	$1,298,074
Laborors	50143	$10.48	$525,499
Supervision	2833	$19.65	$55,668
Hoistmen, waste haulage	27346	$14.61	$399,525
Repair parts			
Sinker	16606	$0.17	$2,823
Cryderman	4070	$8.46	$34,432
Hoist	16714	$6.30	$105,298
33 ton diesel	846	$11.37	$9,619
Ventilation fan	22286	$1.27	$28,303
Electricity			
Hoist	16714	$5.78	$96,607
Ventilation fan	22286	$2.74	$61,064
Fuel			
33 ton diesel	846	$8.81	$7,453
Lubricants			
Sinker	16606	$0.01	$166
Cryderman	4070	$1.10	$4,477
Hoist	16714	$0.82	$13,705
33 ton diesel	846	$2.36	$1,997
Ventilation fan	22286	$0.08	$1,783
Tires			
33 ton diesel	846	$4.78	$4,044
Timber	1904286	$0.48	$914,057
Drill bits, 363.3 feet/bit; 67.6 ft/foot	1200	$58.70	$70,440
Drill rods, 720.9 feet/rod; 67.6 ft/foot	598	$170.00	$101,660
Explosives, 1.4 lbs/ton	115500	$1.18	$136,290
Blasting caps	58896	$1.64	$96,589
Air pipe, sch 40, 8" w/couplings	4000	$18.78	$75,120
Mine water pipe, sch 40, 6" w/couplings	4000	$11.92	$47,680
Potable water pipe, sch 40, 2" w/coup.	4000	$2.39	$9,560
Pipe hangers (chain)	4000	$4.11	$16,440
Vent tubing, spiral wound, 20"	4000	$9.96	$39,840

Vertical shaft cost summary	
Labor	$3,966,107
Repair parts	$180,476
Electricity	$157,671
Fuel	$7,453
Lubricants	$22,128
Tires	$4,044
Timber	$914,057
Steel, bits and rods	$172,100
Steel, pipe and chain	$148,800
Explosives	$232,879
Vent tubing	$39,840
Sales and use tax	$108,068
Total vertical shaft capital	$5,953,624

Main haulage drift, 20' by 20' by 1,800'

Item	Units	Cost/unit	Total Cost
Labor			
Miners	5760	$17.23	$99,245
Laborors	3834	$10.48	$40,180
Supervision	217	$19.65	$4,264
Hoistmen, waste haulage	396	$14.61	$5,786
Repair parts			
2-1/2 inch jumbos	490	$38.29	$18,762
Front end loader	232	$11.40	$2,645
33 ton diesel	751	$11.37	$8,539
Rock bolter	341	$4.77	$1,627
Hoist	230	$6.30	$1,449
Compressor	360	$2.44	$878
Ventilation fan	1440	$1.27	$1,829
Electricity			
Hoist	230	$5.78	$1,329
Compressor	360	$8.70	$3,132
Ventilation fan	1440	$2.74	$3,946
Fuel			
2-1/2 inch jumbos	490	$11.59	$5,679
33 ton diesel	751	$8.81	$6,616
Front end loader	232	$8.51	$1,974
Rock bolter	341	$4.77	$1,627
Lubricants			
2-1/2 inch jumbos	490	$2.99	$1,465
Rock bolter	341	$1.42	$484
Front end loader	232	$2.31	$536
33 ton diesel	751	$2.36	$1,772
Hoist	230	$0.82	$189
Compressor	360	$0.22	$79
Ventilation fan	3468	$0.08	$277
Tires			
2-1/2 inch jumbos	490	$1.47	$720
Front end loader	232	$3.38	$784
33 ton diesel	751	$4.78	$3,590
Drill bits, 363.3 feet/bit	398	$58.70	$23,363
Drill rods, 720.9 feet/rod	200	$170.00	$34,000
Rock bolts, 10 bolt pattern, 4 ft center	2009	$6.07	$12,195
Rock bolt mat, 11", 14 gauge	1105	$3.83	$4,232
Rock bolt bits	109	$16.05	$1,749
Rock bolt rods	34	$75.60	$2,570
Explosives, 2.4 lbs/ton	207788	$0.25	$51,947
Blasting caps	6335	$1.64	$10,389
Air pipe, sch 40, 8" w/couplings	1800	$18.78	$33,804
Mine water pipe, sch 40, 6" w/couplings	1800	$11.92	$21,456
Potable water pipe, sch 40, 2" w/coup.	1800	$2.39	$4,302
Pipe hangers (chain)	1800	$4.11	$7,398
Vent tubing, spiral wound, 20"	1800	$9.96	$17,928

MINE DEVELOPMENT, cont'd	YUCCA9
Main haulage drift	
Labor	$149,475
Repair parts	$35,729
Electricity	$8,407
Fuel	$15,896
Lubricants	$4,803
Tires	$5,094
Steel, bits, rods, bolts, mats	$78,109
Steel, pipe and chain	$66,960
Explosives	$62,336
Vent tubing	$17,928
Sales and use tax	$16,978
Total main haulage drift capital	$461,715

Coarse ore storage, 20,000 ton storage

Item	Units	Cost/unit	Total Cost
Labor			
Miners	3825	$17.23	$65,905
Laborors	1275	$10.48	$13,362
Supervision	125	$19.65	$2,456
Repair parts			
Stopers	1275	$12.66	$16,142
Front end loader	31	$11.40	$353
33 ton diesel	68	$11.37	$773
Compressor	360	$2.44	$878
Ventilation fan	1020	$1.27	$1,295
Electricity			
Compressor	360	$8.70	$3,132
Ventilation fan	1020	$2.74	$2,795
Fuel			
Stopers	1275	$4.88	$6,222
33 ton diesel	68	$8.81	$599
Front end loader	31	$8.51	$264
Lubricants			
Stopers	1275	$1.96	$2,499
Front end loader	31	$2.31	$72
33 ton diesel	68	$2.36	$160
Compressor	360	$0.22	$79
Ventilation fan	1020	$0.08	$82
Tires			
Front end loader	232	$3.38	$784
33 ton diesel	751	$4.78	$3,590
Drill bits, 363.3 feet/bit	120	$58.70	$7,044
Drill rods, 720.9 feet/rod	12	$170.00	$2,040
Explosives, 2.4 lbs/ton	207788	$0.25	$51,947
Blasting caps	6335	$1.64	$10,389
Timber, drill platforms	38250	$0.48	$18,360
Coarse ore storage			
Labor			$81,723
Repair parts			$19,442
Electricity			$5,927
Fuel			$7,085
Lubricants			$2,892
Tires			$4,374
Steel, bits, rods			$9,084
Explosives			$62,336
Timber			$18,360
Sales and use tax			$7,446
Total coarse ore storage capital			$218,669

MINE EQUIPMENT YUCCA9

Item	No.	Cost/unit	Total cost
Mine Equipment			
Front end loaders, 5.2 cu.yard	6	$238,370	$1,430,220
Front end loaders, 7.0 cu.yard	2	$350,700	$701,400
Scoop tram, 8.0 cu.yard	1	$299,510	$299,510
Articulated haul trucks, 33 ton	8	$228,678	$1,829,424
Jumbos, 2.5 inch	4	$642,430	$2,569,720
Bench drills, 3.0 inch	4	$82,000	$328,000
Roof bolters, 1.5 inch	2	$225,000	$450,000
Kerf cutting machines	2	$750,660	$1,501,320
Service truck, 5 ton, 82 hp diesel	6	$56,160	$336,960
Lube truck	1	$75,000	$75,000
Scissor lift truck, 8,000 lb cap.	1	$63,440	$63,440
ANFO loader truck	2	$71,760	$143,520
Personnel carrier, 12 person	5	$61,360	$306,800
Water truck, 475 hp	1	$405,960	$405,960
Grader, 150 hp	2	$133,190	$266,380
Dozer, 200 hp	4	$172,500	$690,000
Dozer, 460 hp	2	$368,800	$737,600
Pickups, 1 ton	20	$32,640	$652,800
Ventilation fans, 800 hp	3	$235,152	$705,456
Mine hoist, 200 inch, 2500 hp drive	1	$1,850,000	$1,850,000
Utility hoist, 60 inch, 250 hp drive	1	$425,000	$425,000
Hoist cable, 2"	8000	$15	$121,280
Misc. mine equipment			$794,490
Mine Equipment Total			$16,684,280
Sales and use tax @ 5.75%			$959,346
Freight @ 7.46%			$1,244,647
Total Mine equipment			$18,888,273

FACILITIES

Concrete	Units	Cost/Unit	Total cost
Shop, 441 cubic yards	400	$310	$124,000
Warehouse, 267 cubic yards	267	$310	$82,667
Dry, 154 cubic yards	140	$310	$43,400
Services, 153 cubic yards	153	$140	$21,467
Structures			
Shop, 12,000 sq.ft.	12000	$8	$96,000
Warehouse, 8,000 sq.ft.	8000	$12	$96,000
Dry, 4,200 sq.ft.	4200	$12	$50,400
Services, 4,600 sq.ft.	4600	$18	$82,800
Construction labor			
Concrete, $140/cubic yard	960	$140	$134,400
Structures, $23/sq.ft.	28800	$23	$662,400
Mine facilities total			$1,454,336

YUCCA MOUNTAIN HOT SPRINGS GOLD MINE, CAPITAL COST SUMMARY

Infrastructure	
Mine road upgrade	$1,313,021
Powerline	$3,536,418
Water system	$976,196
Exploration	
Drilling program	$4,029,754
Development	
Conveyor haulage decline	$513,185
Main access decline	$568,494
Vertical shaft	$5,953,624
Main haulage drift	$461,715
Coarse ore storage	$218,669
Undgerground mine equipment	$18,888,273
Mine facilities, surface and underground	$1,454,336
Engineering and design fees	$7,582,737
Working capital	$5,720,029
Total mine capital	$51,216,451

YUCCA MOUNTAIN HOT SPRINGS GOLD MINE, OPERATING COST ESTIMATES

LABOR YUCCA10

	No.	Cost/year	Cost/day
Adminsitration-salaried			
Operations manager	1	$65,900	$183.06
Mine superintendent	1	$56,751	$157.64
Maintenance superintendent	1	$56,751	$157.64
Development foreman	1	$54,900	$152.50
Maintenance foreman	1	$54,900	$152.50
Mine engineer	1	$44,716	$124.21
Mine geologists	1	$40,651	$112.92
Underground engineers	2	$40,651	$225.84
Underground geologists	2	$36,956	$205.31
Drafting	1	$27,456	$76.27
Accounting	6	$29,040	$484.00
Supplies	8	$29,040	$645.33
Secretarial	6	$19,800	$330.00
Safety officer	1	$36,818	$102.27
Ventilation engineer	1	$36,818	$102.27
Subtotal, Administrative labor	34		$3,211.76

Mine labor	No.	Cost/hour	Cost/day
Mine formen	3	$19.65	$471.60
Maintenance foremen	1	$19.65	$157.20
Miners	55	$17.23	$7,581.20
Scalers	8	$17.21	$1,101.44
LHD operators	22	$17.21	$3,028.96
Truck drivers	20	$17.21	$2,753.60
Blasters	20	$17.45	$2,792.00
Hoistmen/Cage tenders	6	$14.51	$696.48
Utility men	8	$16.76	$1,072.64
Helpers	15	$16.55	$1,986.00
Electricians	5	$17.69	$707.60
Lubrications	10	$17.45	$1,396.00
Welders	12	$17.45	$1,675.20
Machinists	5	$17.69	$707.60
Repairmen	8	$16.98	$1,086.72
Surface men	5	$16.13	$645.20
Subtotal, direct labor	163		$28,772.25
Total labor cost per day	197		$31,984.01
Total cost per ton ore	10000		$3.20

SUPPLIES YUCCA10

	Units	Cost/unit	Cost/day
Drill bits, 2.5"	13.4	$182.00	$2,438.80
Drill bits, 3.0"	10.5	$266.00	$2,793.00
Drill rods	2.11	$126.00	$265.86
Explosives	16200	$0.61	$9,882.00
Boosters	503.00	$0.37	$186.11
Saftey fuse	20856	$0.10	$2,085.60
Timber, board feet	50	$0.34	$17.00
Pipe, 2", linear feet	32	$1.28	$40.96
Pipe, 1", linear feet	32	$1.00	$32.00
Vent tubing, 20" diameter, linear feet	32	$2.66	$85.12
Rock bolts	94	$6.81	$640.14
Propane	360	$0.67	$241.20
Front end loaders, 5.2 cy.yd	13.06		
Lube	13.06	$2.31	$30.17
Fuel	13.06	$8.51	$111.14
Parts	13.06	$11.40	$148.88
Tires	13.06	$3.38	$44.14
Front end loaders, 7 cy.yd	9.08		
Lube	9.08	$3.35	$30.42
Fuel	9.08	$11.81	$107.23
Parts	9.08	$15.55	$141.19
Tires	9.08	$8.59	$78.00
Scoop trams, 8 cy.yd	7.40		
Lube	7.40	$2.14	$15.84
Fuel	7.40	$6.35	$46.99
Parts	7.40	$18.85	$139.49
Tires	7.40	$7.94	$58.76
Diesel truck haulage	45.45		
Lube	45.45	$2.36	$107.26
Fuel	45.45	$8.81	$400.41
Parts	45.45	$11.37	$516.77
Tires	45.45	$4.78	$217.25
Jumbos, 2.5 inch	17.84		
Lube	17.84	$2.99	$53.34
Fuel	17.84	$11.59	$206.77
Parts	17.84	$38.29	$683.09
Tires	17.84	$1.47	$26.22
Bench drills, 3.0 inch	57.71		
Lube	57.71	$1.96	$113.11
Fuel	57.71	$4.88	$281.62
Parts	57.71	$12.66	$730.61
Tires	57.71	$0.00	$0.00
Powder buggies	0.72		
Lube	0.72	$0.45	$0.32
Fuel	0.72	$3.84	$2.76
Parts	0.72	$0.47	$0.34
Tires	0.72	$0.11	$0.08

	Units	Cost/unit	Cost/day
Roof bolters	18.80		
Lube	18.80	$1.42	$26.70
Fuel	18.80	$4.77	$89.68
Parts	18.80	$6.42	$120.70
Tires	18.80	$0.00	$0.00
Scissor lift	5.33		
Lube	5.33	$0.37	$1.97
Fuel	5.33	$0.95	$5.06
Parts	5.33	$2.17	$11.57
Tires	5.33	$0.28	$1.49
Personnel carrier	2.33		
Lube	2.33	$0.45	$1.05
Fuel	2.33	$3.84	$8.95
Parts	2.33	$0.47	$1.10
Tires	2.33	$0.11	$0.26
Supply carrier	9.60		
Lube	9.60	$0.45	$4.32
Fuel	9.60	$3.84	$36.86
Parts	9.60	$0.47	$4.51
Tires	9.60	$0.11	$1.06
Dozer, 200 hp	50.00		
Lube	50.00	$1.88	$94.00
Fuel	50.00	$7.10	$355.00
Parts	50.00	$10.42	$521.00
Tires	50.00	$0.00	$0.00
Dozer, 460 hp	22.52		
Lube	22.52	$4.08	$91.88
Fuel	22.52	$16.33	$367.75
Parts	22.52	$20.31	$457.38
Tires	22.52	$0.00	$0.00
Pickups, 1.0 ton	40.00		
Lube	40.00	$0.48	$19.20
Fuel	40.00	$3.94	$157.60
Parts	40.00	$0.62	$24.80
Tires	40.00	$0.09	$3.60
Water truck, 475 hp	8.00		
Lube	8.00	$3.18	$25.44
Fuel	8.00	$9.00	$72.00
Parts	8.00	$12.67	$101.36
Tires	8.00	$7.18	$57.44
Graders, 150 hp	10.60		
Lube	10.60	$1.28	$13.57
Fuel	10.60	$4.89	$51.83
Parts	10.60	$6.58	$69.75
Tires	10.60	$0.63	$6.68

SUPPLIES, Cont'd YUCCA10

	Units	Cost/unit	Cost/day
Hoist	22.00		
Electricity	22.00	$108.17	$2,379.74
Lube	22.00	$12.29	$270.38
Parts	22.00	$13.08	$287.76
Ventilation	48.00		
Electricity	48.00	$15.28	$733.44
Lube	48.00	$1.68	$80.64
Parts	48.00	$3.05	$146.40
Compressor	48.00		
Electricity	48.00	$8.70	$417.60
Lube	48.00	$0.22	$10.56
Parts	48.00	$2.44	$117.12

Supply Summary		Cost/day
Repair Parts		$3,829.81
Electric Power		$3,530.78
Fuel		$2,301.67
Propane		$241.20
Lube		$990.17
Tires		$494.97
Steel, Bits/Rods/Bolts		$6,137.80
Steel, Pipe		$72.96
Vent tubing		$85.12
Timber		$17.00
Explosives		$12,153.71
Sales and use tax		$1,716.67
Total supply cost		$31,571.87
Total cost per ton ore	10000	$3.16

YUCCA MOUNTAIN HOT SPRINGS GOLD MINE, OPERATING COST SUMMARY

YUCCA10

Item		Cost/day
Administrative labor		$3,211.76
Mine labor		$28,772.25
Steel, bits/rods/bolts		$6,137.80
Explosives, caps/boosters		$12,153.71
Pipe, hangers/valves		$72.96
Vent tubing		$85.12
Timber		$17.00
Fuel		$2,301.67
Electricity		$3,530.78
Propane		$241.20
Lube		$990.17
Parts		$3,829.81
Tires		$494.97
Sales and use tax		$1,716.67
Total mine operating cost		$63,555.88
Mine operating cost per ton	10000	$6.36
Mine operating cost per troy ounce	334	$190.29

YUCCA MOUNTAIN HOT SPRINGS GOLD MINE, MILL CAPITAL COST SUMMARY

PROCESS EQUIPMENT	HP	YUCCA11 Total cost
Crushing equipment		
Grizzly, 5 foot by 20 foot		$57,206
Grizzley motor, 40 hp	40	$1,892
Conveyor, 42" by 50 feet	20	$76,600
Jaw crusher, 48" by 60"		$304,500
Crusher motor, 300 hp	300	$10,129
Conveyor, 60" by 50 feet	25	$118,700
Vibrating feeders, 2 req.	10	$11,248
Conveyor, 48" by 3,000 feet	150	$1,051,500
Surge bin, 150 ton		$13,598
Vibrating feeder, 60" by 168"	10	$11,161
Double deck screen, 6' by 16'	20	$35,000
Cone crusher, 7 foot		$425,000
Crusher motor, 350 hp	350	$12,528
Conveyor, 42" by 50'	20	$76,600
Conveyor, 42" by 100'	30	$97,473
Surge bin, 150 ton		$13,598
Belt feeders, 42" by 6', 2 req.	15	$13,754
Single deck screens, 8'by20', 2 req.		$104,000
Screen motors, 40 hp, 2	80	$1,550
Cone crushers, 7 foot, 2 req.		$950,000
Crusher motors, 350 hp each	700	$25,056
Fine ore bin, 250 ton		$16,308
Mobile equipment		
Haul trucks, 85 ton, 5 req.		$3,306,500
Dozers, 375 hp flywheels, 3 req.		$1,218,300
Graders, 275 hp flywheels, 3 req.		$937,200
Pickups, 1 ton, 5 req.		$163,200
Process recovery plant equipment		
Carbon columns, 5 @ 4'6" x 14'		$30,648
Pregnant solution pump	40	$3,965
Carbon column advance pump	5	$3,606
Strip solution pumps, 3 req.	3	$1,368
Barren solution return pump	60	$12,757
NaOH supply, Acid wash pumps, 2 req.	2	$912
Acid wash circ. pump	5	$3,606
Regenerated carbon pump	5	$3,606
Column carbon supply pump	5	$3,606
Strip carbon transfer pump	5	$3,606
Strip solution transfer pump	1	$456
Process floor pump	5	$3,837
Carbon column feed tank		$988
Caron strip tanks, 2 req.		$11,884
Strip solution tank		$9,383
NaOH tank		$8,881
Plant equipment subtotal	1906	$9,155,710

PLANT EQUIPMENT, cont'd		YUCCA11 Total Cost
NaCN mix tank		$2,200
Acid wash tank		$16,059
Carbon holding tank		$6,502
Carbon quench tank		$2,302
Carbon atttrition tank		$2,995
Electrowinning cell		$29,626
Bridge crane, 7.5ton	7	$31,565
Strip solution agitator	4	$3,588
Carbon attrition agitator	4	$3,588
Mecury retort	30	$41,192
Carbon regeneration kiln	10	$139,135
Induction furnace	167	$71,486
Samplers, 4 req.	4	$1,704
Exhaust fans, 3 req.	3	$2,979
Carbon screen		$7,581
Strip solution heater		$6,297
Plant equipment subtotal	229	$368,799

Subtotal, plant equipment	2135	$9,524,509
Miscellaneous plant equipment		
Analytical lab equipment		$88,578
Assay lab equipment		$59,052
Maintenance tools and equipment		$66,672
Sample preparation equipment		$53,337
Total plant equipment		$9,792,148
Sales and use tax @ 5.75%		$563,048
Freight @ 7.46%		$730,494
Total delivered equipment cost		$11,085,690

CONCRETE FOUNDATIONS	YUCCA11 Total cost
Crushing equipment	
Grizzly, 5 foot by 20 foot	$5,149
Grizzley motor, 40 hp	$76
Conveyor, 42" by 50 feet	$9,192
Jaw crusher, 48" by 60"	$103,530
Crusher motor, 300 hp	$405
Conveyor, 60" by 50 feet	$14,244
Vibrating feeders, 2 req.	$450
Conveyor, 48" by 3,000 feet	$126,180
Surge bin, 150 ton	$748
Vibrating feeder, 60" by 168"	$446
Double deck screen, 6' by 16'	$3,150
Cone crusher, 7 foot	$144,500
Crusher motor, 350 hp	$501
Conveyor, 42" by 50'	$9,192
Conveyor, 42" by 100'	$11,697
Surge bin, 150 ton	$748
Belt feeders, 42" by 6', 2 req.	$550
Single deck screens, 8'by20', 2 req.	$9,360
Screen motors, 40 hp, 2	$62
Cone crushers, 7 foot, 2 req.	$323,000
Crusher motors, 350 hp each	$1,002
Fine ore bin, 250 ton	$897
Process recovery plant equipment	
Carbon columns, 5 @ 4'6" x 14'	$2,758
Pregnant solution pump	$159
Carbon column advance pump	$144
Strip solution pumps, 3 req.	$55
Barren solution return pump	$510
NaOH supply, Acid wash pumps, 2 req.	$36
Acid wash circ. pump	$144
Regenerated carbon pump	$144
Column carbon supply pump	$144
Strip carbon transfer pump	$144
Strip solution transfer pump	$18
Process floor pump	$153
Carbon column feed tank	$89
Caron strip tanks, 2 req.	$1,070
Strip solution tank	$844
NaOH tank	$799
NaCN mix tank	$198
Acid wash tank	$1,445
Carbon holding tank	$585
Carbon quench tank	$207
Carbon atttrition tank	$270
Electrowinning cell	$1,778
Bridge crane, 7.5ton	$3,157
Strip solution agitator	$72
Carbon attrition agitator	$72
Concrete foundations, subtotal	$780,075

CONCRETE FOUNDATIONS, cont'd	YUCCA11 Total cost
Mecury retort	$1,648
Carbon regeneration kiln	$12,522
Induction furnace	$6,434
Samplers, 4 req.	$68
Exhaust fans, 3 req.	$60
Carbon screen	$682
Strip solution heater	$567
Concrete foundations, subtotal	$21,980
Total concrete foundations	$802,055

PLANT PROCESS PIPING	YUCCA11 Total cost
Process recovery plant equipment	
Carbon columns, 5 @ 4'6" x 14'	$14,711
Pregnant solution pump	$1,110
Carbon column advance pump	$1,010
Strip solution pumps, 3 req.	$383
Barren solution return pump	$3,572
NaOH supply, Acid wash pumps, 2 req.	$255
Acid wash circ. pump	$1,010
Regenerated carbon pump	$1,010
Column carbon supply pump	$1,010
Strip carbon transfer pump	$1,010
Strip solution transfer pump	$128
Process floor pump	$1,074
Carbon column feed tank	$474
Caron strip tanks, 2 req.	$5,704
Strip solution tank	$4,504
NaOH tank	$4,263
NaCN mix tank	$1,056
Acid wash tank	$7,708
Carbon holding tank	$3,121
Carbon quench tank	$1,105
Carbon atttrition tank	$1,438
Electrowinning cell	$3,555
Carbon regeneration kiln	$13,914
Strip solution heater	$630
Total process piping	$73,753

PLANT STEEL SUPPORTS	YUCCA11 Total cost
Crushing equipment	
Grizzly, 5 foot by 20 foot	$5,721
Conveyor, 42" by 50 feet	$19,150
Jaw crusher, 48" by 60"	$45,675
Crusher motor, 300 hp	$1,013
Conveyor, 60" by 50 feet	$29,675
Vibrating feeders, 2 req.	$2,250
Conveyor, 48" by 3,000 feet	$262,875
Surge bin, 150 ton	$2,040
Vibrating feeder, 60" by 168"	$2,232
Double deck screen, 6' by 16'	$3,500
Cone crusher, 7 foot	$63,750
Conveyor, 42" by 50'	$19,150
Conveyor, 42" by 100'	$24,368
Surge bin, 150 ton	$2,040
Belt feeders, 42" by 6', 2 req.	$2,751
Single deck screens, 8'by20', 2 req.	$10,400
Cone crushers, 7 foot, 2 req.	$142,500
Fine ore bin, 250 ton	$2,446
Process recovery plant equipment	
Carbon columns, 5 @ 4'6" x 14'	$2,145
Carbon column feed tank	$69
Caron strip tanks, 2 req.	$832
Strip solution tank	$657
NaOH tank	$622
NaCN mix tank	$154
Acid wash tank	$1,124
Carbon holding tank	$455
Carbon quench tank	$161
Carbon atttrition tank	$210
Electrowinning cell	$1,185
Bridge crane, 7.5ton	$9,154
Mecury retort	$1,648
Carbon regeneration kiln	$13,914
Induction furnace	$7,149
Exhaust fans, 3 req.	$596
Carbon screen	$758
Strip solution heater	$630
Total steel supports	$682,996

PLANT INSTRUMENTATION	YUCCA11 Total cost
Crushing equipment	
Grizzly, 5 foot by 20 foot	$7,437
Grizzley motor, 40 hp	$57
Conveyor, 42" by 50 feet	$5,362
Jaw crusher, 48" by 60"	$30,450
Crusher motor, 300 hp	$304
Conveyor, 60" by 50 feet	$8,309
Vibrating feeders, 2 req.	$1,462
Conveyor, 48" by 3,000 feet	$73,605
Surge bin, 150 ton	$680
Vibrating feeder, 60" by 168"	$1,451
Double deck screen, 6' by 16'	$2,800
Cone crusher, 7 foot	$42,500
Crusher motor, 350 hp	$376
Conveyor, 42" by 50'	$5,362
Conveyor, 42" by 100'	$6,823
Surge bin, 150 ton	$680
Belt feeders, 42" by 6', 2 req.	$1,788
Single deck screens, 8'by20', 2 req.	$8,320
Screen motors, 40 hp, 2	$47
Cone crushers, 7 foot, 2 req.	$95,000
Crusher motors, 350 hp each	$752
Fine ore bin, 250 ton	$815
Process recovery plant equipment	
Carbon columns, 5 @ 4'6" x 14'	$2,758
Pregnant solution pump	$119
Carbon column advance pump	$108
Strip solution pumps, 3 req.	$41
Barren solution return pump	$383
NaOH supply, Acid wash pumps, 2 req.	$27
Acid wash circ. pump	$108
Regenerated carbon pump	$108
Column carbon supply pump	$108
Strip carbon transfer pump	$108
Strip solution transfer pump	$14
Process floor pump	$115
Carbon column feed tank	$79
Caron strip tanks, 2 req.	$951
Strip solution tank	$751
NaOH tank	$710
NaCN mix tank	$176
Acid wash tank	$1,285
Carbon holding tank	$520
Carbon quench tank	$184
Carbon atttrition tank	$240
Electrowinning cell	$593
Bridge crane, 7.5ton	$1,263
Strip solution agitator	$144
Instrumentation, subtotal	$305,271

PLANT INSTRUMENTATION, CONT'D	YUCCA11 Total cost
Carbon attrition agitator	$144
Mecury retort	$1,648
Carbon regeneration kiln	$8,348
Induction furnace	$4,289
Samplers, 4 req.	$68
Exhaust fans, 3 req.	$60
Carbon screen	$606
Strip solution heater	$378
Instrumentation, subtotal	$15,541
Total instrumentation	$320,812

PLANT INSULATION	YUCCA11 Total cost
Crushing equipment	
Surge bin, 150 ton	$680
Surge bin, 150 ton	$680
Fine ore bin, 250 ton	$815
Process recovery plant equipment	
Carbon columns, 5 @ 4'6" x 14'	$1,532
Carbon column feed tank	$49
Caron strip tanks, 2 req.	$594
Strip solution tank	$469
NaOH tank	$444
NaCN mix tank	$110
Acid wash tank	$803
Carbon holding tank	$325
Carbon quench tank	$115
Carbon atttrition tank	$150
Total insulation	$6,767

PLANT ELECTRICAL	YUCCA11 Total cost
Crushing equipment	
Grizzly, 5 foot by 20 foot	$11,155
Grizzley motor, 40 hp	$549
Conveyor, 42" by 50 feet	$15,320
Jaw crusher, 48" by 60"	$18,270
Crusher motor, 300 hp	$2,937
Conveyor, 60" by 50 feet	$23,740
Vibrating feeders, 2 req.	$2,812
Conveyor, 48" by 3,000 feet	$210,300
Surge bin, 150 ton	$272
Vibrating feeder, 60" by 168"	$2,790
Double deck screen, 6' by 16'	$6,825
Cone crusher, 7 foot	$25,500
Crusher motor, 350 hp	$3,633
Conveyor, 42" by 50'	$15,320
Conveyor, 42" by 100'	$19,495
Surge bin, 150 ton	$272
Belt feeders, 42" by 6', 2 req.	$3,439
Single deck screens, 8'by20', 2 req.	$20,280
Screen motors, 40 hp, 2	$449
Cone crushers, 7 foot, 2 req.	$57,000
Crusher motors, 350 hp each	$7,266
Fine ore bin, 250 ton	$326
Process recovery plant equipment	
Carbon columns, 5 @ 4'6" x 14'	$1,226
Pregnant solution pump	$1,166
Carbon column advance pump	$1,060
Strip solution pumps, 3 req.	$402
Barren solution return pump	$3,751
NaOH supply, Acid wash pumps, 2 req.	$268
Acid wash circ. pump	$1,060
Regenerated carbon pump	$1,060
Column carbon supply pump	$1,060
Strip carbon transfer pump	$1,060
Strip solution transfer pump	$134
Process floor pump	$1,128
Carbon column feed tank	$40
Caron strip tanks, 2 req.	$475
Strip solution tank	$375
NaOH tank	$355
NaCN mix tank	$88
Acid wash tank	$642
Carbon holding tank	$260
Carbon quench tank	$92
Carbon atttrition tank	$120
Bridge crane, 7.5ton	$6,313
Strip solution agitator	$861
Carbon attrition agitator	$861
Electrical, subtotal	$471,809

PLANT ELECTRICAL, CONT'D	YUCCA11 Total cost
Mecury retort	$2,472
Carbon regeneration kiln	$27,827
Induction furnace	$14,297
Samplers, 4 req.	$494
Exhaust fans, 3 req.	$745
Carbon screen	$1,478
Strip solution heater	$1,259
Electrical, subtotal	$48,572
Total electrical	$520,381

PLANT CONSTRUCTION LABOR	YUCCA11 Total cost
Crushing equipment	
Grizzly, 5 foot by 20 foot	$39,186
Grizzley motor, 40 hp	$1,039
Conveyor, 42" by 50 feet	$58,293
Jaw crusher, 48" by 60"	$120,582
Crusher motor, 300 hp	$5,561
Conveyor, 60" by 50 feet	$90,331
Vibrating feeders, 2 req.	$5,500
Conveyor, 48" by 3,000 feet	$800,192
Surge bin, 150 ton	$8,947
Vibrating feeder, 60" by 168"	$5,458
Double deck screen, 6' by 16'	$23,975
Cone crusher, 7 foot	$168,300
Crusher motor, 350 hp	$6,878
Conveyor, 42" by 50'	$58,293
Conveyor, 42" by 100'	$74,177
Surge bin, 150 ton	$8,947
Belt feeders, 42" by 6', 2 req.	$6,726
Single deck screens, 8'by20', 2 req.	$71,240
Screen motors, 40 hp, 2	$851
Cone crushers, 7 foot, 2 req.	$376,200
Crusher motors, 350 hp each	$13,756
Fine ore bin, 250 ton	$10,731
Process recovery plant equipment	
Carbon columns, 5 @ 4'6" x 14'	$15,600
Pregnant solution pump	$2,177
Carbon column advance pump	$1,980
Strip solution pumps, 3 req.	$751
Barren solution return pump	$7,004
NaOH supply, Acid wash pumps, 2 req.	$501
Acid wash circ. pump	$1,980
Regenerated carbon pump	$1,980
Column carbon supply pump	$1,980
Strip carbon transfer pump	$1,980
Strip solution transfer pump	$250
Process floor pump	$2,107
Carbon column feed tank	$503
Caron strip tanks, 2 req.	$6,049
Strip solution tank	$4,776
NaOH tank	$4,520
NaCN mix tank	$1,120
Acid wash tank	$8,174
Carbon holding tank	$3,310
Carbon quench tank	$1,172
Carbon atttrition tank	$1,524
Electrowinning cell	$5,510
Bridge crane, 7.5ton	$15,719
Construction labor, subtotal	$4,915,143

PLANT CONSTRUCTION LABOR, CONT'D	YUCCA11 Total cost
Strip solution agitator	$1,145
Carbon attrition agitator	$1,145
Mecury retort	$38,144
Carbon regeneration kiln	$128,839
Induction furnace	$66,196
Samplers, 4 req.	$935
Exhaust fans, 3 req.	$1,457
Carbon screen	$5,193
Strip solution heater	$5,831
Construction labor, subtotal	$248,884
Total construction labor	$5,164,028

MILL STRUCTURES			YUCCA11
	Units	Cost/Unit	Total cost
Structures			
Mill building, 46,200 sq.ft.	46200	$12.00	$554,400
Office, 18,900 sq.ft.	18900	$8.00	$151,200
Concrete foundations			
Mill building, 577 cubic yards	577	$310.00	$178,870
Office, 378 cubic yards	378	$310.00	$117,180
Steel items			
Floor gratings, 6,493sq.ft.	6493	$5.00	$32,465
Stairways, 10.7 tons	11	$2,500.00	$26,750
Handrails, 8.6 tons	9	$4,400.00	$37,840
Furnishings			
Administration			$60,000
Mine			$30,000
Labor			
Buildings, 65,100 sq.ft.	65100	$23.00	$1,497,300
Concrete, 955 cubic yards	955	$140.00	$133,700
Steel, gratings, 716 hours	716	$23.00	$16,468
Steel, stairways, 193 hours	193	$23.00	$4,439
Steel, handrails, 233 hours	233	$23.00	$5,359
Mill buildings summary			
Structures			$705,600
Concrete			$296,050
Steel			$97,055
Furnishings			$90,000
Construction labor			$1,657,266
Total, Mill buildings			$2,845,971

LEACH PAD DEVELOPMENT			YUCCA11
	Units	Cost/Unit	Total cost
Pads/ponds, strip/store topsoil, 640,000 cubic yards			
Labor	640000	$0.51	$326,400
Parts	640000	$0.41	$262,400
Fuel	640000	$0.61	$390,400
Lube	640000	$0.15	$96,000
GEC	640000	$0.10	$64,000
Pads/ponds, scarify, grade, compact, 242,000 square yards			
Labor	242000	$0.20	$48,400
Parts	242000	$0.16	$38,720
Fuel	242000	$0.24	$58,080
Lube	242000	$0.06	$14,520
GEC	242000	$0.04	$9,680
Ponds, excavation, 340,000 cubic yards			
Labor	340000	$0.51	$173,400
Parts	340000	$0.41	$139,400
Fuel	340000	$0.61	$207,400
Lube	340000	$0.15	$51,000
GEC	340000	$0.10	$34,000
Ponds, rough grade/fine grade, compact, 167,000 square yards			
Labor	167000	$0.34	$56,780
Parts	167000	$0.27	$45,090
Fuel	167000	$0.40	$66,800
Lube	167000	$0.09	$15,030
GEC	167000	$0.05	$8,350
Ponds, gravel blanket, 6" thick, 27,800 cubic yards			
Labor	27800	$0.32	$8,896
Parts	27800	$0.14	$3,892
Fuel	27800	$0.20	$5,560
Lube	27800	$0.05	$1,390
Gravel	27800	$5.35	$148,730
Fencing, 5,903 linear feet			
Fence, 6 foot, 3 strand barbed wire	5903	$5.20	$30,696
Fence, labor	5903	$2.36	$13,931
Leach system piping, drip hose, 1" stock			
Pipe, 600,000 linear feet	600000	$1.07	$642,000
Labor, 1,600 feet per hour	375	$18.00	$6,750
Leach system piping, mainline, 6" stock			
Pipe, 6,000 linear feet	6000	$7.55	$45,300
Labor, 25 linear feet per hour	240	$18.00	$4,320
Plastic liners, pads and ponds			
Liner, pvc, 40 mil, 2,180,000 sq. ft.	2180000	$0.33	$719,400
Liner, hypalon, 60 mil, 2,180,000 sq.f	2180000	$0.64	$1,395,200
Labor, at $.21 per square foot	4360000	$0.21	$915,600

LEACH PAD DEVELOPMENT YUCCA11

	Units	Cost/Unit	Total cost
Pad/Pond development summary			
Labor			$1,554,477
Parts			$489,502
Fuel			$728,240
Lube			$177,940
GEC			$116,030
Plastic pipe			$687,300
Plastic liners			$2,114,600
Metal fences			$30,696
Gravel			$148,730
Total, pad/pond development capital			$6,047,515

YUCCA11

YUCCA MOUNTAIN HOT SPRINGS GOLD MINE, PLANT CAPITAL COST SUMMARY

Process facilities	
Mill equipment	$11,085,690
Concrete foundations	$802,055
Process piping	$73,753
Structural steel	$682,996
Instrumentations	$320,812
Insulation	$6,767
Electrical system	$520,381
Construction labor	$5,164,028
Mill buildings	$2,845,971
Pad and Pond development	$6,047,515
Engineering and design fees	$7,162,992
Permitting	$3,471,296
Reclamation bonds	$252,000
Working Capital	$4,898,673
Total plant capital	$43,334,930

YUCCA MOUNTAIN HOT SPRINGS GOLD MINE, PLANT OPERATING COSTS

	No.	$/hr-$/ann.	YUCCA8 $/day
Supervision/Administration			
Mill op. super.	1	$54,900.00	$152.50
Mill maint. super.	1	$54,900.00	$152.50
Oper. formen	3	$23.07	$553.68
Maint. formen	3	$23.07	$553.68
Engineer	2	$17.38	$278.08
Metallurgist	2	$21.01	$336.16
Purchasing	3	$11.74	$281.76
Accountant	3	$11.74	$281.76
Clerk	3	$10.45	$250.80
Secretarial	4	$10.45	$334.40
Security	4	$13.05	$417.60
Direct mill labor			
Crushing/conveying operators	18	$16.94	$2,439.36
Crushing/conveying helpers	9	$14.62	$1,052.64
Haul truck drivers	12	$16.94	$1,626.24
Loader operators	3	$17.39	$417.36
Dozer operators	3	$17.39	$417.36
Heap leach system operators	3	$18.32	$439.68
Heap leach system helpers	3	$14.62	$350.88
Recovery plant operators	3	$18.32	$439.68
Recovery plant helpers	3	$14.62	$350.88
Mechanics	6	$17.86	$857.28
Electricians	6	$23.07	$1,107.36
Utility men	3	$15.56	$373.44
Helpers	3	$14.62	$350.88
Assayers	3	$15.56	$373.44
Total Labor	107		$13,465.08
Labor cost per ton ore	10000		$1.35
Labor cost per ounce gold	334		$40.31

Item	SUPPLIES		YUCCA12 $/day
Electric power	2135	15927.1	$931.26
Plant equipment			
Repair parts (10% annually)	4166948	416694.8	$1,157.49
Lubrication (.0000063 x cap./hr)			$630.04
Mobile equipment	hrs/day	Cost/hour	
Repair parts			
Haul trucks	93.3	$4.38	$408.65
Dozers	23.3	$7.38	$171.95
Loaders	23.3	$18.51	$431.28
Pickups	24.0	$0.23	$5.52
Fuel			
Haul trucks	93.3	$12.94	$1,207.30
Dozers	23.3	$8.06	$187.80
Loaders	23.3	$13.86	$322.94
Pickups	24.0	$2.67	$64.08
Lubrication			
Haul trucks	93.3	$3.74	$348.94
Dozers	23.3	$2.06	$48.00
Loaders	23.3	$4.70	$109.51
Pickups	24.0	$0.32	$7.68
Tires			
Haul trucks	93.3	$10.64	$992.71
Dozers	23.3	$0.00	$0.00
Loaders	23.3	$19.74	$459.94
Pickups	24.0	$0.11	$2.64
GEC			
Haul trucks	93.3	$0.00	$0.00
Dozers	23.3	$1.39	$32.39
Loaders	23.3	$0.00	$0.00
Pickups	24.0	$0.00	$0.00
Reagents			
Sodium cyanide, lbs/day	5694	$0.98	$5,580.12
Sodium hydroxide, lbs/day	112	$1.15	$128.80
Caustic Soda, lbs/day	26194	$0.18	$4,714.92
Nitric acid, lbs/day	3300	$0.25	$825.00
Sodium hypochlorite	1139	$1.15	$1,309.85
Calcium hypochlorite	569	$1.25	$711.25
Coconut carbon, lbs/day	60	$1.25	$75.00
Propane, gallons	3000	$0.77	$2,310.00
Plastic liners			
Pvc, 40 mil	12110	$0.33	$3,996.30
Hypalon, 60 mil	12110	$0.64	$7,750.40
Plastic pipe			
Drip pipe	3333	$1.07	$3,566.31
Mainline pipe	33	$7.55	$249.15
Supplies, subtotal			$38,737.23
Sales and use tax			$2,227.39
Total supply cost			$40,964.62
Total supply cost/ton	10000		$4.10
Total supply cost/ounce	334		$122.65

YUCCA MOUNTAIN HOT SPRINGS GOLD MINE, PLANT OPERATING COST SUMMARY

Item		$/day
Mill Labor		$13,465.08
Electric Power		$931.26
Propane		$2,310.00
Fuel		$1,782.12
Reagents		$13,344.94
Repair parts		$2,174.90
Lubricants		$1,144.17
Steel items		$32.39
Tires		$1,455.29
Plastic pipe		$3,815.46
Plastic liners		$11,746.70
Sales and use tax		$2,227.39
Total operating cost per day		$54,429.70
Total operating cost per ton	10000	$5.44
Total operating cost per ounce	334	$162.96

(All Values in Thousands)

Title : YUCCA MOUNTAIN, HOT SPRINGS GOLD
Run Date : 2/8/1990
Evaluation Date : 07/89
Project Start : 01/89
Evaluator : WETZEL

Period Ending	12/89	12/90	12/91	12/92	12/93	12/94	12/95	12/96	12/97	12/98	12/99
Revenue		59,659	59,659	59,659	59,659	59,659	59,659	59,659	59,659	59,659	59,659
-Oper Costs		-42,480	-42,480	-42,480	-42,480	-42,480	-42,480	-42,480	-42,480	-42,480	-42,480
-Sever, Ad-Val		-653	-653	-653	-653	-653	-653	-653	-653	-653	-653
-Development	-17,794										
-Depreciation	-4,876	-8,468	-6,258	-4,659	-3,943	-3,861	-3,861	-740	-740	-740	-740
-Writeoffs											
Before Depltn	-22,670	8,058	10,268	11,868	12,583	12,665	12,665	15,786	15,786	15,786	15,786
-50% Limit		-4,029	-5,134	-5,934	-6,292	-6,333	-6,333	-7,893	-7,893	-7,893	-7,893
-Percent Depl		8,949	8,949	8,949	8,949	8,949	8,949	8,949	8,949	8,949	8,949
-Cost Depltn											
-Loss Forward		-22,670	-18,641	-13,507	-7,573	-1,281					
Taxable	-22,670	-18,641	-13,507	-7,573	-1,281	5,051	6,333	7,893	7,893	7,893	7,893
-Tax @ 44%						-2,211	-2,772	-3,455	-3,455	-3,455	-3,455
Net Income	-22,670	-18,641	-13,507	-7,573	-1,281	2,840	3,561	4,438	4,438	4,438	4,438
+Depreciation	4,876	8,468	6,258	4,659	3,943	3,861	3,861	740	740	740	740
+Depletion		4,029	5,134	5,934	6,292	6,333	6,333	7,893	7,893	7,893	7,893
+Loss Forward		22,670	18,641	13,507	7,573	1,281					
+Writeoffs											
-Capitl Costs	-66,139	-10,619									
Cash Flow	-83,933	5,908	16,526	16,526	16,526	14,315	13,754	13,071	13,071	13,071	13,071

(All Values in Thousands)
Title : YUCCA MOUNTAIN, HOT SPRINGS GOLD
Run Date : 2/8/1990
Evaluation Date : 07/89
Project Start : 01/89
Evaluator : WETZEL

Period Ending	12/00	12/01	12/02	12/03	12/04	12/05	12/06	12/07	12/08	12/09	Salv.
Revenue	59,659	59,659	59,659	59,659	59,659	59,659	59,659	59,659	59,659	59,659	10,619
-Oper Costs	-42,480	-42,480	-42,480	-42,480	-42,480	-42,480	-42,480	-42,480	-42,480	-42,480	
-Sever, Ad-Val	-653	-653	-653	-653	-653	-653	-653	-653	-653	-653	
-Development											
-Depreciation	-740	-740	-740	-740							
-Writeoffs											-10,619
Before Depltn	15,786	15,786	15,786	15,786	16,526	16,526	16,526	16,526	16,526	16,526	
-50% Limit	-7,893	-7,893	-7,893	-7,893	-8,263	-8,263	-8,263	-8,263	-8,263	-8,263	
-Percent Depl	8,949	8,949	8,949	8,949	8,949	8,949	8,949	8,949	8,949	8,949	
-Cost Depltn											
-Loss Forward											
Taxable	7,893	7,893	7,893	7,893	8,263	8,263	8,263	8,263	8,263	8,263	
-Tax @ 44%	-3,455	-3,455	-3,455	-3,455	-3,617	-3,617	-3,617	-3,617	-3,617	-3,617	
Net Income	4,438	4,438	4,438	4,438	4,646	4,646	4,646	4,646	4,646	4,646	
+Depreciation	740	740	740	740							
+Depletion	7,893	7,893	7,893	7,893	8,263	8,263	8,263	8,263	8,263	8,263	
+Loss Forward											
+Writeoffs											10,619
-Capitl Costs											
Cash Flow	13,071	13,071	13,071	13,071	12,909	12,909	12,909	12,909	12,909	12,909	10,619

(All Values in Thousands)
Title : YUCCA MOUNTAIN, HOT SPRINGS GOLD
Run Date : 2/8/1990
Evaluation Date : 07/89
Project Start : 01/89
Evaluator : WETZEL

Revenue Breakeven Analysis

Iter	Revenue %	NPV	Iter	Revenue %	NPV
1	100.00000	-9.96			

Minimum Rate Of Return : 15.00

Revenue at 100.0000% NPV = -9.96

Break Even $/unit at Project Start = 470.13