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Alternative Methods for Disposal of Low-Level Radioactive Wastes

Task 2d: Technical Requirements for Mined Cavity Disposal of Low-Level Waste

Prepared by C. C. McAneny

Geotechnical Laboratory
U.S. Army Engineer Wateıways Experiment Station

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ABSTRACT

Current practice in the US for disposal of commercial low-level radioactive waste (LLW) is shallow land burial (SLB). However, several alternative disposal methods utilizing engineered facilities are possible and may be considered for licensing in coming years. One such method is disposal in mined cavities. Any disposal method, current or alternative, must satisfy Performance Objectives for land disposal of LLW as set forth in Part C of 10 CFR 61.

Underground excavations comprise mines and tunnels. Mines excavated by the open-stoping or room-and-pillar method are the best adapted for storage or disposal purposes.

There are many important differences between the underground environment of a mined cavity and the environment of SLB or other near-surface alternatives. Thus, technical criteria for evaluating mined-cavity disposal facilities may be expected to differ markedly from those appropriate for near-surface facilities. For instance, criteria dealing with strictly surface geological processes are not applicable to mined cavities. The details of important matters such as protection from ground-water intrusion of the wastes must be addressed in fundamentally different ways. About half of the existing 10 CFR 61 technical criteria, however, are still directly or generally applicable to mined-cavity disposal.

Existing criteria are considered one by one in this report, and a recommendation is offered in each case as to acceptance, modification, substitution, or deletion of a criterion for the purpose of application to mined-cavity disposal. Matters that need to be considered in the formulation of supplemental criteria are discussed. Certain matters present technical questions that are unresolved at the present time. Suggestions for further research that may aid in the resolution of these issues are offered.

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ACKNOWLEDGEMENTS

This report presents the results of subtask 2d of the study "Criteria for Evaluating Engineered Facilities," sponsored by the US Nuclear Regulatory Commission (NRC) and performed by personnel of the US Army Engineer Waterways Experiment Station (WES), Geotechnical Laboratory (GL), under Interagency Agreement No. NRC-02-83-046, dated 31 May 1983.

Mr. James Shaffner was the NRC technical monitor, and Mr. David Bennett was the WES principal investigator for the study. Their advice and support are greatly appreciated.

The study was performed under the general supervision of Mr. J. S. Huie, Chief, Rock Mechanics Application Group (RMAG), Engineering Geology and Rock Mechanics Division (EGRMD), GL, and Dr. Don Banks, Chief, EGRMD. Dr. William F. Marcuson III was Chief, GL during this study. Mrs. Mary Anne Kirklin typed the manuscript.

COL Tilford C. Creel, CE, and COL Robert C. Lee, CE, were Commanders and Directors of WES during most of the period of this study, and COL Allen F. Grum was Direction of WES during the last portion of it. Mr. Fred Brown and Dr. Robert W. Whalin were Technical Directors.

1. INTRODUCTION

The Waterways Experiment Station (WES) has been performing a study for the Nuclear Regulatory Commission (NRC) concerning technical criteria for evaluating engineered facilities for low-level radioactive waste (LLW) disposal. Such facilities involve disposal methods that are alternatives to shallow land burial (SLB). Five alternative methods have been considered. The five methods were described, and assessments of the applicability of existing 10 CFR 61 technical criteria to them were offered, in the Task 1 report of this study (Bennett et al., 1984).

This report relates to Task 2 of the study. The goal of Task 2 is to evaluate the need for modifications to existing criteria, and to suggest additional considerations that should be addressed by supplemental criteria as necessary, so as to render the total set of criteria applicable to the respective disposal methods. This report concerns one of the five methods, disposal in mined cavities.

This report is organized as follows. The performance objectives for land LLW disposal systems given in 10 CFR 61, Subpart C, are stated for reference purposes. Since mined cavities will by nature be in rock, a brief general discussion of underground openings in rock is given. Then, since there are numerous fundamental differences between the near-surface environment and the underground rock environment, an extensive discussion of these differences and their implications for LLW disposal is presented. Matters of similarity are also discussed. The existing technical criteria of 10 CFR 61, Subpart D, are then considered one by one as to their relevance for mined-cavity disposal. Pertinent factors are discussed, and analyses and documentation are presented. Recommendations are given, which include acceptance of a criterion as is, modification, replacement by a supplemental criterion, or outright deletion. Each recommendation is based on its preceding discussion. Matters that the Commission may wish to consider in developing supplemental criteria are presented and discussed, again with analysis and documentation as appropriate. Finally, the report is summarized, conclusions are drawn, and recommendations for future research, based on needs that have come to light during the conduct of this study, are made.

2. PERFORMANCE OBJECTIVES

General performance objectives that any facility for the dispoal of LLW must meet are set forth in Subpart C, sections 61.40 through 61.44, of 10 CFR 61. This guidance applies to mined-cavity facilities as well as to all present and future near-surface facilities of whatever type. For reference purposes, these objectives are listed below.

Section 61.40 - General requirement. Land disposal facilities must be sited, designed, operated, closed, and controlled after closure so that reasonable assurance exists that exposures to humans are within the limits established in the performance objectives in sections 61.41 through 61.44.

Section 61.41 - Protection of the general population from releases of radioactivity. Concentrations of radioactive material which may be released to the general environment in ground water, surface water, air, soil, plants, or animals must not result in an annual dose exceeding an equivalent of 25 millirems to the whole body, 75 millirems to the thyroid, and 25 millirems to any other organ of any member of the public. Reasonable effort should be made to maintain releases of radioactivity in effluents to the general environment as low as is reasonably achievable.

Section 61.42 - Protection of individuals from inadvertent intrusion. Design, operation, and closure of the land disposal facility must ensure protection of any individual inadvertently intruding into the disposal site and occupying the site or contacting the waste at any time after active institutional controls over the disposal site are removed.

Section 61.43 - Protection of individuals during operations. Operations at the land disposal facility must be conducted in compliance with the standards for radiation protection set out in Part 20 of this chapter, except for releases of radioactivity in effluents from the land disposal facility, which shall be governed by Section 61.41 of this part. Every reasonable effort shall be made to maintain radiation exposures as low as is reasonably achievable.

Section 61.44 - Stability of the disposal site after closure. The disposal facility must be sited, designed, used, operated, and closed to achieve long-term stability of the disposal site and to eliminate to the extent practicable the need for ongoing active maintenance of the disposal site following closure so that only surveillance, monitoring, or minor custodial care are required.

3. UNDERGROUND EXCAVATION: MINES AND TUNNELS

Underground excavations fall into two basic categories: mines and tunnels. These two types of underground openings have features in common but also have significant differences. In common, both consist of artificial underground spaces, separated from daylight by in-place natural materials, where men can survive, move, and work. The roof of the opening must somehow be supported, either naturally or artificially.

The differences between mines and tunnels relate to the purposes for which they are driven. A mine is essentially a temporary feature, whose objective is to extract the valuable material in the ground. Once that has been done, the mine's reason for being disappears and the mine is commonly abandoned. As expressed by Hoek and Brown (1980), "provided that safe access can be maintained for long enough for the ore in the vicinity of the excavation to be extracted and provided that the subsequent behaviour of the excavation does not jeopardise operations elsewhere in the mine, an underground mining excavation ceases to be an asset after a relatively short space of time."

A tunnel, in contrast, is generally planned as a permanent feature; thus there is more reason to design for permanent stability than in the case of a mine. Since a tunnel is generally part of a transportation, communication, or utility route, its position is relatively fixed, whereas a mine will develop wherever the ore deposit leads. Mine development is sensitive to economics: the high cost of mining in bad ground may make it advisable to avoid a region of otherwise desirable ore. However since a tunnel's route is fixed, the cost of stabilizing any bad ground encountered must simply be absorbed. The size of a tunnel is governed by the vehicles or objects that must move through it, whereas the size of mine openings is most importantly influenced by the thickness of the ore seam. These and other points of similarity and difference between mines and tunnels are discussed by Megaw and Bartlett (1981) and Hoek and Brown (1980).

An outgrowth of tunnel construction has been the development of permanent underground openings for applications other than transportation routes. These applications have included powerhouses, warehouses, office complexes, and military command centers. Some of the underground chambers excavated have been truly enormous in size, with widths of nearly 30 meters, heights of over 50 meters, and lengths of several hundred meters. Hoek and Brown (1980) give a bibliography of over 350 references on large underground excavations.

3.1 Mining, General

Mining basically involves excavating into the earth to extract valuable substances from it. This may be done at the earth's surface or beneath it. As the term is commonly used, mining excludes pits (sand, gravel, earth borrow), quarries (rock), and wells (oil, natural gas), but includes a wide variety of techniques carried out both at and beneath the surface to retrieve both metals and nonmetals. When the valuable substance is a metal, the rock containing it is called ore.

An informative presentation of basic facts and terminology of mining is presented in the Encyclopaedia Britannica articles on Coal Mining and Metal Mining (Evans, 1974; Clark, 1974). An exhaustive glossary of mining terms is given in Thrush (1968). A composite sketch illustrating various terms used in mining is given in Figure 1.

3.2 Types of Mines

The most basic division among mines is between surface (open-pit or open-cast) and underground mines. In the present context only underground mines are of interest.

Underground mines may be classified according to the method of access to the mine workings from the ground surface. In shaft mines a steep, usually vertical, shaft is sunk from the ground surface to the ore body, and the mine is then developed laterally from the shaft at one or more levels. A hoisting system is a vital part of the access to the mine. In slope mines an inclined tunnel takes the place of the shaft. Again, hoisting is a requirement, although on an incline rather than vertically or near-vertically. A drift mine is entered through one or more adits, that is, horizontal or nearly horizontal tunnels whose portals commonly lie in the ore seam. Hoisting is not necessary in a drift mine. Whether a mine is developed as a shaft, slope, or drift mine is controlled by the surface topography in the mine area and by the character and disposition of the ore deposit. Figure 2 shows the headframe structure at a modern shaft mine, and Figure 3 shows several portals at the entrance to a drift mine.

Another classification of mines is by the mining method used. A variety of methods exist, which may be classified as open stoping, sublevel stoping, supported stopes, top slicing and sublevel caving, and block caving (Clark, 1974). A mining method peculiar to coal mining is longwall mining (Evans, 1974). The details which distinguish these mining methods may be found in the referenced articles.

The method chosen to mine any given deposit depends on a complex of geological and rock-mechanical factors, as well as the geometrical shape of the ore body. In effect the choice is based on economics, since the objective is to extract the valuable mineral at the least cost possible consistent with safety and with the local physical conditions at the mine site.

The simplest underground mining method is open stoping (Clark, 1974), which merely involves leaving a portion of the mineral deposit in place to support the roof of the mined openings. So-called "room and pillar" mining is a common variety of open stoping, in which the mined-out "rooms" and the left-in-place "pillars" follow a more-or-less regular arrangement. Open stoping is commonly used in areas of simple geology, to mine deposits of relatively low-value minerals. The most common of these are coal and salt; others are limestone, gypsum, and potash; but the group can extend to any sedimentary mineral deposit, including many iron-ore deposits throughout the world. Because of the relatively low value of the mineral, it is more economical to leave portions of the ore in place as roof-supporting pillars than to install major artificial supports (Clark, 1974). In general, open

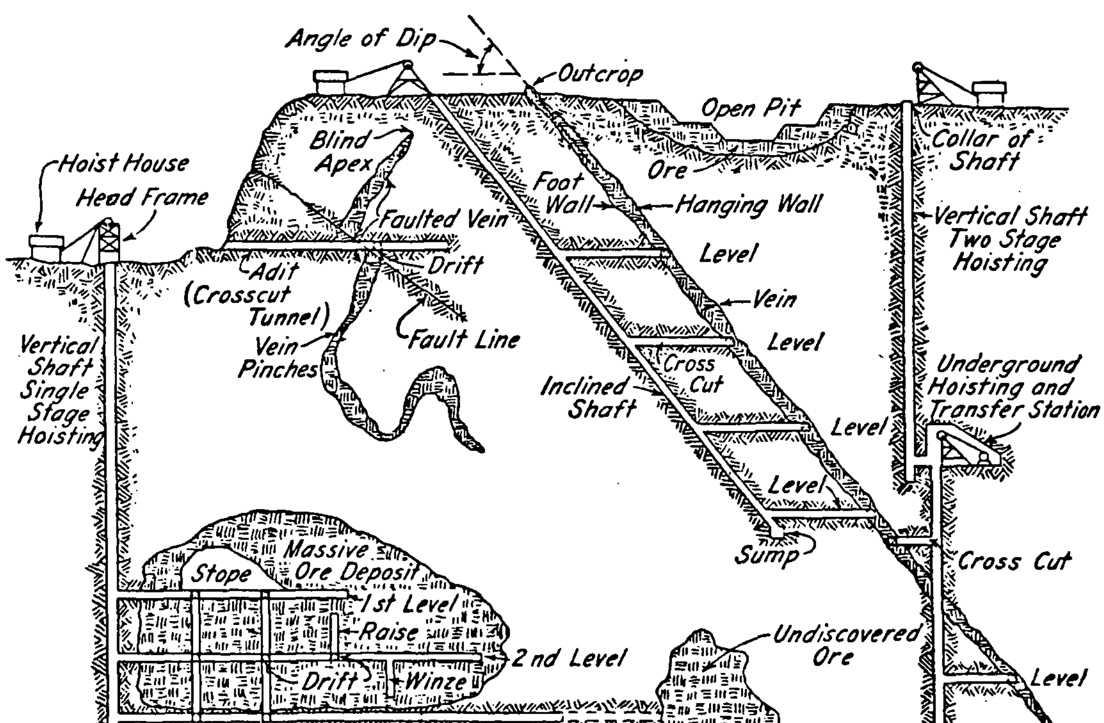

Figure 1. Illustration of terms used in mining. (From Lewis and Clark, 1964; courtesy of John Wiley & Sons, Inc.)

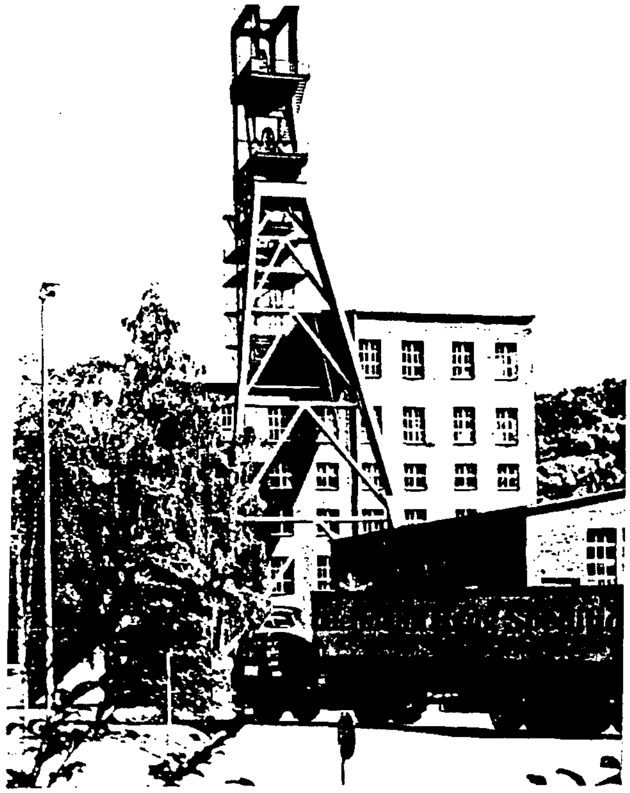

Figure 2. Headframe at one shaft of Wintershall potash mine, West Germany.

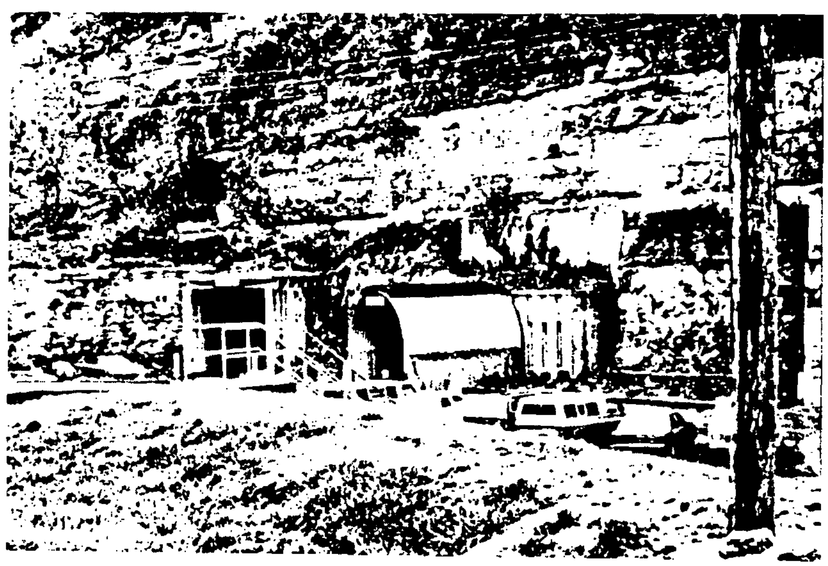

Figure 3. Portals at entry of limestone mine (a drift mine) now utilized as an underground cold-storage warehouse, Kansas City, KS.

stoping requires simple geologic structure, lack of faulting, lack of alteration (as is common with many metallic mineral deposits), and competency (strength) on the part of both the ore deposit and the associated rocks. Because of this strength and simplicity, and the relatively large volumes of underground mined-out space that open stoping creates, worked-out mines of this type are best adapted and most often considered for storage or disposal purposes.

4. DIFFERENCES BETWEEN MINED-CAVITY AND NEAR-SURFACE ENVIRONMENTS WITH REGARD TO LLW DISPOSAL

The presently published criteria of 10 CFR 61 Subpart D were prepared from a background of shallow land burial (SLB) and are specifically directed to near-surface disposal. However, there are many important differences between the underground and the near-surface environments. Mined cavities correspond to "shallow geologic repositories" and "deep geologic repositories," the two methods most dissimilar to SLB of the nine methods of Greater Confinement Disposal identified by Gilbert and Luner (1984).

The purpose of this chapter is to make clear the differences between the underground mined-cavity environment and the near-surface environment. Because of these differences, it is to be expected that many technical criteria for a mined cavity will be different from those at or near the surface. The following paragraphs discuss points of difference between the two types of environments, with particular reference to the effects and implications of these differences relative to LLW disposal. Comparisons between the environments are made only to make clear the differences, and not to recommend one disposal method as being superior to another. In particular, there is no reason to assume that mined cavities are superior to near-surface disposal facilities for low-level waste disposal.

4.1 Shielding and Depth of Burial

An important consideration with near-surface facilities is shielding sufficient to protect a person on the surface from radiation from buried wastes. For this purpose a cover is required and a minimum depth of burial may be prescribed.

For waste disposal in a mined cavity, the rocks that form the roof and walls of the mine chamber provide an automatic cover. The deeper the mine, the greater the thickness of rock available to impede radiation, but even in a relatively shallow mine, the rock overburden must be thick enough to be mechanically stable, and thus should provide a substantial radiation barrier.

Each site must of course be evaluated with regard to its own specific site conditions. However, the nature of a mined cavity furnishes a high probability that adequate cover for shielding purposes will automatically be present.

4.2 Subsidence

Subsidence is a well-known troublesome problem at shallow-land-burial LLW disposal sites (Kahle and Rowlands, 1981; Grant, 1982), where it may result from the collapse of individual waste containers or from the settlement over time of randomly placed, poorly compacted backfill soil. Subsidence is also a common phenomenon over underground mines. By far the most attention to this problem has been in coal-mining regions (Yokel, Salomone, and Gray, 1982; DuMontelle et al., 1981), but surface subsidence over salt mines and iron mines has been documented as well (Wassmann, 1980; Uhlenbecker, 1980; GSF, 1982).

Subsidence over a mined opening varies with the unsupported roof span of the mine rooms, the depth beneath the ground surface, and the character of the rock section overlying the openings. Subsidence is much the most pronounced over longwall mines because this mining method removes the entire support over large regions underground. In general, subsidence does not occur over room-and-pillar mines, provided the extraction ratio (fraction of the original material removed) is small enough and the pillars are large enough and properly designed. Pillar design is discussed in Bieniawski (1984).

The implication for waste disposal in suitable room-and-pillar mines is that wastes need not be in stable containers, nor is there a need for firm backfill, for the purpose of subsidence prevention, although these practices may be desirable for other reasons.

Depending on the quality of the overhead rock, the roofs of mined openings may either be self-supporting or the support may be augmented by a variety of artificial means, including rock-bolting, wire mesh, guniting (shotcrete), or various supporting structures of steel, timber, or other materials. An acceptable mined cavity for waste-disposal purposes would be one with strong roof rocks requiring little or no artificial support. This would minimize the danger of disruption of containers by falling rock, as well as improving safety during facility operations.

4.3 Surface Geological, Meteorological, and Soil-related Processes and Effects

There are several geological and meteorological effects and processes that are important to the design, performance, and stability of a near-surface facility but that have little or no effect on an underground mine. These factors include surface flooding, storms and other weather conditions, surface geological processes, soil mechanics and soil geochemistry.

4.3.1 Surface Flooding

Inundation by surface flood waters is an obvious threat to a near-surface facility, which should not be sited in a floodplain nor in a topographic depression subject to flash flooding. However underground mines should not be, and as a rule never are, endangered by surface flooding. An elementary design step in developing a mine is to locate the portals or shafts in places that are immune to surface flooding. It may be assumed that this will have been done at any given mine, although this should be checked. Conceivably the portals of a drift mine might be located in a valley bottom not far above surface flood elevations. If so, elementary mining safety practice would insure the availability and use of protective measures (flood walls, protective dikes, etc.) to prevent surface flood waters from entering the mine.

Flooding of underground mines is a serious and real hazard and has occurred on a number of occasions (see section 4.7.5 below). In virtually every case, however, mine flooding has occurred as an accident brought on by errors in drilling or mining practice. In most cases ground water, rather than surface water, produced the flooding. To the knowledge of the author, there has never been a mine flooding attributable to a surface meteorological event and no other cause.

4.3.2 Storms, Other Weather Conditions

Some of the weather conditions to which a near-surface facility is exposed are: tornadoes; other violent storms; lightning; snow and ice; freezing and thawing. At an underground mine, only the surface facilities are exposed to these events. Once underground, one is unaware of such events taking place on the surface. An electrical storm might interrupt the power to an underground mine; an emergency power supply should be provided. Severe weather might immobilize the hoisting machinery or block the portal of an underground mine, and thus temporarily interrupt operations. The underground facility itself, however, would be unaffected.

4.3.3 Surface Geological Processes

Some of the geological surface processes that may affect a near-surface facility are: erosion; mass wasting; landsliding; slumping; weathering. One or more of these may affect the surface facilities of an underground mine, but none of them has any effect on the underground workings. The latter are located in rock, removed from surface geologic systems. Technical criteria for a near-surface facility that deal with such geologic surface processes are therefore not applicable to a mined-cavity facility, except as they relate to the surface appurtenances thereof.

4.3.4 Soil Mechanics; Soil Geochemistry

A number of considerations related to soils are important to a near-surface facility. However, since a mine is excavated in rock, outside the range of soil influences, soil-related matters generally have no relevance in an underground mine. Soil factors would be of concern only if surface soil were imported underground for backfill or other purposes. Conversely, of course, rock mechanics and rock geochemistry become important. Some of the special attributes of rock are discussed in the next section.

4.4 Consequences of a Rock Rather Than a Soil Environment

A number of differences from near-surface conditions arise from the fact that a mined cavity is situated, by its nature, in a rock rather than a soil environment.

4.4.1 Structural Geology

Structural geology is a matter of fundamental importance at any rock construction site, and particularly at an underground site. Site-specificity, important at any site, is doubly so at an underground mine. The entire physical environment in three dimensions at any mine is unique to that mine. Anisotropy--the existence of different conditions in different directions--may be expected as a rule rather than an exception. Overwhelmingly, drainages occur in discrete channels, and the geological structure of a mine must be known in detail to operate it properly.

4.4.2 Excavation

The excavation of rock is always more difficult than that of soil, and often assumes the nature of an art. Drilling and blasting are commonly required. Although these may be done safely and with very little damage to the surrounding rock, they must be done with care and skill by knowledgeable and experienced persons. Continuous-excavation machinery may often be used, but again, knowledge and skill are required.

4.4.3 Immutability

At a surface site a certain amount of topography modification, drainage amendment, etc., are possible, given commitment of resources and effort. Underground one can only adapt to existing conditions; it is nearly impossible to change them. Corrective measures are difficult, once the facility is closed. Adequate up-front exploration thus becomes absolutely essential.

4.4.4 Special Expertise Requirements

Above all, as regards an underground rock site, it is necessary to recognize that one is in a unique environment. The specialized expertise of experienced professionals in rock mechanics, tunneling, mining, and underground work in general is an absolute must for successful design and operation.

4.5 Mining Considerations

An operating underground disposal facility will share several requirements with an operating underground mine. These requirements are different from those of a surface operation. Some of them are as follows.

4.5.1 Ventilation

Effective ventilation of an underground mine is of critical importance, both to provide fresh air for working personnel and to carry out stale or hot air, dust, and fumes. Mining laws commonly specify quantities of fresh air that must be supplied to each working man underground (Lewis and Clark, 1964). Also, automotive equipment powered by internal combustion engines are now in common use in many underground mines. These engines pose an additional fresh-air demand.

4.5.2 Haulage and Hoisting Systems

Haulage and hoisting systems are essential features of any underground mine. The same is obviously true of a mined-cavity disposal facility, although the primary movement of materials will be into the latter while it is out of a mine.

4.5.3 Utilities

Utilities, primarily electricity and communications, are essential features of an operating mine and will likewise be so at an operating disposal facility. Water and compressed-air services may also be present.

4.5.4 Drainage and Pumping

A requirement at most mines is drainage and pumping. In this regard a disposal facility should be different, since dryness and consequent lack of need for drainage and pumping is an important characteristic of an acceptable facility site. However, provisions for emergency drainage should be made.

4.5.5 Safety Apparatus

All mining safety apparatus required in an operating mine must be present at an underground disposal facility as well. The necessary equipment and trained personnel must be immediately available on-site, underground, with back-up personnel available at the surface. Because of the special environment in a mine, the potential for serious accidents is always great, whether from fire, explosion, poisoning of the atmosphere, wholesale collapse, or blocking of escape routes. The likelihood of injury from a mining-type accident is probably greater than from a radioactivity accident, but safety measures to treat both types of accidents, or a compound accident (radioactivity accident as a result of a mining accident), must be in place.

4.5.6 Maintenance and Repair Facilities

It may be necessary to locate major maintenance and repair facilities underground, depending on the types of equipment in use underground and the means of access from the surface. Shaft mines are particularly likely to need large-scale underground repair facilities.

4.5.7 Temperatures

Although the gradient of temperature with depth in the earth is variable from place to place (Holmes, 1965), it is generally true that temperatures are high in deep mines, leading to adverse working conditions for personnel. Artificial cooling of mine atmospheres has been practiced in some mines (Lewis and Clark, 1964); sometimes a period of several years has been required to bring temperatures down to acceptable working levels. It may be noted that any underground mine or cavern tends to have a uniform, nonvarying temperature (at any given level).

4.5.8 Mine Surveying

Mine surveying is a somewhat specialized art. Working conditions underground may be dusty or wet. Sight lines must follow mine openings; with steeply inclined or vertical shafts, sights may be difficult. Stations are usually located in the roof rather than the floor. Objects sighted and telescope cross-hairs must be illuminated. These and other aspects of mine surveying are discussed in detail in Staley (1964).

4.5.9 Closure

Underground mines are commonly simply abandoned when their value as an asset has disappeared. Abandonment commonly is followed by flooding and collapse of the workings. A formal closure procedure is seldom followed.

A mined-cavity disposal facility would have to be treated differently, and a formal, carefully designed closure procedure would have to be observed. Sealing of all openings and of pertinent structural weaknesses would have to be carried out so as to prevent or hinder access by ground water. Collapse and caving should be precluded by careful site selection to insure strong roof rock, careful mining practices to preserve pillar strength, and the installation where necessary of strong and lasting roof-support systems.

Many studies and much experimental research on sealing of underground openings have been carried out for the purpose of HLW disposal. Future research might be directed toward the adaptation of sealing technology developed in these research programs to the closure of LLW mined-cavity disposal sites.

4.6 Effects of Tight Quarters

Some consequences of working in relatively tight quarters underground include the following.

Any underground chamber has limited headroom, although the headroom obviously varies from mine to mine. General-service cranes are, as a rule, not usable. Specialized equipment, designed for the clearances at the particular mine, will commonly have to be used. For example, Figure 4 shows a "low-boy" truck used for hauling chemical-waste drums at an underground waste-disposal facility in Germany.

Low-level wastes of relatively high activity require special shielding containers to protect working personnel during handling. These containers may be quite heavy. The repeated handling of heavy shielding containers in tight quarters underground may be an awkward and time-consuming operation, as has been demonstrated at the Asse mine in Germany (Salander, Proske, and Albrecht, 1980).

Some waste containers, and particularly decommissioning wastes, may be of large physical dimensions. It must be assured that the mine hoisting and hauling equipment is adequate to handle such large items. This may be particularly critical in shaft mines.

Any underground installation is serviced by a finite number of entryways (shafts or portals). Alternate routes of approach are not possible. The dimensions of the entryways place an upper limit on the sizes of waste containers or objects that may be brought into the mine.

4.7 Other Matters of Difference

Several matters of difference between surface and underground relate to human activities.

4.7.1 Future Land Use and Development; Interference or Complication

Normal surface development may proceed over an underground-mined area without significant impingement. The deeper the mining, of course, the less is the likelihood of interference, and vice versa. One form of impingement would be mine subsidence at the surface; another would be penetration of the underground space by water or hydrocarbon wells. The impact of future development will be much less direct on a mined-cavity site than on a near-surface site.

Figure 4. "Low-boy" truck hauling chemical wastes at Herfa-Neurode disposal facility, located in a worked-out portion of Wintershall potash mine near Bad Hersfeld, West Germany. Photo courtesy of Kali & Salz AG.

Interference or complication is merely the same problem in a present rather than a future time-frame. An underground mine may be quite compatible with an industrial or residential development directly over it. There is no absolute need to prohibit a disposal site beneath or near a surface development; rather, the specifics of the case need to be carefully studied and an appropriate decision reached thereafter. The Konrad iron-ore mine in West Germany is a case in point (GSF, 1982). A LLW repository will be established in this mine if its license application is approved (Bennett and McAneny, in preparation).

4.7.2 Exploitation of Natural Resources

It is prudent to site near-surface facilities in areas that do not have natural resources, because there is an obvious economic incentive for people to enter such areas and carry out activities that would be likely to disturb a disposal site. An underground mine, however, owes its very existence to the presence of an economic mineral deposit of some kind. To exclude regions of natural resources from consideration for mined-cavity disposal sites would deny access to nearly all of such existing cavities. The mining of new underground space in barren rock would be a very expensive enterprise.

At the same time if existing mined spaces are to be used, the threat of disturbance from future mining or drilling activity must be recognized and dealt with. Mining is generally ceased when an economic limit is reached, when it becomes uneconomical to continue mining because of the combined effect of the grade of the ore and the market conditions prevailing at the time. Seldom is the mineral deposit completely removed. There remains valuable material in the ground, and under a future economic environment it might become economical to attempt to recover it.

Whether regions of natural resources should be absolutely excluded from consideration for waste-disposal sites is a difficult, basic, philosophical question. There are precedents for both approaches. In West Germany, an abandoned iron mine is under study as the site for the nation's LLW disposal. In Sweden, excavation of an underground LLW depository in barren granite has been undertaken, although barrenness was not a siting criterion. It could be a task for future research to explore which approach would be in the best interests of the United States.

4.7.3 Vandalism

Kuck et al. (1981) examined the history of ancient underground structures, particularly tombs and cave-temples in Egypt, China, and India, in an effort to find clues as to the probable long-term stability of low-level wastes if they were to be buried in underground caverns. Their study found that although a variety of processes led to the deterioration of buried objects, the most significant factor was human vandalism. Not only did vandals remove valuable materials themselves, but the vandals' penetrations allowed the entry of water, mud, etc., which accelerated the deterioration of buried objects by natural processes. Most buried wastes would offer no incentive for vandalism, but contaminated scrap metals are a possible exception.

On account of the more difficult access, vandalism should be less of a problem in a mined cavity than at other types of disposal sites.

4.7.4 Inadvertent Intrusion

Inadvertent intrusion is distinct from vandalism in that the latter is purposeful intrusion. Inadvertent intrusion is intrusion that may occur unwittingly as a result of normal pursuits such as agriculture or construction. Such intrusion is a definite possibility at a near-surface facility, particularly in the distant future.

The very nature of a mined cavity makes inadvertent intrusion less likely than for other alternatives. The cavity is situated in rock. Nearly all normal activities do not involve penetration into bedrock. Exceptions do occur in the case of construction, but these are usually shallow; moreover, they must be preceded by subsurface exploration programs. Such programs would reveal the presence of a disposal facility; and any excavation thereinto would definitely be purposeful rather than inadvertent.

The most credible inadvertent-intrusion scenario for an underground disposal facility in a mined cavity would be through well drilling. This is a serious threat. Criteria language to insure positive control of the area and prevent such drilling is essential.

4.7.5 The Water Table, and Ground Water

The position of a mined cavity with respect to the water table is an important matter and a complicated one. As a rule, a mine is far more likely than a near-surface facility to be beneath the water table, simply because of its greater depth. This is particularly true in regions of humid climate.

A distinction may be drawn with regard to water conditions between drift mines and shaft or slope mines (see Section 3.2). Drift mines driven into the side of a hill above the local stream base level may be above the regional water table, which is controlled by the stream network. These mines may be beneath local, perched water tables, however.

Shaft or slope mines are certain to penetrate the water table in humid regions, and are likely to penetrate it even in arid regions unless the mine is relatively shallow and the water table is deep. Mine drainage problems are extremely common (Vranesh, 1979). The most challenging problems during mine development are encountered during shaft sinking, when the mine opening is being driven perpendicular to aquifers and large ground-water reservoirs may be tapped (Greenslade, 1979). But even in fully developed, operating mines, elaborate drainage systems with high-capacity pumps working against high hydraulic heads are often required (Lewis and Clark, 1964).

Clearly, wet mines are the rule and dry mines are the rare exception. Nevertheless, there are dry or nearly dry underground mines. Examples are the Konrad iron-ore mine in Germany (GSF, 1982), several of the underground limestone quarries in the Kansas City area (Stauffer, 1975), and numerous salt mines (e.g. Salander, Proske, and Albrecht, 1980). The very existence of a dry mine attests to the existence, at that mine, of a set of conditions acting to shield the mine from water. The shield or barrier may be of greater or lesser integrity and thickness. It behooves any person considering a mine as a disposal site to explore and demonstrate how good a shield or barrier is in existence at the particular mine, and where the barrier may be vulnerable to penetration.

Exploration of the hydraulic barrier must be done with care, as an exploratory borehole itself may become a perforation of the envelope. Exploratory boreholes should be backfilled using the best grouting technology.

The deeper the mine is, the less likely a penetration event will be. The most threatening form of penetration is that of wells or other boreholes. An example of a disastrous penetration of a previously dry mine occurred at the Jefferson Island salt mine, Louisiana, in 1980, where an oilfield drill, apparently mislocated because of a survey error, penetrated the underground workings. A surface lake immediately commenced to drain into the workings, forming in the process a large vortex, into which the drill rig was carried (MSHA, 1981; Autin, 1984).

Other flooding events known to the author include the Asse and Friedensville mines. Flooding occurred at the Asse potash mine in Germany in 1906 when improper mining of potash salts destroyed some of the covering watertight layers (Salander, Proske, and Albrecht, 1980). The whole mine had to be abandoned. A second shaft was sunk nearby to mine the salt deposits, and it is this shaft that now services the Asse salt mine where radioactive-waste-disposal research is carried on. Great care is now taken to preserve the watertight envelope.

A flooding emergency occurred in the Friedensville zinc mine near Allentown, PA, in 1976 (Cox, 1979), when water broke through the wall of a stope that had been advanced into a region of known ground-water problems. Fortunately emergency plans and equipment were in readiness, and the flooding was controlled without loss of life nor having to abandon the mine.

The reason why dryness is a requisite for an underground disposal facility is to prevent escape of radionuclides by leaching. A wet mine will become flooded after closure; wastes will become soaked, radioactive substances will be leached, and moving ground water may transport these substances into the environment. The path of dissolved radionuclides depends on the regional ground-water flow network.

Regional ground-water flow is a complicated three-dimensional process, subject to boundary conditions such as topography, geologic stratigraphy and structure, and rainfall distribution in space and time. A given area may have a regional flow system and one or more local flow systems interacting with the regional flow system. An excellent discussion of regional ground-water flow may be found in Fetter (1982). Among the points mentioned by Fetter are the merits and risks of burying wastes at points of stagnation, i.e. places where ground water is essentially static.

Conceivably a deep mine might be so situated that ground-water flow would be so slow that diffusion would be a major solute-displacement mechanism, and a time span of many half-lives of the hazardous nuclides present would elapse before contaminants would reach that part of the hydrosphere taking part in the meteoric hydrologic cycle. In that case disposal of LLW in such a mine would be environmentally safe. Such a situation was shown to exist in Germany for the Konrad iron-ore mine (Bennett and McAneny, in preparation). Similar reasoning has been applied in the concept of the Swedish LLW-ILW repository now under construction at Forsmark, Sweden, where ultimate saturation and leaching are accepted, but because of minuscule driving gradients and dilution and dispersion by the Baltic Sea, environmental effects are acceptably low (Bennett and McAneny, in preparation).

4.7.6 Environmental Monitoring

Partly because of the matter of high site-specificity mentioned above and partly because of the simple difficulties of operating underground, environmental monitoring is more difficult with an underground site. Monitoring instruments, especially external to the repository, are hard to place simply because of the problem of access.

The question of monitoring, both during operations and after closure, at a mined geologic repository have been addressed by the U. S. Department of Energy as part of the NWTS (National Waste Terminal Storage) program (USDOE, 1982). Their recommended criterion for monitoring during operations is straightforward. The repository design should provide for monitoring of system performance during operations. The data to be monitored should be those indicative of system performance and should be determined on a site-specific basis to ensure that factors of particular concern at a specific site are monitored.

With regard to post-closure monitoring, USDOE (1982) advances persuasive arguments as to why such monitoring should be performed using surface techniques only, and should not involve subsurface instruments left in place after closure. For one thing, numerous aspects of the process of subsurface data collection and transmission to the surface involve serious questions as to reliability. Thus, it would be impossible to have high confidence in the results. It would be impossible to repair such a system. Also, it would be impossible to check the system out if anomalous data were received. These facts argue strongly for subsurface monitoring only during the operating period, when instruments are relatively accessible and conditions indicated by anomalous readings can be checked out directly. Post-closure sampling of ground water from deep wells surrounding the facility would be a surface-based technique, since it would not involve subsurface instrumentation.

No long-term post-closure subsurface monitoring is planned for the Swedish LLW-ILW (intermediate-level waste) repository now under construction at Forsmark, Sweden. The philosophy represented in the Swedish repository concept may be summarized as follows: concentrate the effort up front; assure a good site and a thoroughly planned system; monitor with care while the disposal operations are actually being carried out; once the system is closed, however, in effect walk away from it, recognizing that at that stage nothing more can be done.

United States practice now calls for long-term post-closure monitoring of land disposal sites (cf. criterion 61.53 (d)). This is at variance with the Swedish philosophy. It is suggested that future research be devoted to studying both the feasibility and the value of long-term monitoring of closed mined-cavity disposal facilities.

4.7.7 Seismic Stability

Several recent studies have been made of earthquake damage to underground facilities (Pratt, Hustrulid, and Stephenson, 1979; Owen and Scholl, 1981; Dowding, 1977). Although the historical data base is random and of varying reliability, it nevertheless seems well establishd that mines and other underground openings suffer less damage from earthquakes than surface structures in the same regions. Many mines have operated for long periods in some of the most seismic areas of the world. The 1964 Alaska earthquake, which produced extreme surface damage, was observed to have produced no significant damage (only a few rocks shaken loose) in several mines, tunnels, and other underground facilities. A simplified mechanical explanation for the difference is that surface structures respond as resonating cantilever beams, amplifying the ground motion; while underground structures respond essentially with the ground itself. Severe damage has been observed underground where mined openings intersect active faults in the epicentral region of earthquakes.

4.7.8 Vulcanism

Vulcanism is a process that is active in the U.S. only in the Cascade Range of the Pacific Northwest. Vulcanism involves the flowage of molten lava, the deposition of volcanic ash, and/or associated phenomena such as volcanic mudflows and nuees ardentes (glowing ash clouds). To the knowledge of the author, no underground mine or tunnel has ever been affected by these phenomena. It would of course be unwise to site a mined-cavity disposal vicinity in the immediate vicinity of an active volcano.

4.8 Matters of Similarity

In some matters of site selection and operation, there is no substantial difference between near-surface and underground sites. In both environments a disposal facility should be so designed as to be in accord with and take full advantage of the site's natural characteristics. Facilities in both environments should be designed so that active disposal operations will not interfere with completed portions of the facility. The policy of disposing of only radioactive wastes is equally applicable underground as it is at the surface. Environmental monitoring during operation is applicable in both environments, as discussed in the previous section, although some environmental components (meteorology, for instance) need less consideration for an underground site.

5. CRITERIA

5.1 General

In this section, recommended technical criteria for mined-cavity low-level-waste disposal facilities are presented. As shorthand, the acronym MCLLWDF is used to represent these facilities.

The first subsection below deals with existing technical criteria. Each technical criterion presently appearing in sections 61.50, 61.51, and 61.52 of 10 CFR 61 is in subsection (a) of its respective section. Subsection (a) in each case deals specifically with near-surface disposal. Subsection (b), dealing with land disposal other than near-surface, was, in each case in 10 CFR 61, "reserved." In fact, since the Mined Cavity option represents disposal other than near-surface, the present report amounts to recommended material for filling in of the 10 CFR 61 61.50, 61.51, and 61.52 subsections "(b)." Section 61.53 of 10 CFR 61 is not subdivided into subsections for near-surface and other-than-near-surface disposal.

The criteria specifically treated below represent "applicable" and "modified" criteria. These are discussed here in the following format. Under the heading of "criterion," a criterion is presented in its present form. Under the heading of "discussion" the reasoning for recommended changes is the criterion, if any, is given. Under "recommendation," the wording of a revised criterion, or other resolution of the matter, is stated. New words are indicated by <u>underlining.</u> In some cases the recommendation involves a departure from the position previously put forward by WES in the Task 1 report (Bennett et al., 1984). Such departures are explained in the discussion.

The second subsection below deals with new technical criteria, specifically pertinent to Mined Cavities. This second group represents "supplemental" criteria. In this section, specific criteria in prescriptive language are not given, but under appropriate subject headings, the points that the criterion should address are stated. Reasoning is presented as an integral part of the recommendation. This method of presentation is felt to be more appropriate than offering specific criteria, as it allows the Commission to consider the facts and develop specific wording that it considers appropriate in each particular case.

5.2 Applicable and Modified Criteria

This discussion deals with technical criteria presented in sections 61.50, "Disposal site suitability requirements for land disposal," 61.51, "Disposal site design for land disposal," 61.52, "Land disposal facility operation and disposal site closure," and 61.53, "Environmental monitoring." Criteria are numbered as they are in 10 CFR 61.

5.2.1 Site Suitability (Section 61.50)

Criterion 61.50 (a)(1)

The purpose of this section is to specify the minimum characteristics a disposal site must have to be acceptable for use as a near-surface disposal facility. The primary emphasis in disposal-site suitability is given to isolation of wastes, a matter having long-term impacts, and to disposal-site features that ensure that the long-term performance objectives of Subpart C of this part are met, as opposed to short-term convenience or benefits.

Discussion. The wording should be changed to make it applicable in the present context of the Mined Cavity disposal option.

Recommendation. The criterion should read as follows: The purpose of this section is to specify the minimum characteristics a disposal site must have to be acceptable for use as a ~~near surface~~ mined-cavity low-level waste disposal facility (MCLLWDF). The primary emphasis in disposal-site suitability is given to isolation of wastes, a matter having long-term impacts, and to disposal-site features that ensure that the long-term performance objectives of Subpart C of this part are met, as opposed to short-term convenience or benefits.

Criterion 61.50 (a)(2)

The disposal site shall be capable of being characterized, modeled, analyzed and monitored.

Discussion. This criterion is stated in very simple terms, whose simplicity suggests the question "what site cannot be characterized, modeled, analyzed, and monitored?" Obviously, the task of characterization, modeling, analysis, or monitoring becomes much more difficult the more complicated is the geology (and other physical environmental frameworks) of the site. By implication, it is desirable that these tasks be done easily and with a relatively high degree of confidence.

The implication is that a site should be one with simple geologic stratigraphy and structure, with simple hydrological conditions. These are certainly desirable characteristics. However it has been the author's experience that searches for sites that are simple almost always turn out to be frustrating, because apparent simplicity gives way to complexity the more the details of a site are learned.

This being the case, the author sees no way short of extensive legalistic modification to improve the wording of the criterion.

Recommendation. The criterion may be retained in its present form.

Criterion 61.50 (a)(3)

Within the region or state where the facility is to be located, a disposal site should be selected so that projected population growth and future developments are not likely to affect the ability of the disposal facility to meet the performance objectives of Subpart C of this part.

Discussion. The matter of interference between an underground mine and human activities at the surface is discussed above in sections 4.7.1. In essence the threat of impingement by surface development on an underground facility is minimal, except for penetration by wells or other borings. Therefore, this criterion is largely unnecessary. However, no harm is done by leaving it in its present form.

Recommendation. The criterion may be retained in its present form.

Criterion 61.50 (a)(4)

Areas must be avoided having known natural resources which, if exploited, would result in failure to meet the performance objectives of Subpart C of this part.

Discussion. The point addressed by this criterion, natural resources, is a point of fundamental difference between Mined Cavity and near-surface sites. Underground mines owe their very existence to the presence of an economic mineral deposit. When mining is discontinued it is for economic reasons, and a portion of the mineral deposit is always left in the ground. The question is discussed above in section 4.7.2. To rule out regions with natural resources would be to deny access to virtually all existing underground openings. Exceptions would be for tunnels or excavations for facilities such as powerhouses, but all of these excavations would be expected to be still in use. Successful waste-disposal operations in Europe (Bennett and McAneny, in preparation) are located in regions of developed natural resources. The criterion in its present form is highly restrictive toward the use of mined cavities.

Recommendation. The whole question of whether and to what extent regions with natural resources should be admitted for consideration for possible MCLLWDF sites is a difficult and philosophical one. It is recommended that a future research effort explore the question; taking into account the experiences of other countries, particularly France and West Germany, in an effort to identify what would be in the best interests of the United States. In the meantime, it is recommended that this criterion be replaced by a supplementary criterion. Guidance for the formulation of such a criterion is offered in section 5.4.1.1.

Criterion 61.50 (a)(5)

The disposal site must be generally well drained and free of areas of flooding or frequent ponding. Waste disposal shall not take place in a 100-year flood plain, coastal high-hazard area or wetland, as defined in Executive Order 11988, "Floodplain Management Guidelines."

Discussion. This criterion deals strictly with surface flooding. As explained above in section 4.3.1, an underground mine is generally not subject to surface flooding, provided the surface openings are suitably sited and engineered. The surface facilities associated with a MCLLWDF may be threatened by surface flooding if they are ill-sited. The criterion needs to be reworded to make it clear that the surface facilities and mine openings of a MCLLWDF, but only these features, are of concern with regard to choosing a site that is free from surface flooding.

Some wet mines may experience variations in water inflow that correlate with rises and falls in the ground-water table, surface flooding, or other external hydrologic events. However, any wet mine is unacceptable as a waste-disposal site.

Recommendation. The criterion should read as follows. The ~~disposal site~~ surface facilities associated with a MCLLWDF must be situated in an area that is generally well drained and free ~~of areas of~~ from flooding or frequent ponding. ~~Waste disposal shall not take place.~~ Such facilities shall not be located in a 100-year flood plain, coastal high-hazard area or wetland, as defined in Executive Order 11988, "Floodplain Management Guidelines." The surface openings to a MCLLWDF must be so situated or engineered or both that surface floodwaters cannot enter the underground workings through these openings.

Criterion 61.50 (a)(6)

Upstream drainage areas must be minimized to decrease the amount of runoff which could erode or inundate waste disposal units.

Discussion. This criterion deals with erosion and inundation by surface waters. Both of these processes pose serious threats over the entire operating postclosure lifetime of a near-surface facility. However, as discussed above in sections 4.3.1 and 4.3.3, the underground portion of a MCLLWDF, where wastes are actually disposed of, is not subject to either of these threats. The threat to associated surface facilities during the operating life of a MCLLWDF from these processes is within the scope of ordinary engineering and construction practice, and a criterion such as this is not necessary.

Recommendation. This criterion should be deleted.

Criterion 61.50 (a)(7)

The disposal site must provide sufficient depth to the water table that ground water intrusion, perennial or otherwise, into the waste will not occur. The Commission will consider an exception to this requirement to allow disposal below the water table if it can be conclusively shown that disposal site characteristics will result in molecular diffusion being the predominant means of radionuclide movement and the rate of movement will result in the performance objectives of Subpart C of this part being met. In no case will waste disposal be permitted in the zone of fluctuation of the water table.

Discussion. The wording of this criterion clearly implies that a near-surface site is under consideration. The intent of the criterion is that the water table (the upper surface of the ground water) be sufficiently deep underfoot that the trenches, pits, or other components of the near-surface disposal facility can be excavated under dry conditions.

The criterion is not applicable to mined cavities, however. Commonly a mined cavity will be well beneath the water table, but if the cavity is dry - a rare case, but a necessary one, for acceptability as a disposal site - it is dry because of a natural barrier shielding the cavity from the surrounding and overlying ground water. Whether the top surface of this ground water - the water table - lies ten feet or one hundred feet beneath the ground surface is irrelevant. The important factor is the existence, and the maintenance, of the hydrologic barrier surrounding the cavity.

The exception to the criterion refers to molecular diffusion as a mechanism of radionuclide transport. For molecular diffusion to dominate over ground-water flow, flow velocities must be extremely small. An analogous situation for a mined cavity would be a cavity so situated that ground-water flow velocities around it (and through it if it were to become flooded) were extremely slow.

The subject of water in mines is discussed at length in section 4.7.5, to which the reader is referred.

Recommendation. This criterion should be deleted and replaced with a Supplementary Criterion dealing with water conditions in a MCLLWDF. See section 5.4.1.2.

Criterion 61.50 (a)(8)

The hydrogeologic unit used for disposal shall not discharge ground water to the surface within the disposal site.

Discussion. For almost any conceivable MCLLWDF, the discharge of ground water from the hydrogeologic unit in which the wastes are stored - which will be a rock unit, since a MCLLWDF is by its very nature located in rock - within the bounds of the disposal site is not a realistically likely occurrence. The criterion is thus largely unnecessary. It may, however, be left in place unmodified.

The pumping out of mine waters and discharging them within the site boundary might be construed to fall within the meaning of this criterion. The point is moot, however, because any mine that generates enough water to require pumping would be unacceptable as a MCLLWDF site.

Recommendation. This criterion may be left unmodified. It could also be deleted without harm, however.

Criterion 61.50 (a)(9)

Areas must be avoided where tectonic processes such as faulting, folding, seismic activity, or vulcanism may occur with such frequency and extent to significantly affect the ability of the disposal site to meet the performance objectives of Subpart C of this part, or may preclude defensible modeling and prediction of long-term impacts.

Discussion. The criterion refers to tectonic processes in general and then mentions four specific examples. Of these, vulcanism is a threat only in the Pacific Northwest area of the United States, and even there it is not a threat to underground mines (see section 4.7.8). Folding and faulting are structural geologic processes that take place on a grand scale; if the effects of either of these are to be of realistic impact on humans and human endeavers, such effects will be manifested through seismic activity. Accordingly, strictly speaking, only seismic activity would need to be mentioned in a criterion for a MCLLWDF. Even seismic (earthquake) activity need not completely rule out any given mined-cavity site, since the seismic stability of underground chambers is generally superior to that of surface sites (see secton 4.7.7).

Nevertheless, the criterion as written is nonrestrictive, since a given site, even in an area characterized by one of these tectonic processes, still needs to be evaluated with regard to Performance Objectives and modeling and prediction. Accordingly, there is no reason why the criterion may not be retained as is.

Recommendation. The criterion may be retained in its present form.

Criterion 61.50 (a)(10)

Areas must be avoided where surface geologic processes such as mass wasting, erosion, slumping, landsliding, or weathering occur with such frequency and extent to significantly affect the ability of the disposal site to meet the performance objectives of Subpart C of this part, or may preclude defensible modeling and prediction of long-term impacts.

Discussion. The surface geologic processes mentioned in the criterion do not affect underground mine workings, with the possible exception of portals and areas of the mine immediately adjacent to a portal. Wastes will not be placed in portal areas but will be placed in secure chambers deeper in the mine.

The intent of the criterion is to insure that the Performance Objectives be met and that modeling and impact prediction not be impaired. Whether these goals are met will be a function of the chambers and surroundings where the wastes are actually laid, not of the surface appurtenances of the facility or of the mine portal areas. Since the deep spaces where the wastes are laid will not be affected by the surface processes, there is no conceivable way in which these processes, even if they were active at the mine portals, could compromise the desired goals.

Recommendation. In the opinion of the author, the criterion should be deleted, since it is not applicable to a mined cavity disposal site.

Criterion 61.50 (a)(11)

The disposal site must not be located where nearby facilities or activities could adversely impact the ability of the site to meet the performance objectives of Subpart C of this part or significantly mask the environmental monitoring program.

Discussion. As discussed above in section 4.7.1, the mutual interference between an underground facility and nearby surface developments is likely to be minimal. However the criterion is still acceptable as a matter of policy.

Nearby underground activity would be controlled by the facility owner's control of a rock buffer zone, which control should be called for in a Supplemental Criterion. See section 5.4.1.1.

The last clause in the criterion might be interpreted to rule out uranium mines as potential MCLLWDF sites merely because their minerals would complicate the monitoring process. It is felt that such an exclusion is not warranted. A strong argument could be advanced in favor of placing wastes in an area that is already unavoidably subject to radioactivity. The problem of monitoring radioactivity from a disposal facility located in or near a uranium mine might be made more difficult thereby, but this difficulty ought to be accepted and overcome rather than allowing a technicality to overrule an otherwise valid site selection.

The word "facility" should be substituted for "site" as being more appropriate for an underground facility.

Recommendation. The criterion should read as follows. The disposal ~~site~~ facility must not be located where nearby facilities or activities could adversely impact the ability of the site to meet the performance objectives of Subpart C of this part or significantly mask the environmental monitoring program. The proximity of natural radioactive mineral deposits, however, would not rule out an otherwise desirable or acceptable MCLLWDF site.

5.2.2 Design (Section 61.51)

Criterion 61.51 (a)(1)

Site design features must be directed toward long-term isolation and avoidance of the need for continuing active maintenance after site closure.

Discussion. The intent of the criterion is perfectly valid for a MCLLWDF. However, the word "facility" would be preferable to "site" in the context of an underground facility.

Recommendation. The criterion should read as follows. ~~Site~~ Facility design features must be directed toward long-term isolation and avoidance of the need for continuing active maintenance after ~~site~~ facility closure.

Criterion 61.51 (a)(2)

The disposal site design and operation must be compatible with the disposal site closure and stabilization plan and lead to disposal site closure that provides reasonable assurance that the performance objectives of Subpart C of this part will be met.

Discussion. The intent of the criterion is perfectly valid for a MCLLWDF. However, the word "facility" would be preferable to "site" in the context of an underground facility.

Recommendation. The criterion should read as follows. The disposal ~~site~~ facility design and operation must be compatible with the disposal ~~site~~ facility closure and stabilization plan and lead to disposal ~~site~~ facility closure that provides reasonable assurance that the performance objectives of Subpart C of this part will be met.

Criterion 61.51 (a)(3)

The disposal site must be designed to complement and improve, where appropriate, the ability of the disposal site's natural characteristics to assure that the performance objectives of Subpart C of this part will be met.

Discussion. The intent of the criterion is perfectly valid for a MCLLWDF. However, the word "facility" would be preferable to "site" in the context of an underground facility.

Recommendation. The criterion should read as follows. The disposal ~~site~~ facility must be designed to complement and improve, where appropriate, the ability of the disposal site's natural characteristics to assure that the performance objectives of Subpart C of this part will be met.

Criterion 61.51 (a)(4)

Covers must be designed to minimize to the extent practicable water infiltration, to direct percolating or surface water away from the disposed waste, and to resist degradation by surface geologic processes and biotic activity.

Discussion. This criterion deals with covers and surface waters, and is directed toward specifying functions that covers must perform in keeping surface waters away from wastes. As discussed in Chapter 4, covers and surface waters are not matters of concern for a MCLLWDF, and therefore this criterion is irrelevant and should be deleted in its present form. This represents a departure from the Task 1 report (Bennett et al., 1984). Ground water, a matter of direct concern to a MCLLWDF, is treated at other places in these criteria.

It is important at a MCLLWDF to minimize the exposure of wastes to water through engineered as well as natural means. Even though, in the long term, permeation of the wastes in a MCLLWDF by ground water is likely, as discussed in section 4.7.5, it is a desirable feature of facility closures that they impede water, i.e. slow its movement through the wastes to the lowest rate possible. A supplemental criterion dealing with this aspect of closures is desirable. See sections 4.5.9, 5.4.4, and 5.4.1.2.

Recommendation. This criterion should be deleted and replaced with a Supplementary Criterion as discussed above.

Criterion 61.51 (a)(5)

Surface features must direct surface water drainage away from disposal units at velocities and gradients which will not result in erosion that will require ongoing active maintenance in the future.

Discussion. This criterion deals with surface waters and erosion, and protection of the disposal units from the effects thereof. There are virtually no ways in which erosion caused by surface waters will affect the disposal units, which are located in mined cavities underground. Erosion will affect only the surface appurtenances. These are of concern only during the active life of the facility, during which active maintenance will be a routine activity. This criterion has no applicability to a MCLLWDF and is unnecessary.

Recommendation. In the opinion of the author, this criterion could be eliminated for the reasons stated above.

Criterion 61.51 (a)(6)

The disposal site must be designed to minimize to the extent practicable the contact of water with waste during storage, the contact of standing water with waste during disposal, and the contact of percolating or standing water with wastes after disposal.

Discussion. The important question of water has already been encountered in criterion 61.50 (a)(7), which requires extensive modification in the context of Mined Cavity disposal. The present criterion deals with design. Measures may be taken, such as lining of walls and roof and grouting, to mitigate water problems in an underground mine or tunnel. However, these measures should not be regarded as being permanently effective. Only the selection of an inherently dry site will give assurance that the wastes will not come in contact with water in the long term. However, see also the discussion above under criterion 61.51 (a)(4). The word "site" should be changed to "facility" in the context of a MCLLWDF.

Recommendation. The criterion may be retained as is, but the inherent shortcomings of design, as opposed to site selection, for inhibiting water contact with wastes should be understood. "Site" should be changed to "facility."

5.2.3 Operations and Closure (Section 61.52)

Criterion 61.52 (a)(1)

Wastes designated as Class A pursuant to 61.55, must be segregated from other wastes by placing in disposal units which are sufficiently separated from disposal units for the other waste classes so that any interaction between Class A wastes and other wastes will not result in the failure to meet the performance objectives in Subpart C of this part. This segregation is not necessary for Class A wastes if they meet the stability requirements in 61.56(b) of this part.

Discussion. The primary reason for segregation of unstable Class A wastes in a near-surface facility is to prevent or localize subsidence of the cover and consequent infiltration problems. As discussed in section 4.2, subsidence at a MCLLWDF, if it occurred, would result from factors other than unstable wastes, and thus the segregation of unstable wastes for stability purposes is not necessary. However the possible buildup of explosive gas mixtures underground is a real problem, and the recommended wording of the criterion is expanded to take this into account.

Recommendation. The criterion should read as follows: It is desirable that wastes designated as Class A pursuant to 61.55 ~~must~~ be segregated from other wastes by placing in disposal units which are sufficiently separated from disposal units for the other waste classes so that any interaction between unstable Class A wastes and other wastes will not ~~result in the failure tomeet the performance objectives in Subpart C of this part. This~~ take place. Such waste segregation is not necessary ~~for Class A wastes if they meet thestability requirements in 61.56(b) of this part.~~ in a MCLLWDF for prevention of ground subsidence, however, as it is (necessary) in near-surface disposal facilities. Monitoring of the mine atmosphere must be conducted during operations to detect the possible buildup of an explosive atmosphere underground resulting from decay of organic components in Class A wastes, and corrective ventilation measures must be instituted should such a problem be detected.

Criterion 61.52 (a)(2)

Wastes designated as Class C pursuant to 61.55, must be disposed of so that the top of the waste is a minimum of 5 meters below the top surface of the cover or must be disposed of with intruder barriers that are designed to protect against an inadvertent intrusion for at least 500 years.

Discussion. This criterion deals with depth beneath the surface of the cover. The question of cover as a means of achieving shielding above the wastes is irrelevant in a MCLLWDF, as discussed in section 4.1. Thus the first clause in the criterion is unnecessary.

Recommendation. This criterion should read as follows. Wastes designated as Class C pursuant to 61.55 must be disposed of ~~so that the top of thewaste is a minimum of 5 meters below the top surface of the cover or mustbe disposed of~~ with intruder barriers that are designed to protect against an inadvertent intrusion for at least 500 years.

Criterion 61.52 (a)(3)

All wastes shall be disposed of in accordance with the requirements of paragraphs (a)(4) through (11) of this section.

Discussion. This criterion contains no technical information and appears to be unnecessary.

Recommendation. Unless there are other than technical reasons for retaining it, this criterion should be omitted.

Criterion 61.52 (a)(4)

Wastes must be emplaced in a manner that maintains the package integrity during emplacement, minimizes the void spaces between packages, and permits the void spaces to be filled.

Discussion. Minimization of void spaces is not as critical in underground emplacement as it is in near-surface emplacement. However, the criterion may be retained in its present form.

Recommendation. The criterion may remain as is.

Criterion 61.52 (a)(5)

Void spaces between waste packages must be filled with earth or other material to reduce future subsidence within the fill.

Discussion. In a mined-cavity facility, if backfill were to serve as a roof-supporting, subsidence-preventing measure, the backfill material would have to be non-compressible and be emplaced so as to fully fill all inter-canister void space between the floor and the roof of the chamber. Backfill of this nature is desirable in a near-surface facility, in order to prevent subsidence and disruption of the cover, and it is clearly this type of backfill that is intended by this criterion.

However, as discussed above in section 4.2, the primary means of subsidence prevention in a mined cavity is by insuring adequate pillar support and roof rock integrity, and backfill plays at most a subordinate role.

A more appropriate function of backfill in a mined cavity is as a retardant, both of water moving through the wastes (low-permeability material) and of radionuclide out-migration (high-sorptive-capacity material).

The placement of such backfill may be delayed until shortly before closure of the facility, or it may be carried out as the wastes are emplaced; the matter is a management decision.

The reader wishing more information should consult sections 4.5.9 and 4.6.1 of USDOE (1982).

Recommendation. This criterion should be deleted and replaced with a supplemental criterion dealing with backfilling between containers underground. See section 5.4.4.

Criterion 61.52 (a)(6)

Waste must be placed and covered in a manner that limits the radiation dose rate at the surface of the cover to levels that at a minimum will permit the licensee to comply with all provisions of 20.105 of this chapter at the time the license is transferred pursuant to 61.30 of this part.

Discussion. This criterion refers to radiation dose rate at the surface of the cover. Cover, as discussed in several places above, is irrelevant in a MCLLWDF. As discussed in section 4.1, any MCLLWDF will probably have sufficient rock overlying the wastes to meet the dose-rate requirements of this criterion.

Recommendation. This criterion should read as follows. Waste must be placed and covered in a manner that limits the radiation dose rate at the ground surface ~~of the cover~~ to levels that at a minimum will permit the licensee to comply with provisions of 20.105 of this chapter at the time the license is transferred pursuant to 61.30 of this part.

Criterion 61.52 (a)(7)

The boundaries and locations of each disposal unit (e.g., trenches) must be accurately located and mapped by means of a land survey. Near-surface disposal units must be marked in such a way that the boundaries of each unit can be easily defined. Three permanent survey marker control points, referenced to United States Geological Survey (USGS) or National Geodetic Survey (NGS) survey control stations, must be established on the site to facilitate surveys. The USGS or NGS control stations must provide horizontal and vertical controls as checked against USGSD or NGS record files.

Discussion. The purpose of this criterion is to make clearly and unequivocally known the positions of buried wastes. The present language of the criterion, however, is unmistakably directed toward near-surface facilities. The specification of locations underground involves different procedures from that of locations at or near the surface, and the language of the criterion needs to be modified accordingly.

Mine maps are an essential record of any mine. A variety of maps are used, which form permanent records (Staley, 1964). Individual maps are prepared for each mine level. Mine levels are designated by numbers representing depth below the surface, conventionally measured in feet in the U.S.; e.g. the 1400 level is 1400 feet belowground. A rectangular coordinate grid is established for the mine, with an arbitrary zero point usually placed some distance to the southwest of the workings, so that all coordinates will be positive north and east. Location description for a given point in the mine is a matter of specifying level and coordinates, and referencing to the mine map of that level.

Recommendation. The criterion should read somewhat as follows. The Commission may wish to amend the detailed wording. ~~The boundaries and locations of each disposal unit (e.g., trenches) must beaccurately located and mapped by means of a land survey. Near-surface-diposalunits must be marked in such a way that the boundaries of each unit canbe easily defined.~~ The site of the MCLLWDF shall be permanently marked with the multiple high-visibility markers designed to withstand expected regional events and processes such as tornadoes, earthquakes, acid rain, and weathering. Three permanent survey marker control points, referenced to United States Geological Survey (USGS) or National Geodetic Survey (NGS) survey control stations, must be established ~~on~~ near the site to facilitate ~~surveys~~ positive location identification. The USGS or NGS control stations must provide horizontal and vertical controls as checked against USGSD or NGS record files. Mine maps showing the layout of the workings and the locations of all wastes shall be filed in at least three separate permanent public records centers. Information regarding the location and hazard of the facility should be widely disseminated to minimize the potential for inadvertent interference.

Criterion 61.52 (a)(8)

A buffer zone of land must be maintained between any buried waste and the disposal site boundary and beneath the disposed waste. The buffer zone shall be of adequate dimensions to carry out environmental monitoring activities specified in 61.53(d) of this part and take mitigative measures if needed.

Discussion. The word "land" refers to the two-dimensional surface of the ground, and is an inappropriate term with reference to an underground mine. Any buffer zone surrounding an underground mine will be situated in rock. The thickness of such a zone will inevitably be somewhat indefinite, but such a thickness should be governed by the need physically to protect a MCLLWDF from disturbance or penetration from without, rather than by any consideration of monitoring.

Recommendation. A buffer zone ~~of land~~ must be maintained ~~between any buried waste and the disposal site boundary and beneath the disposed waste. The buffer zone shall be of adequate dimensions to carry out~~ on all sides of the MCLLWDF of sufficient thickness to protect the facility from accidental disturbance or penetration from outside, and to allow for environmental monitoring ~~activities specified in 61.53(d) of this part and take mitigative measures if needed~~.

Criterion 61.52 (a)(9)

Closure and stabilization measures as set forth in the approved site closure plan must be carried out as each disposal unit (e.g., each trench) is filled and covered.

Discussion. Reference to a trench is obviously out of place in a criterion directed toward mined-cavity disposal. Beyond this single phrase, however, the criterion as a whole addresses a question, namely stability, with regard to which a MCLLWDF is fundamentally different from a near-surface facility. This matter is discussed above in section 4.2.

Immediate closure of individual disposal units is desirable in a near-surface facility for stabilization purposes. In an underground facility this need does not exist.

Recommendation. This criterion should be deleted and replaced by a supplemental criterion dealing with closure of individual disposal units underground.

This is a departure from the position advanced in the Task 1 report (Bennett et al., 1984), reached after due deliberation concerning the mined-cavity disposal option.

Criterion 61.52 (a)(10)

Active waste disposal operations must not have an adverse effect on completed closure and stabilization measures.

Discussion. The criterion is applicable as written. However, since a MCLLWDF may have filled and inactive but not closed disposal units, the criterion should be expanded to cover such units.

Recommendation. The criterion should read as follows. Active waste disposal operations must not have an adverse effect on completed closure and stabilization measures, nor on inactive but not yet closed disposal units within the facility.

Criterion 61.52 (a)(11)

Only wastes containing or contaminated with radioactive material shall be disposed of at the disposal site.

Discussion. The criterion is applicable as written. However, the word "facility" would be preferable to "site" for a MCLLWDF.

Recommendation. The criterion should read as follows. Only wastes containing or contaminated with radioactive material shall be disposed of at the disposal ~~site~~ facility.

5.2.4 Environmental Monitoring (Section 61.53)

Criterion 61.53(a)

At the time a license application is submitted, the applicant shall have conducted a preoperational monitoring program to provide basic environmental data on the disposal site characteristics. The applicant shall obtain information about the ecology, meteorology, climate, hydrology, geology, geochemistry, and seismology of the disposal site. For those characteristics that are subject to seasonal variation, data must cover at least a twelve month period.

Discussion. The ecology, meteorology, and climate of a disposal site are of less importance for a MCLLWDF than for a near-surface disposal facility. The other named factors are equally important underground as near the surface. However, a complete collection of environmental information is desirable for a MCLLWDF site, so the criterion may be considered applicable as is.

Recommendation. The criterion may be left in its present form.

Criterion 61.53 (b)

The licensee must have plans for taking corrective measures if migration of radionuclides would indicate that the performance objectives of Subpart C may not be met.

Discussion. The intent of this criterion is valid for any LLW disposal facility, including a MCLLWDF. At a MCLLWDF, ground water is the principal and perhaps the only credible release path for radionuclides. If monitoring during the operating life of the facility indicates that radionuclides are leaving the site in ground water, so that performance objective 61.41 may not be met, remedial measures may be effective, i.e. by improving the waste form or packaging, grouting, lining, use of sorptive backfill, etc. If radionuclides are detected after closure, so that either Performance Objective 61.41 or 61.44 may fail to be met, it might be very difficult to implement effective corrective measures, because of the inaccessibility and difficulty of access of the wastes and their close surroundings.

Recommendation. The criterion is valid as written, but the caution as to post-closure remedial measures expressed in the above discussion should be clearly understood by licensees and regulators alike.

Criterion 61.53 (c)

During the land disposal facility site construction and operation, the licensee shall maintain a monitoring program. Measurements and observations must be made and recorded to provide data to evaluate the potential health and environmental impacts during both the construction and the operation of the facility and to enable the evaluation of long-term effects and the need for mitigative measures. The monitoring system must be capable of providing early warning of releases of radionuclides from the disposal site before they leave the site boundary.

Discussion. For a MCLLWDF the "site boundary" is a somewhat meaningless term in a technical sense as regards environmental monitoring. The property limit at the ground surface bears very little relation to places where or routes by which radioactive substances might leave the facility should leaching and ground-water transport of contaminants take place. The wording of the last sentence is therefore unrealistic.

In fact it may be difficult to design and implement a monitoring system that, with certainty, keeps under surveillance all avenues of release of radionuclides from a MCLLWDF. It is not certain whether any monitoring system instituted can have high reliability.

Recommendation. It is recommended that a future research effort be instituted to study the problems of monitoring releases from an underground waste deposit and to attempt to assess the feasibility and probable reliability of a monitoring system.

For the time being, the criterion may be retained as is, but the final clause "before they leave the site boundary" should be omitted.

Criterion 61.53 (d)

After the disposal site is closed, the licensee responsible for post-operational surveillance of the disposal site shall maintain a monitoring system based on the operating history and the closure and stabilization of the disposal site. The monitoring system must be capable of providing early warning of releases of radionuclides from the disposal site before they leave the site boundary.

Discussion. The question of the feasibility of monitoring has been mentioned in the discussion of the previous criterion. As regards long-term, post-closure monitoring, both the feasibility and value of such monitoring need to be carefully considered, and a future research effort to study that problem is recommended.

Arguments cited by USDOE against using subsurface instrumentation for post-closure monitoring have been cited earlier in this report, as has the Swedish decision to dispense with long-term monitoring at Sweden's LLW-ILW repository.

Assuming that long-term monitoring is to be conducted, the criterion may be left as is, with minor modifications.

Recommendation. This criterion should be revised to read as follows. After the disposal ~~site~~ facility is closed, the licensee responsible for post-operational surveillance of the disposal site shall maintain a monitoring system based on the operating history and the closure and stabilization of the disposal site. The monitoring system must be capable of providing early warning of releases of radionuclides from the disposal site ~~before they leave the site boundary~~ , and must be of demonstrable reliability for long-term use.

5.3 Summary of Recommendations

Recommendations as to existing criteria are summarized in Table 1.

5.4 Considerations for Supplemental Criteria

As discussed above, some existing 10 CFR 61 criteria require total revision for application to a MCLLWDF. The subjects that they address are relevant, but basic differences between the underground and near-surface environments make completely different rules necessary. Moreover, the special nature of the underground environment requires that numerous aspects unique to that environment be considered. Therefore, supplemental criteria are required for both these purposes.

The formulation of specific criteria is probably best done by the Commission, which can stress exactly the points that it deems most appropriate in each case. Accordingly, specific criteria are not offered here. Subjects that should be considered in formulating supplemental criteria, however, are discussed below. These discussions are grouped according to the following major typics: Siting, Design, Operation, and Closure. Extensive reliance has been placed on USDOE (1982).

5.4.1 Siting

5.4.1.1 Natural Resources

Criterion 61.50 (a)(4), dealing with regions with natural resources, is highly restrictive toward the Mined Cavity option for reasons as stated in section 5.2.1. Since a mined cavity will probably be situated in a region with such resources, attention needs to be directed toward control of the threat that such a fact presents rather than avoidance of the problem through mere avoidance of the region.

The primary threat to a waste-disposal facility caused by the presence of

SUMMARY OF RECOMMENDATIONS FOR EXISTING CRITERIA

Existing Technical Criterion		Recommendation (See Key below) A	B	C	D	E
61.50(a)(1)	Acceptability	X				
(2)	Characterizability	X				
(3)	Population development	X				
(4)	Natural resources				X	
(5)	Surface flooding			X		
(6)	Runoff					X
(7)	Ground-water intrusion				X	
(8)	Ground-water discharge	X				
(9)	Tectonic hazards	X				
(10)	Surface geologic processes					X
(11)	Nearby activities		X			
61.51(a)(1)	Isolation, maintenance avoidance	X				
(2)	Closure capability	X				
(3)	Enhancement of natural characteristics	X				
(4)	Covers				X	
(5)	Erosion					X
(6)	Water/waste contact	X				
61.52(a)(1)	Waste segregation			X		
(2)	Class C waste burial		X			
(3)	General instruction					X
(4)	Waste emplacement guidance	X				
(5)	Backfilling				X	
(6)	Surface radiation limits	X				
(7)	Waste location specification			X		
(8)	Buffer zone			X		
(9)	Closure of individual units				X	
(10)	Active/completed noninterference		X			
(11)	Radioactive wastes only	X				
61.53(a)	Preoperational monitoring	X				
(b)	Corrective-measures plan	X				
(c)	Construction/operation monitoring		X			
(d)	Postclosure monitoring		X			

Key

A: Leave alone, or 1-2 words modified
B: Revise moderately
C: Revise extensively
D: Replace, with a Supplementary Criterion
E: Delete

natural resources is that of inadvertent disruption of the facility caused by exploration or mining activities. This threat should be met in two ways.

First the facility should be designed and developed in such a way as to take maximum advantage of areas that have already been thoroughly exploited and areas that would be unlikely to be exploited for reasons of ore grade or thickness, geological structure, or any other practical reason. To follow this avenue the general and mining geology and the history and status of mining at the site must be thoroughly explored and documented.

Secondly the site owner, whatever type of entity that may be, must exercise complete and positive control of the underground site, the land area above it, and the subsurface rock area surrounding it so as to be able to prevent, absolutely, any uncontrolled drilling, tunnel driving, or any other underground penetration activity that might impinge on the facility. To set up a framework for this control legal expertise, particularly in the fields of mining law and law governing petroleum exploration, should be retained, and the legal peopel should work closely with experienced technical persons in these fields. In addition to setting up the control, it must be effectively exercised, and the site owner/operator should be required to establish a surveillance and reporting plan to insure that the intented control is indeed carried out.

5.4.1.2 Water Conditions

Water conditions at the MCLLWDF are the most important single factor regarding long-term containment of the radionuclides in the wastes. Aspects of the water problem have been discussed above in section 4.7.5.

An ideal MCLLWDF would be dry, and a realistic MCLLWDF site should be as dry as possible. The dryness should be demonstrably due to natural conditions, and should not require pumping to maintain facility dryness during operation. The best way to demonstrate dry natural conditions is through a documented history of dryness while the mine was in operation.

Any dry or substantially dry mine owes its dryness to the existence of a hydraulic barrier zone surrounding it and shielding it from water. Criteria should require that the configuration of this barrier zone be well established. The weakest or most penetration-prone parts of the barrier should be identified.

The importance of preventing penetration of the barrier zone should be recognized. This is a prime reason for the maintenance of a controlled rock buffer zone, which is addressed elsewhere in these criteria. Any exploration boreholes in the barrier zone should be backfilled using the best available grouting technology.

It is appropriate to allow an exception to the mine dryness requirement similar to the diffusion exception of present criterion 61.50 (a)(7). A deep mine might be so situated that waste disposal in it would be environmentally safe, for reasons as discussed above in section 4.7.5 and having to do with slow migration and long elapsed decay times. The criteria should contain language to allow such an exception, given a suitable demonstration of safety.

5.4.2 Design for Radiological Safety

The material in this section is taken mainly from a Department of Energy analysis of questions of radiological safety at an HLW repository (USDOE, 1982). For the most part the same factors would operate at a MCLLWDF as at an HLW repository. A minority of factors pertinent only to HLW have been omitted here.

The criteria should provide that systems important to safety be designed and located to withstand, and continue functioning under, expected normal operating conditions, probable natural phenomena, and design basis accident conditions. Considerable discussion of such systems and the adverse conditions that they might have to face is given in USDOE (1982).

The facilities at a MCLLWDF should be designed to ensure that radiation exposure of working personnel is as low as reasonably achievable. Maintainability and reliability of components of the MCLLWDF should be considered in limiting occupational exposure.

The MCLLWDF should be designed to have means to monitor and control any effluents that might emanate from its surface facilities. The radioactivity in any such effluents must be maintained below appropriate regulatory limits. Enough holding capacity should be provided for retention, if necessary, of effluents containing radioactive materials. The design of a MCLLWDF should provide for control of access to the facility and to areas of potential contamination or high radiation within the facility. The facility should be designed so that the spread of contamination during emergencies would be confined to controlled zones and monitored. Radiation alarm systems should be provided to warn facility personnel of significant increases in radiation levels in normally accessible spaces and of excessive radioactivity released in plant effluents.

Overall mining strategies should be prepared and implemented for the development of underground workings to ensure that mine development does not unnecessarily interfere with waste-emplacement activities. Blasting operations should be carefully coordinated so that waste-emplacement operations are not affected. Blasting safety is discussed in section 5.4.3.1.

Hoisting systems utilized for moving waste should be physically separated if possible from hoisting systems utilized for the haulage of personnel and materials and for emergency escape. To the extent feasible, hoisting systems for waste should be dedicated exclusively for that use. Hoisting configurations for waste should be designed to minimize the spread of contamination and to facilitate frequent inspection and maintenance. Methods should be provided, either as part of the hoisting system or in the form of auxiliary systems such as emergency braking systems, impact absorbers, isolation systems, and so forth, to mitigate the consequences of a failure of the waste-hoisting system and to confine the consequences to a limited area of the facility.

Separate mine openings should be provided for main intake-air and return-air currents. Ventilation systems should be designed to assure that air may flow from mine development areas to waste emplacement areas but not vice versa. Separate ventilation systems should be provided for mine development and waste emplacement areas. Main fans should be located on the surface.

The MCLLWDF design should take into account the need to minimize human interference with the disposal system both during and after waste-disposal activities.

5.4.3 Operations

5.4.3.1 Mining Safety

Simply because a MCLLWDF operates in an underground-mine environment, it shares many safety problems with underground mines in general. The following guidance cited in USDOE (1982) is derived largely from existing Federal regulations dealing with mining safety.

Methods and equipment for excavating, conveying, loading, hauling, dumping, and processing mined material should conform to the latest version of MSHA standards. Frequent inspection of faces and haulageways should be conducted by appropriate facility management personnel to ensure that proper methods and equipment are employed. All standard blasting and explosives safety procedures, as required by Federal and State mining authorities, should be spelled out and enforced. The best underground blasting practice should be followed so as to preclude structural damage to the roof and walls of the disposal facility.

A program for underground fire prevention and control should be developed and implemented. This program should provide for fire-fighting equipment adequate for the mine at any stage of development, and should address the placement, maintenance, and inspection of the equipment; training of personnel in its use; installation of alarm systems; development of emergency plans; control of welding and similar processes; control and use of combustible materials; and procedures for controlling fire hazards in inactive areas of the facility.

Systems should be provided to minimize personnel exposure to harmful airborne contaminants by preventing contamination, removing exhaust ventilation, and diluting contaminants with uncontaminated air, or some combination thereof. Dust, gas, mist, and fume surveys should be conducted as frequently as necessary to determine the adequacy of control measures. Should potentially hazardous concentrations be found, active work areas should be sampled as often as necessary to ensure that exposures of operating personnel be kept within acceptable levels. Temperatures in the underground workings should be maintained to within safe operating limits.

The storage and handling of all materials underground should follow a prescribed procedure, with the degree of storage and handling precautions established in the procedures being commensurate with the hazards associated with each material. Surplus mined material should be hoisted to the surface and stored or disposed of as necessary, either on or off site, in an environmentally acceptable manner.

Power-supply systems to support underground operations should conform to the mandatory requirements of 30 CFR 57.12. Trailing cables should be properly bridged or protected from being run over by mobile equipment.

Programs should be developed and implemented to foster the occupational safety and protection of all underground personnel. These programs should include safety training and indoctrination programs; periodic formal safety inspections with written reports of findings and recommendations; procedures for implementing recommendations and remedial actions to eliminate unsafe conditions; designation of first aid and emergency teams and equipment; and the design, installation, inspection, testing, and maintenance of safety restraint and interlock systems. Personnel should not engage in work activities that they have not been properly trained for and qualified to perform. All personnel underground should be equipped with, and trained in the use of, appropriate protective equipment and clothing.

Detailed plans should be developed and implemented as necessary for dealing with underground emergencies such as rock bursts, rockfalls, gas, squeezing and swelling rock, fires, flooding, explosions, and malfunction of hoisting equipment. These plans should include evacuation procedures, routes, and shelters; designation of front-line crews to cope with the emergency; arrangement for outside assistance as necessary; and procedures and tests for determining the suitability of resuming operations when the emergency has passed.

Hoisting, excavation, and utility systems, and systems provided to foster occupational safety, should be designed to permit frequent in-place inspection, testing, and maintenance. The frequency of such activities should be commensurate with the safety and maintenance requirements of the system.

5.4.3.2 Long-term Containment and Isolation of Radioactive Materials

Assurance of long-term containment depends on the soundness of the MCLLWDF. The integrity of the latter must not be compromised by intersection with harmful geologic weaknesses nor by damaged rock resulting from poor mine-development practices. There must not be structural damage to the roof or wall rocks produced by poor excavation or mining practices during the former active life of an abandoned mine. In the site qualification and site documentation procedures, particular attention needs to be paid to the structural condition of roof and wall rocks.

Each potential MCLLWDF site is unique in its geologic setting and surroundings. Where a watertight envelope is presently intact but might easily be violated by further mine development, it could be appropriate that the facility license require all excavation to be completed before waste emplacement begins. At other sites where there is ample room for mine development with reasonable confidence in maintaining the watertight integrity, no such restriction is necessary. The Konrad mine in West Germany is an example of the latter category.

Expansion of underground disposal areas into virgin host rock areas should be preceded by an exploratory program to properly document the preemplacement state of the host rock unit in that area. Such exploration should identify local anomalies sufficiently in advance to allow analysis of the threat that such anomalies might pose to disposal areas developed in their vicinity. Exploration boreholes, which if left open would represent potential serious breaches in the watertight envelope, should be backfilled using the best available grouting technology.

When rock is excavated underground, the balance of the forces present in the geologic formation is altered. As equilibrium is reestablished, localized fracturing around the perimeter of the excavated areas can result from stress concentrations. Fracturing can also occur as a direct effect of blasting. Fracturing around the excavation, if extensive, may provide a potential pathway for ground water. The extent of fracturing depends on the rock type, the extent of natural jointing or fracturing, the depth of the facility, in situ stress, and the excavation techniques used.

The excavation of rooms and tunnels underground will induce a new stress state and displacement field in the host environment. The nature of these stresses and displacement fields depends on the cross-sectional geometry and orientation of the excavation, the layout of the tunnels and rooms, and the extraction ratio (the ratio of the volume removed to the total volume). Of interest to long-term containment and isolation is the possibility of subsidence in the strata overlying the facility in some geologic media, which might lead to adverse perturbations in the hydrologic regime.

To limit fracturing, the following excavation controls should be exercised. Design of the excavated areas should take into consideration extraction ratios and room geometries which limit the extent of fracturing due to stress concentrations. If blasting is used, control should be exercised in designing blasting patterns and in selecting charge sizes and types and sequence of detonation. Mechanical excavation methods should be used wherever feasible and practical. The extent of possible subsidence of the ground surface, if significant, should be reduced by employing relatively low extraction ratios, artificial roof-support measures, and, if necessary, backfilling of the excavated areas after waste emplacement.

5.4.4 Closure

Backfilling and closure of individual disposal units are discussed here under the heading of closure, although they affect operations as well. Two existing criteria, 61.52(a)(5) and 61.52(a)(9), were recommended above for replacement by supplemental criteria. The Commission should decide how many criteria are necessary to deal with these related subjects.

The reader should refer to section 4.5.9, to the discussions under criteria 61.52 (a)(5) and 61.52(a)(9), and to the discussions in sections 4.5.9 and 4.6.1 of USDOE (1982). Backfilling between the waste containers does not fulfill the same immediate-stabilization role in a MCLLWDF that it does in a near-surface facility. Similarly, immediate closure of completed individual disposal units--which in a MCLLWDF would be disposal rooms or groups of rooms in an area--is not as necessary for stability as it is in a near-surface facility.

A vital step in closure is the sealing of all penetrations associated with the facility, since discrete channels are of extreme importance in the underground flow of fluids. Penetrations include shafts, boreholes, entrance tunnels, and all similar openings. Important characteristics of seals are their long-term durability, ability to prevent transmission of fluids, and mechanical properties. Seals should be designed on a site-specific basis to insure that materials and techniques used are compatible and appropriate for local conditions. The goal of sealing is to render the total three-dimensional region of the facility as solid, stable, and impervious as possible.

A great deal of research into sealing materials and methods has been performed in programs devoted to HLW disposal, in the U. S. and in other countries as well (e.g. Lopez, Cheung, and Dixon, 1984; Muroi et al., 1984; Pusch, 1983). Findings from this research could be applied to MCLLWDF closures. It has not been attempted in this study to examine in detail the possible MCLLWDF applications of closure research conducted to date. It is recommended, however, that a future effort be conducted to relate the findings of such research to the sealing of LLW mined-cavity disposal facilities.

5.4.5 Environmental Monitoring

The four existing criteria addressing environmental monitoring, sections 61.53 (a) through (d), deal adequately with the subject, provided they are modified as recommended herein. No supplemental criteria appear to be necessary for dealing with environmental monitoring for mined-cavity disposal.

6. SUMMARY AND RECOMMENDATIONS

6.1 Summary of Findings

This report has considered the Mined Cavity alternative, one of several alternative concepts of LLW disposal. It was recognized at the outset that the Mined Cvity environment differs in fundamental ways from that of near-surface alternatives. Many of the differences were discussed as they relate to LLW disposal. No attempt was made to rank Mined Cavities as being superior or inferior to near-surface disposal.

In view of the differences, it would be expected that technical criteria for Mined Cavity disposal should differ in many ways from those governing near-surface disposal. In fact, over half the existing 10 CFR 61 criteria were found to be applicable to Mined Cavity disposal with no more than minor modifications. However, nearly half the existing criteria were found to be seriously inappropriate for application to Mined Cavities. Of these, some were found to require extensive modification, some to require outright replacement by criteria addressed to the same subject but differently formulated, and a handful to be not applicable to the mined-cavity environment and thus be recommended for complete omission.

A number of new criteria (supplemental criteria not substituting for existing criteria) appear to be needed, in view of the special nature of the underground environment. Diligent effort may be required by the Commission, or by others on its behalf, first to decide which specific technical matters need to be covered by criteria, and then to formulate the same. Matters to be considered in preparing these criteria have been outlined in this report.

Several technical matters are prominent, either because of their basic importance or because they represent unresolved questions. Ground water is a technical factor of the greatest importance, and criteria relating to ground water figure prominently. Protection of the hydrologic envelope surrounding a mined cavity is a matter of urgency. Remedial measures in the event the site fails to meet the Performance Objectives, particularly after closure, may be very difficult to implement with a Mined Cavity site; therefore proper site qualification in advance is very important. Partially unresolved matters include the acceptability of natural resource areas for consideration for Mined Cavity disposal sites and the feasibility of and need for long-term environmental monitoring following closure of a Mined Cavity disposal site. These and other uncertainties are suggested as worthwhile topics for future research (see next section).

6.2 Recommendations

It is recommended that further research be devoted toward the topics listed below.

6.2.1 Regions with Natural Mineral Resources

There is an undeniable conflict in the use of mined space in regions of natural mineral resources. A purist position would be: no acceptance of a region with natural resources that would serve as an impetus toward violation of the integrity of a disposal facility. Is this position really justified and necessary? And does it in fact deny access to desirable existing underground spaces that may be, in fact, safe? Can the realistic threat to safety in using spaces in such regions be quantitatively evaluated?

A corollary avenue of inquiry might be: what about disposal in underground uranium mines, even wet ones? What incremental environmental contamination would result from waste disposal, over and above that inevitably present from the existence of the mine itself?

6.2.2 Long-term Monitoring of Closed Mined Cavity LLW Disposal Sites

U.S. regulatory policy (10 CFR 61.53 (d)) now calls for long-term post-closure monitoring of all LLW land disposal sites. There is a precedent in the Swedish system for no planned long-term subsurface monitoring, after closure, of Sweden's underground LLW/ILW repository. Is the U.S. policy realistic? The question that might be researched is: In view of the inaccessible underground location of a closed MCLLWDF, could any subsurface monitoring technique, and if so which one(s), be realistically expected to give a valid indication of environmental contamination coming from the MCLLWDF?

6.2.3 Site Qualification Procedure for MCLLWDF

Remedial measures are expected to be difficult at a MCLLWDF, particularly after closure, because of the inaccessibility of the site. Even during the site operating period, a defective site may give intractable problems. The site qualification procedure for a MCLLWDF is of paramount importance. Because of the special features of the Mined Cavity environment, different and distinct from that of a near-surface disposal facility, it is recommended that research be devoted toward identifying the necessary elements of a Site Qualification procedure for a MCLLWDF. The Site Qualification procedures used in foreign countries (West Germany, Sweden) should be examined in detail in this research.

6.2.4 Adaptation of Sealing Technology to MCLLWDF Closures

The sealing of openings is a very important step in the closure of a MCLLWDF. Much attention has been devoted to sealing measures for underground spaces in studies both in the U.S. and elsewhere. LLW sealing requirements will be unique in some respects. A well-defined research project would be to survey the results of sealing investigations to date and to match them to the requirements of MCLLWDF site closure.

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Alternative methods for low-level radioactive waste disposal using engineered facilities may be considered for licensing in the coming years. One such method is disposal in mined cavities. Technical considerations in licensing a mined cavity disposal facility pursuant to 10 CFR Part 61 are discussed herein.

There are many important differences between the underground environment of a mined cavity and the environment of near-surface alternatives. Technical criteria for evaluating mined cavity disposal facilities may be expected to differ from those appropriate for near-surface facilities. While many of the technical criteria must be addressed in fundamentally different ways for mined cavity disposal, about half of the 10 CFR Part 61 technical criteria were found to be directly applicable.

Each of the 10 CFR Part 61 criteria for siting, design, operations and closure, and monitoring are considered in this report and in each case a recommendation is made as to its applicability to mined cavity disposal. Suggestions for supplemental criteria are also presented. Finally, the report offers suggestions for further research related to unresolved technical issues.

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