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Evaluation of Engineering Aspects of Backfill Placement for High Level Nuclear Waste (HLW) Deep Geologic Repositories

Final Report (Task 5)
June 1981 - February 1983

Prepared by W. Roberds, J. Kleppe, L. Gonano

Golder Associates

Prepared for
U.S. Nuclear Regulatory
Commission

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W. Roberds, J. Kleppe, L. Gonano

Golder Associates
2950 Northup Way
Bellevue, WA 98004

Prepared for
Division of Waste Management
Office of Nuclear Material Safety and Safeguards
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555
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PREVIOUS REPORTS IN SERIES

(Contract No. NRC-02-81-037)

Report Number	Issuance Date	Contract Task	Title
NUREG/CR-2613	3/12/82	1	Identification of Characteristics Which Influence Repository Design - Tuff
NUREG/CR-2614	3/12/82	1	Identification of Characteristics Which Influence Repository Design - Domal Salt
NUREG/CR-3065	11/15/82	2	In Situ Test Programs Related to Design and Construction of High Level Nuclear Waste (HLW) Deep Geologic Repositories
NUREG/CR-2854	7/9/82	3	Evaluation of Alternative Shaft Sinking Techniques for High Level Nuclear Waste (HLW) Deep Geologic Repositories
NUREG/CR-2959	10/12/82	4	Relationship of an In Situ Test Facility to a Deep Geologic Repository for High Level Nuclear Waste

ABSTRACT

This report represents the results of Task 5, "Evaluation of Engineering Aspects of Backfill Placement for High Level Nuclear Waste (HLW) Deep Geologic Repositories," of U.S. Nuclear Regulatory Commission (NRC) Contract NRC-02-81-037, "Technical Assistance for Repository Design."

The purpose of the complete project is to provide NRC with technical assistance to enable the focused, adequate review by NRC of aspects related to design and construction of an in situ test facility and final geologic repository, as presented in U.S. Department of Energy (DOE) Site Characterization Reports (SCR) and License Application (LA).

This report includes the identification and subjective evaluation of alternative schemes for backfilling around waste packages and within emplacement rooms. The aspects of backfilling specifically considered in this study include construction (i.e., preparation of material and additives, if any, and subsequent placement and compaction, if any) and testing; costs have not been considered. However, because construction and testing are simply implementation and verification of design, a design basis for backfill is required. In the absence of an accepted backfill design basis, a generic basis has been developed for this study by first identifying qualitative performance objectives for backfill and then weighting each with respect to its potential influence on achieving the repository system performance objectives of public safety in short-term construction/operation and long-term waste containment/isolation. In this assessment, backfill is considered to be an integral component of the repository system. However, as quantitative performance assessment is beyond the scope of this study, the identification and weighting of objectives has been based on defined premises and perceptions regarding repository design concepts, performance assessment methodology, and media/site conditions, hence resulting in a qualitative design basis. Although deemed sufficient for the purposes of this study (i.e., for comparative evaluations of alternative backfill schemes), the design basis must be refined on a site-specific basis by quantitative performance assessment prior to any use (which has not been intended here) in guiding backfill design.

Alternative backfill materials and additives, as the principal contributors to achieving the design basis, have been identified and evaluated with respect to the perceived extent to which each combination can be expected to achieve the backfill design basis. Based on this subjective evaluation, several distinctly different combinations of materials and additives which are perceived to have the highest potential for achieving the backfill design basis have been selected for further study. These combinations include zeolite/clinoptilolite, bentonite, muck, and muck mixed with bentonite. Feasible alternative construction and testing procedures for each selected combination have been discussed. To the extent possible, recommendations have been made regarding appropriate backfill schemes for hard rock (i.e., basalt at Hanford, Washington, tuff at Nevada Test Site, and generic granite) and salt (i.e., domal salt on the Gulf Coast and generic bedded salt). Additional recommendations have been made regarding the utilization of Task 5 results by NRC and also regarding potentially effective future work.

EXECUTIVE SUMMARY

ES.1 INTRODUCTION

This report presents the results of Task 5, "Evaluation of Engineering Aspects of Backfill Placement for High Level Nuclear Waste (HLW) Deep Geologic Repositories," of U.S. Nuclear Regulatory Commission (NRC) Contract NRC-02-81-037, "Technical Assistance for Repository Design."

The purpose of the complete project is to provide NRC with technical assistance for the following reasons:

- To enable the focused, adequate review by NRC of aspects related to design and construction of an in situ test facility and final geologic repository, as presented in U.S. Department of Energy (DOE) Site Characterization Reports (SCR)
- To ascertain that the DOE site characterization program will provide, as far as possible, all the information necessary to permit a review to be conducted by NRC of a License Application (LA).

This report includes the identification and subjective evaluation of alternative schemes for backfilling around waste packages and within emplacement rooms, where a scheme essentially consists of:

- Material and possible additives used for backfill
- Procedures used in preparing, placing and possibly compacting the backfill
- Schedule of backfill construction.

Also, tests verifying that the backfill design basis has been reasonably achieved by specific backfill schemes have been identified.

However, the identification of alternatives has been restricted to those presently available, and the evaluation of alternatives has not been based on either quantitative performance assessments or cost estimates, as both are outside the scope of this report. Hence, the evaluation must be considered to be subjective rather than objective.

To the extent possible, recommendations have been made regarding appropriate backfill schemes for:

- Hard rock, including
  - basalt at Hanford, Washington
  - tuff at Yucca Mountain, Nevada Test Site
  - granite at an unspecified site

- Salt, including
  - domal salt at specific Gulf Coast sites
  - bedded salt at an unspecified site.

ES.2 PERSPECTIVE

Deep geologic repositories for permanent disposal of high level nuclear waste (HLW) must achieve certain performance objectives related to public safety. These repository system performance objectives can be simply summarized as:

- Reasonably minimizing hazards jeopardizing the safety of the public and personnel during repository construction and operation (i.e., short term)

- Reasonably minimizing radionuclide transmission to the accessible environment and thus minimizing hazards jeopardizing public safety after decommissioning (i.e., long term).

Once a suitable site has been selected, the repository must be designed for that site so as to achieve the performance objectives. The repository must subsequently be constructed and operated in accordance with that design. Verification will then be required that the design has been implemented and that the performance objectives have been or will be achieved.

When backfill is utilized to influence repository system performance, it must be considered as an integral component of the repository system. Thus, backfill must be designed to maximize its contribution towards achieving the performance objectives, and subsequently constructed and tested with reference to that design. This design will essentially consist of desired in-place characteristics of backfill, which will be primarily a function of the materials/additives and construction procedures used. Hence, once the design basis has been established, appropriate materials/additives and construction procedures can be selected to meet this design and appropriate tests specified to verify that the design has been met.

However, there is presently no clearly accepted design basis for backfill. In fact, the role of the backfill component in the repository system, and moreover its effect on system performance, has not in Golder Associates' opinion previously been established explicitly. It is Golder Associates' opinion that a design basis for backfill must be logically and explicitly derived in order to be defensible, and furthermore that this derivation must be based on backfill's potential contribution to achieving the repository system performance objectives.

ES.3 APPROACH

ES.3.1 Introduction

Based on the above perspective (Section ES.2), the following sequential activities have been completed under Task 5 (see Figure ES.1), and summarized in the following subsections:

- Development of a design basis for backfill (in Section ES.3.2)
- Development of a methodology to comparatively evaluate alternative backfill schemes (in Section ES.3.3)
- Identification of alternative backfill schemes (in Section ES.3.4)
- Preliminary evaluation of alternative backfill materials/additives (in Section ES.3.5)
- Evaluation of selected alternative backfill schemes (in Section ES.3.6).

Based on the results of these activities, Golder Associates has made recommendations regarding backfilling. Recommendations have also been made regarding NRC's use of these Task 5 results in their review process and regarding potentially effective future work.

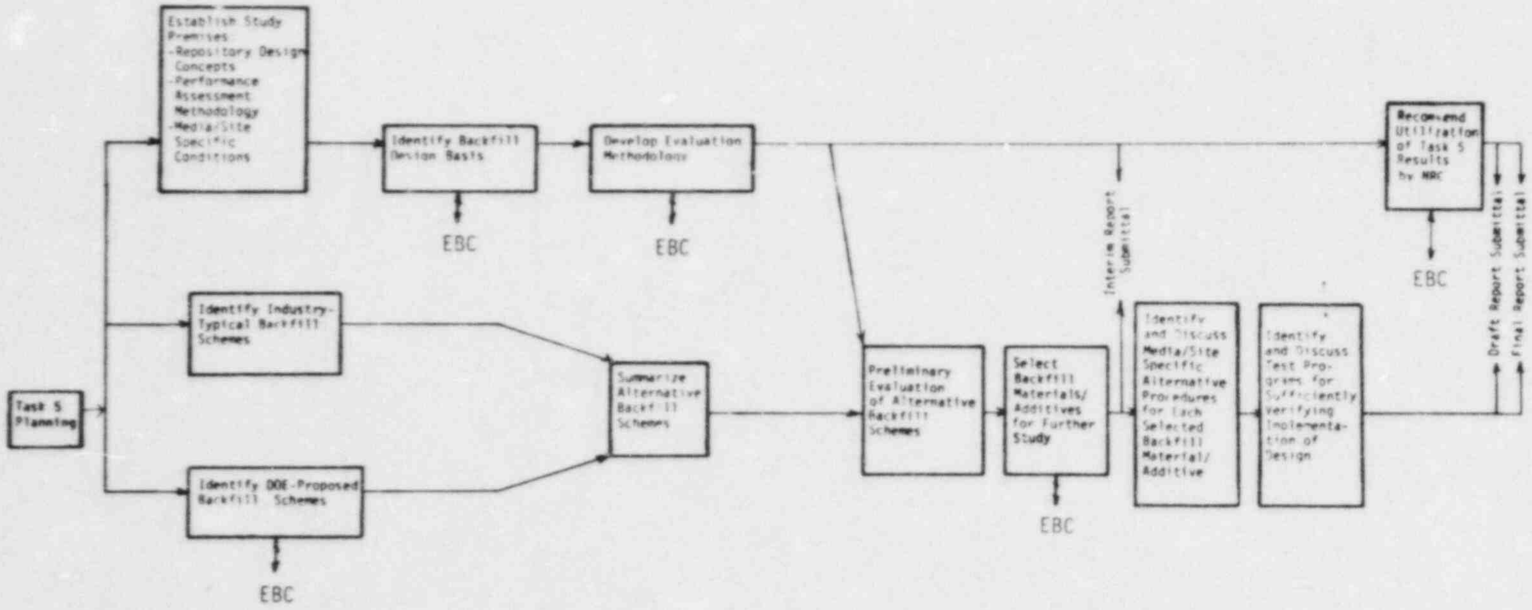
ES.3.2 Development of a Design Basis for Backfill

In the absence of an accepted design basis for backfill, a reasonable comprehensive design basis sufficient for the purposes of this study had to be developed. This generic design basis consists of subjectively weighted backfill design objectives (see Table ES.1), which have been explicitly derived from the repository system performance objectives of safety in short-term construction/operation and long-term waste containment/isolation. This explicit derivation has consisted of:

- Identifying all the significant contributors (not only backfill) to each repository system performance objective. This has been accomplished by first identifying a reasonable comprehensive set of contributors to each of the two repository system performance objectives, and then identifying a more detailed set of contributors to each of the higher order contributors, and so on until backfill design objectives have been identified. The manner in which each aspect of backfill contributes to achieving the repository system performance objectives, and thus backfill's role in the repository system, has been established through this hierarchy

- Weighting each of the significant contributors, relative to each other, with respect to achieving the repository system performance objectives. This has been accomplished by first weighting each of the (subordinate) contributors in a comprehensive set with respect to its potential contribution (relative to the other members in the set) to achieving the parent. This weighting has been based on the perceived sensitivity of the parent to the subordinate and the possible range in the subordinate, assuming generic site conditions.

TASK 5 - ACTIVITY FLOW CHART



EBC - interaction with NRC Contract (NRC-02-81-027) entitled "Performance of Engineered Barriers in a Geologic Repository"

Backfill includes material placed around the waste package, in the mined openings and in tunnels, but not including shafts or boreholes.

Backfill procedures include preparing, placing, compacting and testing.

Backfill schemes include backfill materials/additives (including source), backfill procedures (including equipment), and backfilling schedule.

Figure ES.1

BACKFILL DESIGN BASIS: COMPREHENSIVE SET OF WEIGHTED BACKFILL DESIGN OBJECTIVES

Table ES.1
1 of 4

	BACKFILL DESIGN OBJECTIVES			RELATIVE WEIGHT OF BACKFILL DESIGN OBJECTIVES WITH RESPECT TO ACHIEVING REPOSITORY SYSTEM PERFORMANCE OBJECTIVES		
				PERIOD OF CONCERN		
	Scale	Code	Objective	-1) During Retrieval Period	-2) Post Decommissioning To Resaturation	-3) Post Resaturation
SCHEDULE	Room Scale	bsr1a	[Minimize] time to placement of backfill (room scale)	**B**		
		bsr1b	[Delay and minimize] backfilling of tunnels along possible egress routes	**C**		
		bsro1a	[Maximize] time to placement of backfill (room scale)	**C**		
		bsro1b	[Maximize] time to placement of backfill (room scale), and ventilate	**C**		
		bsro1c	[Maximize] time to start resaturation process (i.e., maximize time to placement of backfill, room scale, while dewatering)	**A**		
	Waste Package Scale	bsh1	[Minimize] time to placement of backfill around waste package	**C**		
		bsho1	[Maximize] time to placement of backfill around waste package,and ventilate	**C**		
PROCEDURES	Room Scale	bpr1	[Minimize] volume of backfill (room scale) (if placed during retrieval period)	**C**		
	Room and Waste Package Scale	bp1	[Maximize] use of safe/reliable equipment for backfilling	**B**		
		bp2	[Maximize] monitoring of potentially hazardous underground conditions as backfilling occurs	**B**		
		bp3	[Maximize] quick and efficient mitigation of detected underground hazards as backfilling occurs	**B**		
		bp4	[Minimize] personnel requirements for backfilling (i.e., maximize mechanization and remote operations)	**B**		
		bp5	[Minimize] total effort required for backfilling (e.g., no backfilling)	**C**		

(SEE KEY AT END OF TABLE)

BACKFILL DESIGN BASIS: COMPREHENSIVE SET OF WEIGHTED BACKFILL DESIGN OBJECTIVES

Table ES.1
2 of 4

			BACKFILL DESIGN OBJECTIVES	RELATIVE WEIGHT OF BACKFILL DESIGN OBJECTIVES WITH RESPECT TO ACHIEVING REPOSITORY SYSTEM PERFORMANCE OBJECTIVES		
				PERIOD OF CONCERN		
	Scale	Code	Objective	-1) During Retrieval Period	-2) Post Decommissioning To Resaturation	-3) Post Resaturation
MECHANICAL CHARACTERISTICS	Room Scale	bmr1	[Minimize] integrity (compaction) of backfill (room scale) (if placed during retrieval period)	C		
		bmr2a	[Maximize] support pressure (or structural support) provided by backfill (room scale)	B		
		bmr2b	[Maximize] increase in support pressure (or structural support) provided by backfill (room scale)		D	D
		bmr2c	[Minimize] decrease in support pressure (or structural support) provided by backfill (room scale)		D	D
		bmro2a	[Minimize] support pressure (or structural support) provided by backfill (room scale)	C		
		bmro2c	[Maximize] decrease in support pressure (or structural support) provided by backfill (room scale)		E	E
	Waste Package Scale	bmh1	[Minimize] stress transfer through backfill around waste package	C	C	B
		bmh2a	[Minimize] swelling pressure of backfill around waste package	C		
		bmh2b	[Minimize] increase in swelling pressure of backfill around waste package		C	C
THERMAL CHARACTERISTICS	Room Scale	btr1	[Maximize] insulation of waste package from rock mass around underground opening (room scale)	C	D	D
		btro1	[Minimize] insulation of waste package from rock mass around underground opening (room scale)	D	E	E
	Waste Package Scale	bth1	[Maximize] insulation of waste package from rock mass around emplacement hole	D	D	D
		btho1	[Minimize] insulation of waste package from rock mass around emplacement hole	C	C	B

(SEE KEY AT END OF TABLE)

BACKFILL DESIGN BASIS: COMPREHENSIVE SET OF WEIGHTED BACKFILL DESIGN OBJECTIVES

Table ES.1
3 of 4

	BACKFILL DESIGN OBJECTIVES			RELATIVE WEIGHT OF BACKFILL DESIGN OBJECTIVES WITH RESPECT TO ACHIEVING REPOSITORY SYSTEM PERFORMANCE OBJECTIVES		
				PERIOD OF CONCERN		
	Scale	Code	Objective	-1) During Retrieval Period	-2) Post Decommissioning To Resaturation	-3) Post Resaturation
HYDROLOGIC CHARACTERISTICS	Room Scale	bhr1a	[Minimize] hydraulic conductivity (and effective porosity) of backfill and interface (room scale)	**D**	**B**	**A**
		bhr1b	[Maximize] decrease in hydraulic conductivity (and effective porosity) of rock mass (room scale) (i.e., sealing/filling of discontinuities) by backfill			**B**
		bhr2	[Maximize] porosity of backfill (room scale)	**B**	**B**	
	Room and Waste Package Scale	bh1	[Maximize] distance from waste package through repository along flow path due to backfill			**A**
GEOCHEMICAL CHARACTERISTICS	Room Scale	bgr1	[Maximize] protection of exposed rock surface underground (room scale) by backfill	**D**	**E**	**E**
		bgr2	[Maximize] thickness/adsorption of backfill (room scale)	**B**		
	Waste Package Scale	bgh1	[Maximize] mitigation of corrosive groundwater by backfill (waste package scale)	**B**	**B**	**B**
		bgh2	[Maximize] thickness/adsorption of backfill around waste package	**C**		
	Room and Waste Package Scale	bg1	[Maximize] length of flow path from waste package through backfill adsorbing material			**B**
		bg2	[Maximize] cross-sectional area of flow path from waste package through backfill adsorbing material (i.e., maximize volume of backfill)			**B**
		bg3	[Maximize] surface area per unit volume of backfill adsorbing material along flow path from waste package			**B**
		bg4	[Maximize] adsorption potential of backfill along flow path from waste package to accessible environment			**A**

(SEE KEY AT END OF TABLE)

BACKFILL DESIGN BASIS: COMPREHENSIVE SET OF WEIGHTED BACKFILL DESIGN OBJECTIVES

Table ES.1
4 of 4

KEY FOR CODE:

	Subject of Concern	Scale	Opposite to Identifier No.	Identifier No.	Similarity with Identifier No.		Time Period
b	s-schedule p-procedure m-mechanical t-thermal h-hydrologic g-geochemical	r-room scale h-waste package scale blank-room and waste package scale	blank o-opposite objective	1 2 3 . . .	blank a-similar b- " c- " . .	-	1-during retrieval period 2-post decommissioning to resaturation 3-post resaturation

For example:

b s r 1 a - 1

KEY FOR RELATIVE WEIGHT:

A $10^{-2} \leq$ Relative Weight (most significant)

B $10^{-3} \leq$ Relative Weight $< 10^{-2}$

C $10^{-4} \leq$ Relative Weight $< 10^{-3}$

D $10^{-5} \leq$ Relative Weight $< 10^{-4}$

E Relative Weight $< 10^{-5}$ (least significant)

NOTE: The weights of these backfill design objectives with respect to their contribution to achieving the repository system performance objectives have been explicitly derived. This development has been based on preconceived repository design concepts (specifically vertical waste emplacement), performance assessment methodology, and generic site conditions; should these premise change, the weights may change. For example, backfill design objectives and their weights may be slightly different for horizontal waste emplacement; these potential differences are discussed elsewhere. Also, the weights entail significant subjectivity in their assessment, and should thus be considered only as approximate indicators of relative significance.

Although deemed sufficent for the purposes of this study (i.e., a design basis for comparative evaluations of alternative backfill schemes), this generic design basis would have to be refined on a site-specific basis by quantitative performance assessment prior to any use (which has not been intended here) in guiding backfill design.

> These subjectively assessed weights have then been compounded down through the hierarchy (by simple multiplication) to determine the weight of any contributor with respect to its potential contribution (relative to all other contributors) to achieving the repository system performance objectives. By this weighting, the significance of each backfill design objective with respect to achieving the repository system performance objectives has been established for generic site conditions; this significance of backfill design objectives is not only relative to each other, but also relative to all other components of the repository system. The weight of the set of backfill design objectives with respect to achieving the repository system performance objectives, relative to all other repository components, has been determined to be about 0.16 for a generic site.

The weighted backfill design objectives (Table ES.1) have been categorized in terms of the subject of concern (i.e., schedule, procedures, mechanical characteristics, thermal characteristics, hydrologic characteristics, or geochemical characteristics), the scale of concern (i.e., room scale, waste package scale, or both), and the period of concern (i.e., during the retrieval period, post-decommissioning to resaturation, or post-resaturation). Many of the most important detailed backfill design objectives can be summarized as relating to the primary objectives of providing structural support, water flow attenuation, or radionuclide transport attenuation.

The identification and subsequent weighting of these backfill design objectives have been based on certain premises and perceptions, especially regarding assumed repository design concepts, performance assessment methodology, and media/site specific conditions (where applicable); should these premises change, the objectives and especially the weights might change. However, these premises have been defined, as much as possible, and the derivations based on these premises have been clearly exposed for discussion. Also, due to the subjective nature of the assessments, there is significant uncertainty inherent in the weights. Hence, although deemed sufficient for the purposes of this study (i.e., for comparative evaluations of alternative backfill schemes), this generic design basis would have to be refined on a site-specific basis by quantitative performance assessment prior to any use (which has not been intended here) in guiding backfill design. The natural variability of site conditions, as they pertain to backfill, must be assessed and considered in such a refinement.

ES.3.3 Development of a Methodology to Comparatively Evaluate Alternative Backfill Schemes

A methodology for comparatively evaluating alternative backfill schemes with respect to meeting the design basis has been developed. This methodology consists of subjectively evaluating the percentage of each detailed design backfill design objective which might reasonably be achieved by a backfill scheme's expected performance. This percentage can then be multiplied by that objective's previously assessed weight. An indication of how well the design basis might be achieved, and thereby an indication of the relative contribution to achieving the repository system performance objectives, can then be obtained for any backfill scheme by summing the products for all the backfill design objectives.

This methodology is useful for comparatively evaluating alternative backfill schemes, as required in this study, but does not address the adequacy of any scheme. In other words, although it allows for a ranking of schemes, it does not determine whether any scheme is satisfactory. This determination of any scheme's acceptability must be made by site-specific quantitative system performance assessment, with reference to system performance criteria; however, this determination is outside the scope of this study.

ES.3.4 Identification of Alternative Backfill Schemes

A representative set of alternative backfill schemes has been identified from schemes previously proposed by DOE, schemes typically used in the civil and mining industries, and schemes identified under the complementary "Engineered Barriers" NRC contract (NRC-02-81-027). The combinations of backfill materials and additives which are perceived to be most viable for either room or waste emplacement hole backfill have been identified and their primary objective(s) defined (see Table ES.2). The ranges of properties of these backfill materials/additives have been identified, where possible, based on available literature. The principal alternative placement procedures which have been identified include mechanical, pneumatic or hydraulic methods. The principal alternative compaction procedures which have been identified include mechanical (static or dynamic), vibratory, electro-osmosis, drainage or consolidation methods. Appropriateness of various placement and compaction procedures depends on the type of material/additive and the desired in-place characteristics of the backfill.

ES.3.5 Preliminary Evaluation of Alternative Backfill Materials/Additives

The 60 most viable combinations of waste emplacement hole and room backfill materials/additives have been identified and preliminarily evaluated with respect to achieving the generic design basis (Section ES.3.2) using the subjective evaluation methodology (Section ES.3.3). It is apparent from the results of this preliminary evaluation that, for any type of room backfill, the radionuclide attenuation type backfills (i.e., illite, clinoptilolite, or zeolite) might be most effective around the waste package, with bentonite next most effective. Similarly, it is apparent that, for any type of backfill around the waste package, the radionuclide attenuation type backfills might also be most effective as room backfill, with bentonite and muck (i.e., excavated

SUMMARY OF ALTERNATIVE BACKFILL MATERIALS/ADDITIVES

Table ES .2

	Primary Objectives		
Material/Additive	Structural Support	Water Flow Attenuation	Radionuclide Transport Attenuation
None			
Concrete	●	o	
Concrete with sand-cement grout	●	●	
Muck	●		
Muck with sand-cement grout	●	●	
Muck mixed with bentonite	●	●	
Sand	●		
Sand with sand-cement grout	●	●	
Sand mixed with bentonite	●	●	
Bentonite		●	
Illite		o	●
Clinoptilolite			●
Zeolite (synthetic)			●

(Room Scale or Waste Package Scale)
● Principal objective of backfill material/additive
o Secondary objective of backfill material/additive

host rock) mixed with bentonite next most effective. These evaluations, however, have been subjective and in any case relate to a generic design basis; both the design basis and the subsequent evaluations have been based on defined premises and perceptions, and not on quantitative performance modeling. Also, this is a comparative evaluation only, which can be used to suggest the best material/additive combination for the given generic design basis, but it does not address the acceptability of any (even the best) combination. Site-specific quantitative performance assessment would be necessary to address acceptability of any scheme and, in addition, the results of such assessments might change the design basis and comparative evaluations.

Based on the results of the preliminary evaluation of alternative backfill schemes, the backfill materials/additives with the highest apparent effectiveness have been selected for further study. These are zeolite/clinoptilolite, bentonite, and muck mixed with bentonite. Muck has also been included for further study, as it is strongly being considered by the DOE.

ES.3.6 Evaluation of Selected Alternative Backfill Schemes

Feasible procedures for each selected backfill material/additive have been identified, and appropriate equipment also identified for each procedure. The backfill schemes, consisting of materials/additives and appropriate procedures, which are perceived to best achieve the generic design basis, and thereby the repository system performance objectives, have been identified for hard rock and salt (see Tables ES.3 and ES.4, respectively).

Tests which are presently available to verify that the backfill design has been correctly implemented have been identified and appropriate ones then selected (see Table ES.5). Clearly, the tests which should be performed will depend to a large extent on the specific backfill design. This identification of available tests has relied on the results of Task 2 of this project, entitled, "In Situ Test Programs Related to Design and Construction of High Level Nuclear Waste (HLW) Deep Geologic Repositories," (NUREG/CR-3065, November 1982). The extent and schedule of testing, i.e., prior or subsequent to LA, will depend on the level of confidence in satisfactory repository system performance required for licensing purposes at LA and on the reliance placed on backfill in achieving this performance, neither of which have been clearly established.

ES.4 SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Golder Associates believes that a logical and explicit approach has been utilized in this Task 5 study to:

- Develop a generic design basis for backfill sufficient for the purposes of this study
- Identify and discuss alternative backfill schemes

SUMMARY OF ALTERNATIVE PROCEDURES FOR SELECTED COMBINATIONS OF BACKFILL MATERIALS/ADDITIVES – HARD ROCK

Table ES.3

Waste Emplacement Hole Backfill Material/Additive	Room Backfill Material/Additive			
	3. Muck	3B. Muck mixed with bentonite	5. Bentonite	7. Clinoptilolite/Zeolite
3. Muck	●			
3B. Muck mixed with bentonite	●	●		
5. Bentonite	●	●	●	
7. Clinoptilolite/Zeolite	●	●	●	●

Combination of Backfill Materials/Additives	Waste Emplacement Hole Backfill Material/Additive	3	3	3	3	3B	3B	3B	3B	5	5	5	5	7	7	7	7
	Room Backfill Material/Additive	3	3B	5	7	3	3B	5	7	3	3B	5	7	3	3B	5	7
Waste Emplacement Hole Backfill Procedures	**Preformed** Backfill Shapes					●	●			●	●	●					
	Mechanical Placement of Dry Backfill	●				●	●			●	●	●		●	●	●	●
	Pneumatic Placement of Dry Backfill	●												●	●	●	●
Room Backfill Procedures	Mechanical Placement of Loose Dry or Moist Backfill/No Compaction	●				●	●			●	●	●		●	●	●	●
	Mechanical Placement of Loose, Dry or Moist Backfill/Compaction in Lifts	●				●	●			●	●	●		●	●	●	●
	Mechanical Placement of Preformed Backfill Shapes/ No Compaction						●				●	●			●	●	
	Pneumatic Placement of Loose, Dry or Moist Backfill/No Compaction	●				●				●				●			●

- ● viable alternative combination of materials/additives and procedures for waste emplacement hole and room backfill

SUMMARY OF ALTERNATIVE PROCEDURES FOR SELECTED COMBINATIONS OF BACKFILL MATERIALS/ADDITIVES - SALT

Table ES. 4

Waste Emplacement Hole Backfill Material/ Additive	Room Backfill Material/Additive			
	3. Muck	3B. Muck mixed with bentonite	5. Bentonite	7. Clinoptilolite/ Zeolite
3. Muck	●			
3B. Muck mixed with bentonite				
5. Bentonite				
7. Clinoptilolite/Zeolite	●			●

Combination of Backfill Materials/ Additives	Waste Emplacement Hole Backfill Material/Additive	3	3	3	3	3B	3B	3B	3B	5	5	5	5	7	7	7	7
	Room Backfill Material/Additive	3	3B	5	7	3	3B	5	7	3	3B	5	7	3	3B	5	7
Waste Emplacement Hole Backfill Procedures	Preformed Backfill Shapes																
	Mechanical Placement of Dry Backfill	●												●			●
	Pneumatic Placement of Dry Backfill	●												●			●
Room Backfill Procedures	Mechanical Placement of Loose Dry or Moist Backfill/No Compaction	●												●			●
	Mechanical Placement of Loose, Dry or Moist Backfill/Compaction in Lifts	●												●			●
	Mechanical Placement of Preformed Backfill Shapes/ No Compaction																
	Pneumatic Placement of Loose, Dry or Moist Backfill/No Compaction	●												●			●

● viable alternative combinations of materials/additives and procedures for waste emplacement hole and room backfill

SUMMARY OF TESTING/MONITORING METHODS AVAILABLE TO VERIFY BACKFILL DESIGN

Table ES. 5

SIGNIFICANT BACKFILL CHARACTERISTICS	LABORATORY TESTS	CONSTRUCTION MONITORING		IN SITU TESTS		IN SITU PERFORMANCE MONITORING	
		Waste Emplacement Hole	Room	Waste Emplacement Hole	Room	Waste Emplacement Hole	Room
PERFORMANCE:							
(MECHANICAL)							
Strength	●				●		
Deformation	●				●		
Creep	●				○		
Consolidation/ Swelling	●				○		○
(THERMAL)							
Thermal Conductivity	●				●	○	○
Heat Capacity	●				●		
Thermal Expansion	●				●		
(HYDROLOGIC)							
Hydraulic Conductivity	●				●		
Effective Porosity	●				●		
Specific Storage	●				○		
(GEOCHEMICAL)							
Radionuclide Retardation/Adsorption	●				●	○	○
Alteration/Solubility Potential	●				○		
PHYSICAL:							
Homogeneity		○	●		○		
Material Type	●	●	●		○		
Gradation	●	●	●		○		
Particle Shape	●	●	●		○		
Moisture Content	●	●	●		○		
Density	●	○	●		●		

● primary testing/monitoring method
○ possible secondary testing/monitoring method

NOTE: Performance characteristics are primarily a function of specific physical characteristics. Appropriate testing/monitoring methods will depend on the significance of each characteristic, which in turn will depend on backfill design. It is unlikely that all of these identified methods will be necessary for any given backfill scheme. The extent and schedule of testing/monitoring, e.g., prior or subsequent to LA, will depend on the level of confidence in satisfactory repository system performance required for licensing purposes (especially at LA) and on the reliance placed on backfill in achieving this performance, neither of which have yet been clearly established.

- Comparatively evaluate the identified feasible alternative backfill schemes with respect to the design basis.

Indeed, it is felt that the identification of backfill design objectives, which are explicitly derived from and thus related to the repository system performance objectives, is an important development in the definition of the role of backfill as an integral component of the repository system. The subsequent weighting of these backfill design objectives gives additional focus as to their relative significance within the repository system. The development of an evaluation methodology using these weighted backfill design objectives provides a useful tool in the comparative evaluation of alternative backfill schemes. However, it must be emphasized that performance assessment of the repository system, including backfill as an integral component, on a site specific basis will be necessary for a rigorous evaluation of any backfill design. Indeed, such performance assessments, in the form of sensitivity studies and including consideration of the natural variability of site conditions, would refine the weighting estimates and thus guide backfill design.

It is Golder Associates' opinion that the NRC should utilize the Task 5 results in their review of backfill aspects contained within an SCR or LA, as follows:

- Backfill design basis - Are the applicant's design objectives consistent with the generic backfill design basis, especially the most significant backfill design objectives, developed here; i.e., does the applicant correctly perceive backfill's role in the repository system? If the applicant's design basis is significantly different, to what extent will that affect the probability of satisfactory repository system performance? This impact can be roughly assessed through the hierarchy of performance objectives developed here. Does the applicant's design basis take into proper account the natural variability in site conditions?

- Backfill materials/additives - Are the applicant's proposed backfill materials/additives consistent with his and the generic Task 5 design basis; i.e., can the materials/additives reasonably achieve the design basis? This can be assessed by consulting the discussions presented here on alternative backfill materials/additives, their range in properties, and the evaluation of each with respect to achieving the generic Task 5 design basis.

- Procedures - Are the applicant's proposed backfill procedures feasible and appropriate for the proposed materials/additives in achieving the design basis? This can be answered by consulting the discussions presented here on the feasibility of alternative backfill procedures (including equipment) for each material/additive in hard rock or salt. Also, is the applicant's QA/QC program regarding procedures sufficient to adequately ensure proper implementation of design?

- Testing - Is the applicant's test program sufficient to verify that the backfill design has been correctly implemented? This can be partially determined by consulting the discussions presented here on the tests which are available for assessing the various significant in-place characteristics of backfill and thus verifying design. However, sufficiency regarding the extent and schedule of testing will depend on presently undefined licensing requirements and the role of backfill.

Although the backfill design basis for this study has been explicitly developed, it should be further refined for future application. Also, as performance assessment of the repository system, including backfill, will ultimately be necessary to assess the site-specific suitability of any backfill design, this methodology should be further developed and applied in this refinement.

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1. INTRODUCTION

1.1 INTRODUCTION

This report presents the results of Task 5, "Evaluation of Engineering Aspects of Backfill Placement for High Level Nuclear Waste (HLW) Deep Geologic Repositories," of U.S. Nuclear Regulatory Commission (NRC) Contract NRC-02-81-037, "Technical Assistance for Repository Design."

The purpose of the complete project is to provide NRC with technical assistance for the following reasons:

- To enable the focused, adequate review by NRC of aspects related to design and construction of an in situ test facility and final geologic repository, as presented in U.S. Department of Energy (DOE) Site Characterization Reports (SCR)
- To ascertain that the DOE site characterization program will provide, as far as possible, all the information necessary to permit a review to be conducted by NRC of a License Application (LA).

The design of backfill, as an integral component of the repository system, and the subsequent implementation and verification of that design, will have to be evaluated during this review process. The objective of Task 5 is to qualitatively assess available backfill technology, especially related to construction and testing, with regard to potential application for HLW deep geologic repositories.

The results of Task 5 include:

- The definition of justifiable weighted backfill design objectives (based on generic site conditions) to serve as a reasonable comprehensive design basis for this study
- The identification of a representative set of available alternative backfill schemes
- The development of a methodology to comparatively evaluate the extent to which the backfill design basis might be achieved by any alternative backfill scheme
- The preliminary subjective evaluation of the identified alternative backfill schemes with respect to achieving the generic design basis using the developed methodology
- The identification and discussion of appropriate procedures for selected backfill materials/additives in hard rock and in salt
- The identification and discussion of test programs which will sufficiently verify backfill design implementation

- The recommendation of NRC's utilization of Task 5 results and of potentially effective future work.

It must be emphasized that the development of weighted backfill design objectives and, to a lesser degree, the preliminary evaluation of alternative backfill schemes are based on preconceived repository design concepts and performance assessment methodology, as well as on generic site conditions. Should any of these premises change, the results and subsequent conclusions of this study may require revision. These premises have been defined, as much as possible, and the derivations based on these premises clearly exposed.

1.2 PERSPECTIVE

Deep geologic repositories for permanent disposal of high level nuclear waste (HLW) must achieve certain performance objectives related to public safety. These repository system performance objectives can be summarized as:

- Reasonably minimizing hazards jeopardizing the safety of the public and personnel during repository construction and operation

- Reasonably minimizing radionuclide transmission to the accessible environment and thus minimizing hazards jeopardizing public safety after decommissioning.

Other performance objectives can be considered as subordinate to these two summary performance objectives. Performance criteria, e.g., NRC's draft 10-CFR-60 or EPA's draft 40-CFR-191, define and, where possible, quantify these objectives.

The performance objectives can be achieved through appropriate:

- Site screening and selection
- Repository design, construction and operation.

That is, a suitable site with a reasonably high probability of achieving the performance objectives must first be selected. The repository must then be designed for that site so as to achieve the performance objectives. The repository must subsequently be constructed and operated in accordance with the design. As a part of repository construction/operation, verification will be required that the repository has been constructed and operated in accordance with the design, and that the performance objectives either have been or can reasonably be expected to be achieved.

When utilized to contribute to achieving the performance objectives, the design/construction of engineered repository barriers, including backfill, must be considered as an integral aspect of repository design/construction/operation. Hence, backfill should be designed, in terms of schedule, configuration and in-place characteristics, to reasonably contribute towards achieving the performance objectives. The in-place characteristics of backfill, which will affect repository performance, will be a function primarily of:

- The backfill materials/additives selected
- The procedures used in preparing, placing, and compacting the backfill
- The environmental conditions under which the backfill is placed and must subsequently function (i.e., media/site specific conditions during and after the backfilling phase of repository development).

The above three aspects are closely related and thus cannot be evaluated independently. For a given repository design/schedule at a site, there will be a set of conditions which are expected to occur at the time of placement and beyond. There should then be one backfill scheme which is optimum with respect to helping achieve the performance objectives under these expected conditions, although any number of these schemes may be acceptable. For the purposes of this study, a backfill scheme is defined as a compatible combination of: materials and additives; procedures for preparation, placement, and compaction; and schedule of placement. In addition, a test program will be necessary to assess and verify that the backfill design has been properly implemented.

1.3 SCOPE

This study is limited to the backfill component of the engineered barrier system, specifically to backfill placed around the waste package and in the mined openings and tunnels. The waste package considered is limited to that for spent fuel waste. Backfill or buffers located within the waste package, as well as backfill or seals of shafts and boreholes, are outside the scope of this study.

This study is further limited to the construction aspects of this backfill and also testing the backfill to verify that it has been constructed according to design. The design and associated performance assessment of backfill are covered in a complementary NRC contract (NRC-02-81-027) entitled "Performance of Engineered Barriers in a Geologic Repository." However, the pertinent results of this other study, in the form of appropriate backfill designs, have not been available for this study. Therefore, in concert with the Engineered Barriers contract, a backfill design basis has first been developed for this study prior to studying construction and testing procedures.

Although quantitative performance assessments and costs have not been considered, the means by which they can be incorporated in establishing the backfill design basis are discussed.

1.4 APPROACH

A reasonable comprehensive design basis for backfill is first needed in order to evaluate the construction/testing aspects. Presently, there is no clearly accepted design basis for backfill. For example, based on preliminary results from the Engineered Barriers contract, the typical assumption that backfill should have a very low permeability needs to be more carefully investigated. Hence, a backfill design basis must be defined which is logically and explicitly derived. The definition of this backfill design basis may well be the most valuable result of this study.

Because the repository system, including both geologic and engineered components, is very complex, a relatively rigorous approach in defining a design basis for backfill is warranted. This approach involves an explicit description of the steps in backfill design so that each step can be followed and interim evaluations and results can be revised, as appropriate, as premises change.

This approach consists of first identifying specific and detailed subobjectives to the two summary repository system performance objectives. Backfill design objectives, through which the repository system performance subobjectives related to backfill can be achieved, can then be identified and their relative significance assessed. Design of the backfill consists of optimizing with respect to these backfill design objectives. Construction and testing of the backfill can then simply focus on meeting this design. The evaluation of backfill construction and testing techniques, which is the subject of this study, can thus be made by assessing how well the backfill design has been met.

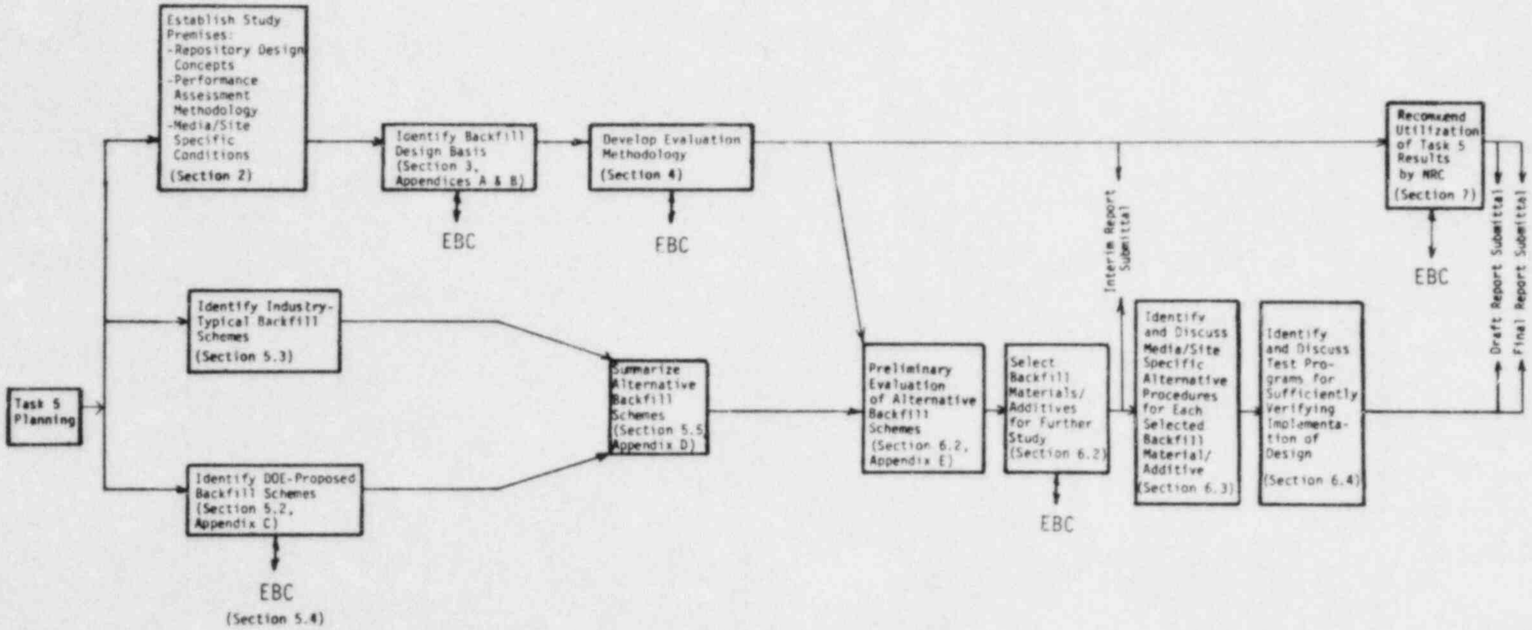
Using this approach in the performance of Task 5, the following activities have been completed (see Figure 1.1):

- Establish Study Premises

  The premises which underlie this study regarding the evaluation of backfill, as an integral part of the repository system, have been identified (see Section 2.0). These premises include assumed repository design concepts, performance assessment methodology, and media/site specific conditions.

- Identify Backfill Design Basis

  Specific and detailed design objectives have been identified (see Appendix A) and summarized (see Section 3.3) for backfill material placed around the waste package and in mined openings. These have been derived by identifying a hierarchy of subobjectives to the two summary repository system performance objectives. Hence, the relationship between each identified backfill design objective and the summary performance objectives is explicit and logical.



EBC - interaction with NRC Contract (NRC-02-81-027) entitled "Performance of Engineered Barriers in a Geologic Repository"

Backfill includes material placed around the waste package, in the mined openings and in tunnels, but not including shafts or boreholes.

Backfill procedures include preparing, placing, compacting and testing.

Backfill schemes include backfill materials/additives (including source), backfill procedures (including equipment), and backfilling schedule.

TASK 5 - ACTIVITY FLOW CHART

Figure 1.1

The relative significance, or weights, of each identified backfill design objective, with respect to achieving the repository system performance objectives, have been subjectively evaluated (see Appendix B) and summarized (see Section 3.4). These weights have been derived by subjectively assessing the relative weights within subsets of the hierarchy of subobjectives, and then compounding down through the hierarchy. Hence, a priority can be established among the backfill design objectives. Many of these backfill design objectives may prove to be relatively insignificant.

The set of weighted backfill design objectives constitutes the design basis required for this study. However, the development and subsequent weighting of the hierarchy of subobjectives to the two summary repository system performance objectives are a function of the assumed repository design concepts, performance assessment methodology, and site conditions. Due to the subjective nature of the weighting assessments and due to the assumption of generic site conditions, this design basis is generic and very approximate, but sufficient for the purposes of this study.

- Develop Evaluation Methodology

  The methodology by which backfill schemes can be comparatively evaluated with respect to achieving the identified weighted backfill design objectives (i.e., the design basis) has been developed (see Section 4.0). This methodology consists of subjectively evaluating the percentage of each backfill design objective which can be expected to be achieved by a given backfill scheme, and then multiplying that percentage by the objective's relative weight (i.e., significance). By summing these products for all significant backfill design objectives, a backfill scheme's relative effectiveness or contribution in achieving the repository system performance objectives can be roughly assessed. Although useful for comparing and ranking alternative schemes, this methodology does not address the acceptability of any (even the best) alternative.

- Identify DOE-Proposed Backfill Schemes

  The backfill materials/additives, associated procedures, and schedules currently being considered by DOE for each prospective media/site have been identified (see Appendix C) and summarized (see Section 5.2), based on available information and in concert with the Engineered Barriers contract.

- Identify Industry-Typical Backfill Schemes

  The backfill materials/additives and associated procedures typically used in industry (e.g., mining and surface civil engineering) have been identified (see Section 5.3). Although the backfill design objectives and the conditions for industry are typically different from those for repositories, established procedures offer viable potential alternatives.

- Summarize Alternative Backfill Schemes

  Based on the identified DOE-proposed and industry-typical backfill schemes, and in conjunction with the Engineered Barriers contract, the alternative backfill schemes to be considered in this study have been summarized (see Section 5.5). The ranges in properties of each backfill material/additive have been identified, where possible, based on available literature (see Appendix D).

- Preliminary Evaluation of Alternative Backfill Schemes

  Each of the identified alternative backfill schemes have been preliminarily evaluated, with regard to satisfying the generic backfill design basis (see Appendix E). This preliminary evaluation has utilized the subjective evaluation methodology established in a previous activity, and has been summarized (see Section 6.2).

- Select Backfill Materials/Additives for Further Study

  Based on the results of the preliminary evaluation of alternative backfill schemes, the backfill materials/additives with the highest potential for achieving the generic backfill design basis, and thereby the repository system performance objectives, have been selected for further evaluation (see Section 6.2). Further study has been limited to these backfill materials/additives.

- Identify and Discuss Media/Site Specific Alternative Procedures for Each Selected Backfill Material/Additive

  Alternative procedures for each selected backfill material/additive have been summarized and discussed (see Section 6.3) for hard rock and salt, based on the previously identified DOE-proposed and industry-typical procedures. This has included identification of specific equipment which can be utilized.

  The backfill schemes, consisting of materials/additives and procedures, which have been perceived to best achieve the design basis (i.e., identified weighted backfill design objectives), and thus would also be optimum with respect to achieving the repository system performance objectives, have been identified for hard rock and salt (see Section 6.3).

- Identify and Discuss Test Programs for Sufficiently Verifying Implementation of Design

  Tests which are presently available to verify that a given backfill design has been correctly implemented have been identified and appropriate ones then selected (see Section 6.4).

- Recommend Utilization of Task 5 Results by the NRC

  The appropriate utilization of Task 5 results by the NRC, specifically in SCR or license application reviews, has been determined and recommended (see Section 7.2). Clearly, the generic backfill design basis developed here, and the discussions of construction procedures and testing for implementing and verifying the design, should be considered by the NRC in their review process.

Additional effective work in this area has also been recommended (see Section 7.3).

2. STUDY PREMISES

2.1 INTRODUCTION

The basic premises which are perceived to have a significant influence on the results of this study are:

- Repository design concepts
- Performance assessment methodology
- Media/site specific conditions.

If these premises change, the results and conclusions of this study may require revision. Hence, these premises must be defined and constantly checked for appropriateness. An attempt has been made herein to point out where these premises have been incorporated, and furthermore to point out how and where changes in these premises could arise. Otherwise, changes in these premises have not been considered.

2.2 REPOSITORY DESIGN CONCEPTS

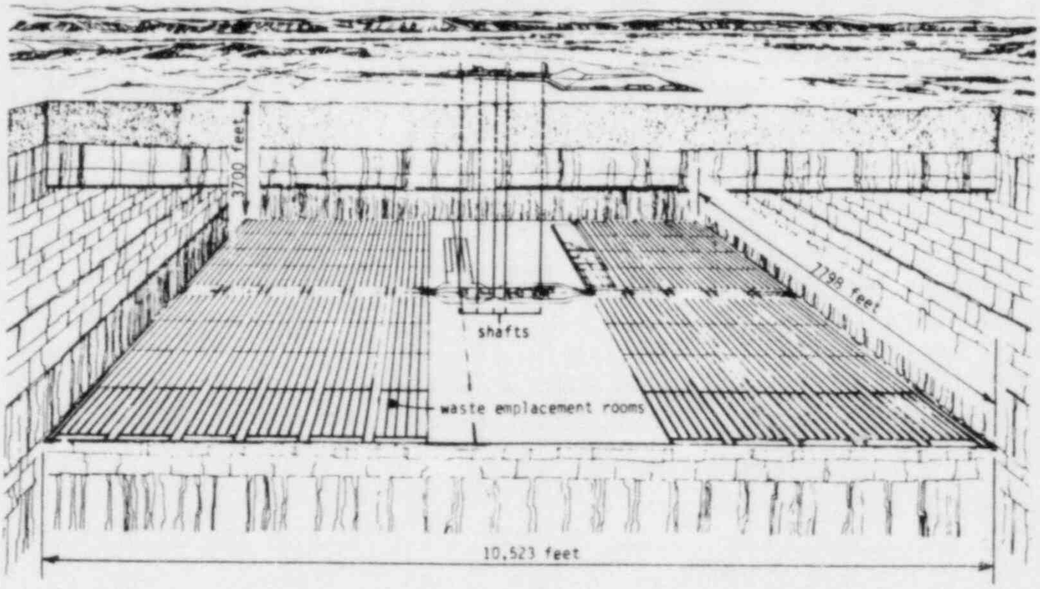
Repository design concepts have been synthesized for this study from a number of commonly proposed preconceptual designs. These design concepts, both on the repository and room scales, include schematic layouts and schedules (see Figures 2.1 to 2.3). Within these design concepts, backfill (if used) is one integral component of the repository system.

It has been assumed that the waste package will be placed in a vertical hole in the floor of a deep underground room (see Figure 2.2a) or in a horizontal hole in the wall (see Figure 2.2b). Backfill might then be placed around the waste package and within the room. It has been further assumed that room cross sections will be identical.

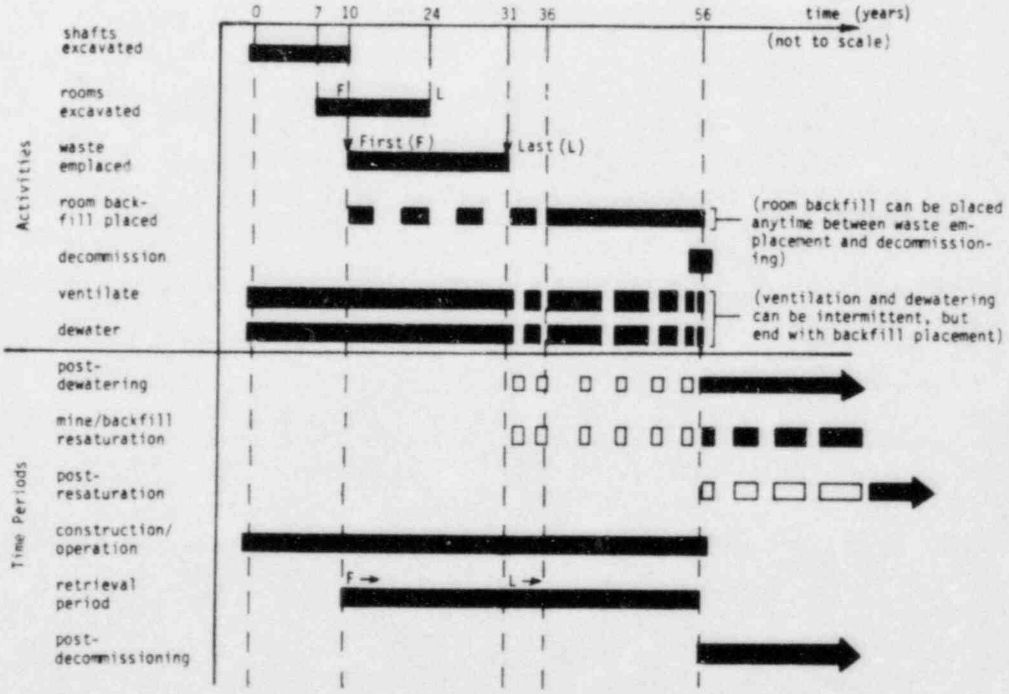
It has been assumed that the sequence of activities which occurs at each room cross-section will be essentially the same (see Figure 2.3). However, these activities will occur at different times for different cross-sections, and the time between activities will also vary for each cross-section. Some of the activities will overlap, and some may occur essentially simultaneously (e.g., hole excavated, waste emplaced, and hole backfilled can occur either in one operation or in three widely separated operations). Assuming that backfill will be utilized, backfilling of the room/tunnel would occur some time after backfilling around the waste package; both backfilling operations would occur during the retrieval period after waste emplacement and before decommissioning. The timing of backfilling will affect the duration of ventilation and dewatering, which in turn will affect when the mine/backfill becomes resaturated and when post-resaturation gradients from the waste package to the accessible environment will be established.

REPOSITORY DESIGN CONCEPTS - REPOSITORY SCALE

Figure 2.1



a) Repository Layout

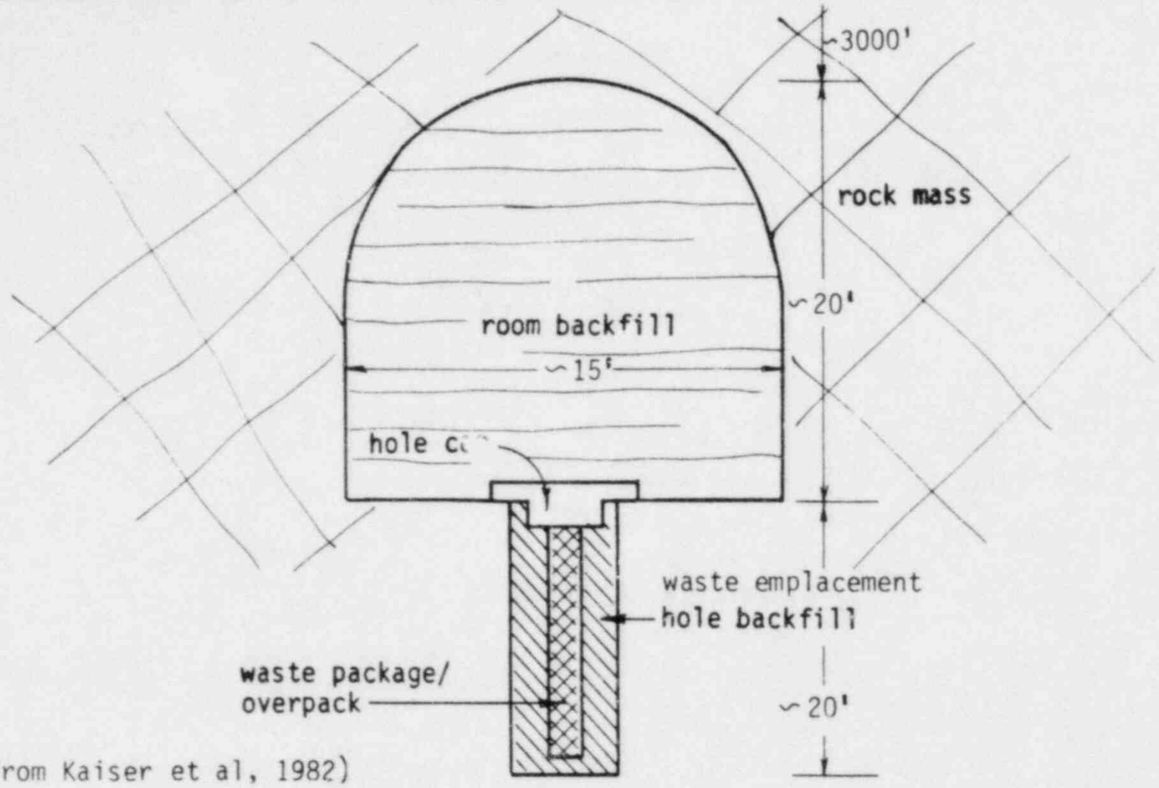


b) Repository Development Schedule

Note: These repository design concepts, especially dimensions and durations, are specifically for basalt. (ref. Kaiser Engrs., 1982)

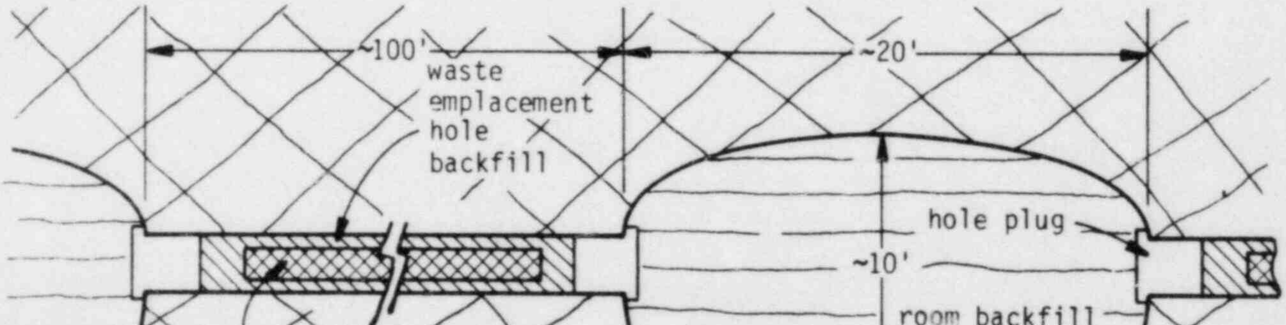
REPOSITORY DESIGN CONCEPTS RELEVANT TO BACKFILL - ROOM GEOMETRY

Figure 2.2



(from Kaiser et al, 1982)

a) VERTICAL EMPLACEMENT (schematic cross-section)

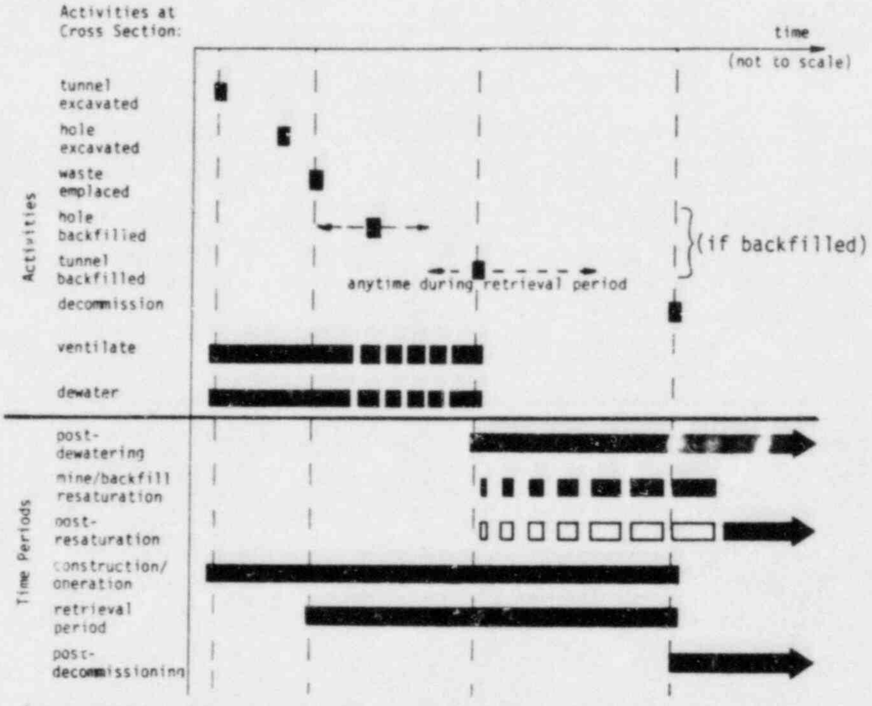


(from H.B. Dietz et al, BWIP, viewgraphs presented to the NRC at a meeting in Richland, Washington, June 9, 10, 12, 1982)

b) HORIZONTAL EMPLACEMENT (schematic cross-section)

REPOSITORY DESIGN CONCEPTS RELEVANT TO BACKFILL - ROOM DEVELOPMENT SCHEDULE

Figure 2.3



(schematic for each cross-section - see Figure 2.2)

Note: This schedule is consistent with the repository development schedule (see Figure 2.1b)

2.3 PERFORMANCE ASSESSMENT METHODOLOGY

As backfill (if used to influence repository system performance) will be an integral component of the repository system, rational optimization of backfill design must necessarily be based on a repository system performance assessment methodology. This methodology should reflect the significant features of repository system performance, i.e., waste/rock/backfill interaction. Using coupled thermal, mechanical, hydrologic, and geochemical response functions/models with appropriate input (see Figure 2.4), the pertinent aspects of performance for a modeled site/repository design can be predicted (see Table 2.1). There is a wide variety of models available for predicting the various aspects of repository performance (e.g., see SAI, 1979). Each of these models involves different assumptions and simplifications, and thus results in different levels of uncertainties.

The predicted performance can be evaluated with respect to established performance criteria (e.g., NRC's draft 10-CFR-60 and EPA's draft 40-CFR-191) in order to assess site suitability and adequacy of repository design. However, there will be significant uncertainty in these predictions, especially in the complex environment of a repository system and over the very long time frame of interest, due not only to the models themselves but also to the input. Hence, these uncertainties and the associated level of risk also need to be assessed and evaluated.

2.4 MEDIA/SITE SPECIFIC CONDITIONS

2.4.1 Introduction

The DOE site screening/selection process is presently focused on five media (see Table 2.2): basalt, tuff, domal salt, bedded salt, and granite. For the purposes of this study, domal salt and bedded salt are considered as one medium.

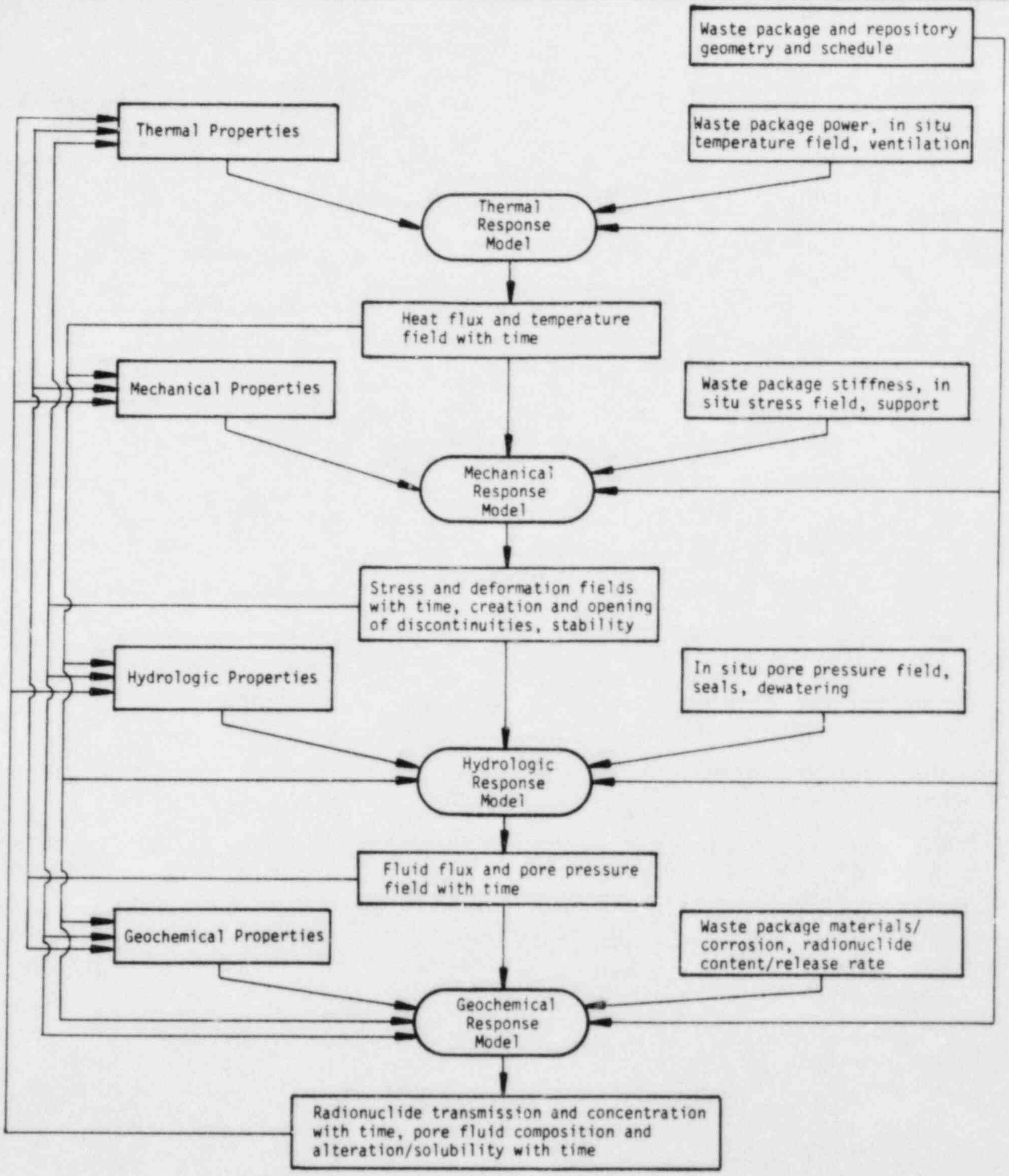
The conditions which are considered to be significant with respect to backfill at each media/site are a function primarily of the following:

- Media/site characteristics
- Repository design and development schedule.

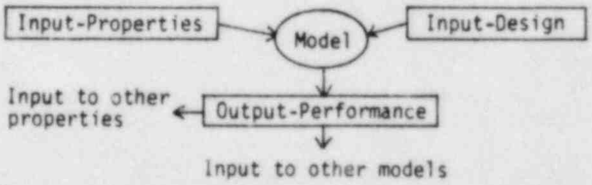
The repository design and development schedule have been assumed to be identical for all media/sites (Section 2.2). The significant characteristics of each media/site have been previously identified in numerous reports, and are sufficiently summarized for each media in the Task 2 report (Golder Associates, 1982c). These conditions have been resummarized in the following sections for each of the media/sites under consideration, with primary emphasis on the repository horizon (see Table 2.3). Although deemed sufficient for the purposes of this study, this assessment of media/site specific conditions should only be considered as a qualitative indication of the conditions which are likely to be encountered.

REPOSITORY PERFORMANCE ASSESSMENT METHODOLOGY

Figure 2.4



Note: These coupled models, in which output of one becomes input for the others, may be coupled in a variety of ways.



PERTINENT ASPECTS OF REPOSITORY PERFORMANCE

Table 2.1

Thermal Response

Predict mine temperatures prior to backfilling and waste package temperatures as input to mechanical, hydrologic, geochemical response models (i.e.: mechanical, hydrologic, and geochemical response characteristics are functions of temperature; changes in temperature will cause mechanical and possibly geochemical (alteration) responses; heat flux may cause hydrologic response).

Mechanical Response

Predict deformations and stability of openings and stress on waste package, as well as input to hydrological, geochemical response models (i.e.: hydrologic response characteristics will be a function of stress and especially fracture/joint aperture; geochemical as well as thermal response characteristics may also be a function of stress).

Hydrologic Response

Predict mine inflows prior to backfill, mine/backfill resaturation time, and flow through repository after resaturation, as well as input to geochemical response model (i.e.: hydraulic flux will cause geochemical response and possibly thermal response; mechanical and geochemical (and possibly thermal) response characteristics will be functions of pore pressure).

Geochemical Response

Predict the extent of geochemical alteration (of rock mass and backfill) and corrosion/leaching of waste package, as well as the rate of radionuclide transport after emplacement (i.e.: thermal, mechanical, and hydrologic response characteristics will be functions of alteration/solution and pore fluid composition, and possibly radiation dose).

Note: Refer to Figure 2.4 - Repository Performance Assessment Methodology.

PRESENT STATUS OF DOE SITE SCREENING/ SELECTION PROCESS

Table 2.2

- Basalt at Hanford Reservation, Washington

  Basalt Waste Isolation Project (BWIP), DOE prime contractor - Rockwell:

  The prospective repository horizon is in basalt flow (presumably the Umtanum, which is about 80 feet thick and 3800 feet deep) in Cold Creek Syncline at Hanford Reservation, Washington; SCR submittal is expected in late 1982, exploratory shaft is expected to be initiated in early 1983.

- Tuff at Yucca Mountain, Nevada Test Site, Nevada

  Nevada Nuclear Waste Storage Investigations (NNWSI), DOE prime contractor - Sandia (to be changed):

  The prospective repository horizon is in tuff (possibly the Bullfrog formation, which is about 400 feet thick and 2100 feet deep, but 3 other formations are being studied to similar levels) under Yucca Mountain at Nevada Test Site (NTS), Nevada; SCR submittal is expected in mid 1983, exploratory shaft is expected to be initiated in 1983.

- Domal Salt at Richton or Cypress Creek, Mississippi, or Vacherie, Louisiana

  Gulf Coast Domal Salt Investigation, DOE prime contractor - ONWI*:

  A choice between Vacherie Dome in Louisiana, Richton Dome and Cypress Creek Dome in Mississippi is expected to be made in 1983; a subsequent choice between the selected dome and the selected salt basin is expected to be made in 1983 for exploratory shaft initiation.

- Bedded Salt at unspecified site (generic)

  Bedded Salt Investigation, DOE prime contractor - ONWI*:

  A choice between the Paradox Basin in Southeastern Utah and the Permian Basin in Northwest Texas is expected to be made in 1983; a subsequent choice between the selected basin and the selected salt dome is expected to be made in 1983 for exploratory shaft initiation.

- Granite at unspecified site (generic)

  Granite Investigation, DOE prime contractor - ONWI*(to be changed):

  The investigation and site selection process for a suitable site in granite is expected to begin throughout the eastern portion of the U.S. in 1982; SCR submittals for as many as three selected sites are expected in about 1986.

* ONWI - Office of Nuclear Waste Isolation is managed for DOE by Battelle-Columbus

Note: This perceived status is as of November 1982, and is subject to update and revision.

Table 2.3
1 of 2

SUMMARY OF MEDIA/SITE SPECIFIC CHARACTERISTICS

CHARACTERISTICS	MEDIA/SITES (ref. Table 2.2)			
	BASALT	TUFF	SALT	GRANITE
GEOLOGIC SETTING			Generic:	Generic:
Stratigraphic/structural	Flow structure: Umtanum flow (24m thick and 1000m deep)	Flow structure: Bullfrog member (60m thick and 1000m deep)	Salt dome (with folding); bedded salt (with porous interbeds) (650m deep)	Massive (1000m deep)
Pore fluid composition: type	Sodium chloride bicarbonate	Sodium potassium bicarbonate	Saturated brine	(generic)
total dissolved solids (mg/l)	850	180	(generic)	(generic)
pH	9.7	9.7	(generic)	(generic)
Tectonic	Low seismicity, some possibly capable faults	Low seismicity (also nuclear weapons testing effects)	Diapirism	(generic)
In situ stress field: (at repository horizon) σv (MPa)	28	22	16	26
σ hmax (MPa)	56	33	16	(generic)
σ hmin (MPa)	28	11	16	(generic)
In situ hydraulic field: (at repository horizon) pressure head (m)	1050	300	(generic)	(generic)
gradient	2×10^{-2}	1×10^{-2}	(generic)	(generic)
direction	upward	downward	(generic)	(generic)
In situ temperature field (at repository horizon) (C°)	46	35	50	46
RESPONSE				
MECHANICAL (repository hori[illegible] mass)			Generic:	Generic:
Strength	41	38	plastic behavior	40
(MPa)	22	3	at low stresses	0.5
Deformation E (GPa)	7.6	6	6	35
ν	0.25	0.20	0.35	0.18
Creep/fusing	Insignificant	May be significant	Very significant	Insignificant

Table 2.3
2 of 2

SUMMARY OF MEDIA/SITE SPECIFIC CHARACTERISTICS

CHARACTERISTICS	MEDIA/SITES (ref. Table 2.2)			
	BASALT	TUFF	SALT	GRANITE
RESPONSE				
THERMAL (repository horizon rock mass)			Generic:	Generic:
Thermal conductivity (J/m sec °C)	1.4	1.2	4.8	2.6
Heat Capacity (J/kg °C)	880	1500	920	1000
Linear thermal expansion ($°C^{-1}$)	6.9×10^{-6}	10×10^{-6}	40×10^{-6}	2.5×10^{-6}
HYDROLOGIC (repository horizon rock mass)			Generic:	Generic:
Hydraulic conductivity: vertical (cm/sec)	10^{-7}	10^{-5}	10^{-12}	10^{-7}
horizontal (cm/sec)	10^{-9}	10^{-6}	10^{-12}	10^{-7}
Effective porosity	10^{-5}	.02	10^{-3}	10^{-5}
Specific storage (cm^{-1})	10^{-10}	5×10^{-8}	10^{-9}	10^{-9}
GEOCHEMICAL (repository horizon rock mass)			Generic:	Generic:
Dispersivity: longitudinal (m)	130	60	10	60
transverse (m)	80	30	3	30
Adsorption/retardation*	Moderate	Good	Poor	Moderate
Alteration/solubility	Insignificant	Significant potential for alteration	Very soluble	Insignificant

*Adsorption/retardation coefficients for the repository horizon rock mass will vary for each radionuclide considered, and thus only a qualitative description is used here to indicate the average condition.

NOTE: The value of characteristics presented here represent "best guess" estimates for the repository horizon, based on readily available information, and do not indicate the varying level of uncertainty associated with each (ref. Task 2 report, Golder Associates, 1982c). These values are considered sufficient for the purposes of this Task 5 study, but should not be used as other than qualitative indicators of characteristic values likely to be encountered. These estimates may change significantly as actual site investigation and characterization proceeds.

2.4.2 Basalt

The site in basalt at the Hanford Reservation in Washington exhibits several significant features, including:

- Relatively complex geology (flow structures)
- Potential for tectonic activity
- High horizontal in situ stresses
- High in situ temperatures
- Proximity to a major water resource
- Highly fractured rock mass, especially vertical cooling joints; the intact rock is relatively strong, brittle, abrasive, impermeable, and thermally conductive, but the fractures dominate rock mass strength, stiffness, hydraulic conductivity, effective porosity and adsorption/retardation (similar to granite, see Section 2.4.5).

2.4.3 Tuff

The site in tuff at Yucca Mountain at the Nevada Test Site exhibits several significant features, including:

- Relatively complex geology (flow structures)
- Potential for tectonic activity
- Deep water table
- Very porous, fractured rock mass; the rock mass is relatively weak and may have high hydraulic conductivity, although it may be highly adsorptive
- Susceptibility of rock to alteration, especially with elevated temperatures.

2.4.4 Salt

The potential sites in domal salt along the Gulf Coast exhibit several significant features, including:

- Relatively complex geology (folding)
- Possibly ongoing diapirism (dome building).

Sites in bedded salt are expected to exhibit several significant features, including:

- Possible existence of continuous, porous interbeds.

The rock mass characteristics at the repository horizon are expected to be very similar for sites in both domal salt and bedded salt, and can be summarized as:

- Relatively weak and plastic rock mass, which exhibits creep and self-healing/fusing (minimal fracturing); mechanical characteristics degrade rapidly with increasing temperature
- Relatively impermeable rock mass, but the rock is soluble and the pore fluid is corrosive.

2.4.5 Granite

Sites in granite are expected to exhibit several significant features, including:

- Rock mass with widely spaced joints; the intact rock is relatively strong, brittle, abrasive, impermeable, and thermally conductive, but the fractures dominate rock mass strength, stiffness, hydraulic conductivity, effective porosity and adsorption/retardation (similar to basalt, see Section 2.4.2).

3. BACKFILL DESIGN BASIS

3.1 INTRODUCTION

A reasonable comprehensive design basis for backfill must be established in order to evaluate backfill's construction/testing aspects, i.e., the implementation and verification of design. Prior to this study, there was no clearly accepted design basis for backfill, nor in Golder Associates' opinion had the role of backfill within the repository system been explicitly and logically derived.

Design objectives for backfill have been defined, and their relative significance for generic site conditions roughly assessed, in this section. This comprehensive set of generic backfill design objectives provides a sufficient basis for subsequent comparative evaluations of backfill construction and testing techniques. However, this set of generic backfill design objectives alone should not be considered sufficient for final backfill design, which in any case is outside the scope of this study. With further development, this set could be used for backfill design guidelines, but final backfill design will also require site-specific quantitative performance assessment.

Backfill (if used) will be one of a number of integrated geologic and engineered components which comprise the repository system. Hence, backfill design objectives must be developed in the context of the backfill component's perceived role in the repository system. Performance objectives for the repository system have thus been first identified, and the methodology for optimizing the various components of the repository system with respect to these performance objectives then discussed (see Section 3.2). Subsequently, those aspects of performance which are perceived to be affected by backfill have been focused on, and backfill design objectives which contribute to achieving the repository system performance objectives derived (see Section 3.3). Finally, the relative significance of each identified backfill design objective, with respect to its potential contribution towards achieving the repository system performance objectives for generic site conditions, has been assessed sufficiently for the purposes of this study (see Section 3.4).

3.2 REPOSITORY PERFORMANCE OBJECTIVES

Deep geologic repositories for permanent disposal of high level nuclear waste (HLW) must achieve certain performance objectives related to public safety. These repository system performance objectives can be summarized as:

- Short-term construction and operation objective (through decommissioning, about 100 years) of minimizing hazards jeopardizing the safety of the public and personnel during repository construction and operation (including possibly retrieval and decommissioning activities).

- Long-term waste containment and isolation objective (post-decommissioning, from about 100 to 10,000's years) of minimizing radionuclide flux (rate/unit area) to the accessible environment and thus minimizing hazards jeopardizing public safety after decommissioning. This objective dictates maintaining a waste retrieval capability for a specified period after waste emplacement and prior to decommissioning, thereby providing the opportunity for verifying a sufficiently high probability of satisfactory long-term performance and also providing a contingency plan for demonstrated non-verification.

These repository system performance objectives can be cost-efficiently achieved by optimizing among the aspects related to:

- Site screening and selection
- Repository design, construction, and operation.

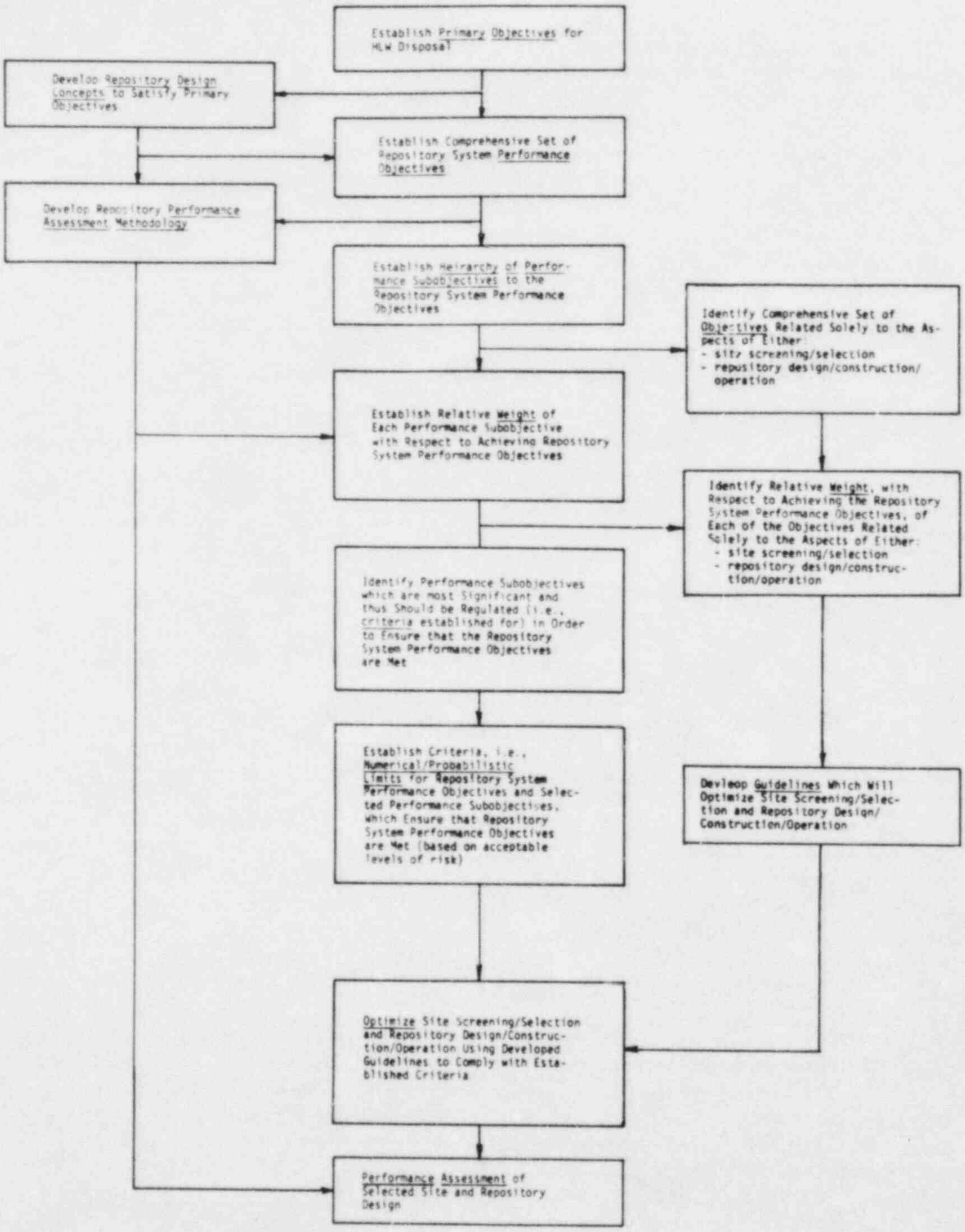
The process of optimization, with respect to the repository system performance objectives, among all of the various aspects related to site screening/selection and repository design/construction/operation will be based on preconceived repository design concepts and performance assessment methodology (Section 2.0). (Hereafter, the various aspects related to site screening/selection and repository design/construction/operation will be referred to as simply repository variables.)

However, the repository system will be very complex. In fact, it is not presently clear, nor is there technical concurrence, on how and to what extent each of the repository variables will affect performance and thus contribute to achieving the repository system performance objectives. The large number of repository variables generally makes thorough system performance sensitivity studies intractable and, even if tractable, various components should not be considered independently, but as an integral part of the repository system. Due to this complexity, a systematic approach will be required for repository optimization (see Figure 3.1). This approach would consist of the following four major steps:

1) Identifying a hierarchy of performance subobjectives, by subdividing each repository system performance objective into a reasonable comprehensive set of contributors (or performance subobjectives) and then in turn further reducing each of these subobjectives as appropriate, and so on. This process could be taken down through many levels, until an objective related solely to the aspects of either site screening/selection or repository design/construction/operation has been explicitly related to the repository system performance objectives. This hierarchy of performance subobjectives, and the resulting comprehensive set of repository variable objectives, would be based on preconceived repository design concepts and performance assessment methodology (Section 2). The development of this hierarchy is further discussed in Appendix A.

REPOSITORY OPTIMIZATION METHODOLOGY

Figure 3.1



2) Weighting the performance subobjectives, and thus the repository variable objectives, with respect to achieving the repository system performance objectives. This would be based on first assessing the potential contribution of each subordinate subobjective in a comprehensive set to achieving its sovereign subobjective, relative to the other members in the set. This weighting would be based on the perceived relationship (or sensitivity) between the two and the possible range in achieving the subordinate subobjective. These contributions would then be compounded down through the hierarchy to obtain the potential contribution, or weight, of each subobjective with respect to achieving the repository system performance objectives, relative to all other subobjectives. These weights would be based on preconceived repository design concepts and performance assessment methodology, as well as on any already satisfied objectives (e.g., media/site specific conditions) (Section 2). The development of these weights is further discussed in Appendix B.

3) Estimating the costs associated with each repository variable objective. However, costing is outside the scope of this report.

4) Optimizing among the competing repository variable objectives, in terms of cost and contribution to achieving the repository system performance objectives. Similarly, alternative media/sites and/or repository design/construction/operation schemes could be comparatively evaluated with respect to how well they would achieve these objectives. However, costing and consideration of repository variables other than backfill is outside the scope of this report.

It should be stressed that the above approach, which will subsequently be used to establish a design basis for backfill in the context of a repository system, involves subjective assessments regarding the significance (or sensitivity) of each subobjective. The results should thus be considered as qualitative only. However, the approach is logical and forces explicit consideration of all relevant factors.

Using the above approach, a hierarchy of performance subobjectives which contribute to the achievement of the repository system performance objectives has been identified through several layers of detail, and the weights or relative significance of each subjectively assessed (see Figure 3.2).

Although the hierarchy of performance subobjectives can be structured in various ways, it is believed that each internal set identified is relatively comprehensive and still tractable. Clearly, the relative weight of each performance subobjective with respect to achieving its immediate sovereign subobjective could be explicitly determined by sensitivity analyses. However, it is felt that the subjectively assessed weights are reasonable, although some will vary between media/sites, especially for more detailed subobjectives. The weights for less detailed subobjectives will tend to be more generic in nature and thus be media/site independent. Also, those weights assessed for less detailed

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subobjectives, which are generally harder to assess, will have a significant influence on the compounded weights of the more detailed subobjectives.

A comprehensive set of repository variable objectives for achieving the repository system performance objectives could be obtained if the hierarchy of performance subobjectives were completely developed. The relative weight of each objective of this comprehensive set with respect to achieving the repository system performance objectives could then be determined based on any level of prior information. This would then provide guidelines, which are clearly and explicitly justified, for optimization among the remaining repository variables. This would also provide an overview for repository development, focusing on those repository variables which will be most important. Areas of technical disagreement regarding repository variable objectives and/or their weights could be identified using this framework and resolved, e.g., by adding/deleting/modifying specific performance subobjectives and by doing sensitivity analyses and subsequently modifying the assessed weights. Similarly, updating the weights, as more information becomes available or as decisions are made, could easily be done. For example, the weights of repository design/construction/operation objectives will typically change once a site has been selected and the site conditions determined.

Although feasible and even crucial for establishing and justifying regulatory criteria and guidelines, as well as for decision analyses related to actual design, the complete development of a comprehensive set of weighted repository variable objectives is outside the scope of this report, as is the consideration of costs. This study has been limited to the consideration of backfill, which will be only one component of repository design/construction/operation. Also, it is assumed that backfill design will be site-specific so that site screening/selection objectives will have already been achieved to some degree; generic site conditions relevant to backfill have thus been assumed, as appropriate.

3.3 IDENTIFICATION OF BACKFILL DESIGN OBJECTIVES

In the absence of accepted backfill designs, or even accepted backfill design objectives, for this study, it has been necessary to first generate a justifiable backfill design basis. The methodology for repository optimization (Section 3.2) has thus been applied, focusing on the backfill component of the repository system.

A comprehensive set of backfill design objectives (see Table 3.1) has been explicitly derived by further selective development of the hierarchy of repository performance subobjectives (Figure 3.2); only those performance subobjectives perceived to be significantly related to backfill have been focused on in this development (see Appendix A). In this way, the relationship of each backfill design objective to the repository system performance objectives has been clearly defined within the context of backfill as an integral part of the repository system.

SUMMARY OF BACKFILL DESIGN OBJECTIVES

Table 3.1
1 of 4

	BACKFILL DESIGN OBJECTIVES			PERIOD OF CONCERN		
	Scale	Code	Objective	-1) During Retrieval Period	-2) Post Decommissioning To Resaturation	-3) Post Resaturation
SCHEDULE	Room Scale	bsr1a	[Minimize] time to placement of backfill **(room scale)**	●		
		bsr1b	[Delay and minimize] backfilling of tunnels along possible egress routes	●		
		bsro1a	[Maximize] time to placement of backfill (room scale)	●		
		bsro1b	[Maximize] time to placement of backfill (room scale), and ventilate	●		
		bsro1c	[Maximize] time to start resaturation process (i.e., maximize time to placement of backfill, room scale, while dewatering)	●		
	Waste Package Scale	bsh1	[Minimize] time to placement of backfill around waste package	●		
		bsho1	[Maximize] time to placement of backfill around waste package, and ventilate	●		
PROCEDURES	Room Scale	bpr1	[Minimize] volume of backfill (room scale) (if placed during retrieval period)	●		
	Room and Waste Package Scale	bp1	[Maximize] use of safe/reliable equipment for backfilling	●		
		bp2	[Maximize] monitoring of potentially hazardous underground conditions as backfilling occurs	●		
		bp3	[Maximize] quick and efficient mitigation of detected underground hazards as backfilling occurs	●		
		bp4	[Minimize] personnel requirements for backfilling (i.e., maximize mechanization and remote operations)	●		
		bp5	[Minimize] total effort required for backfilling (e.g., no backfilling)	●		

(SEE KEY AT END OF TABLE)

SUMMARY OF BACKFILL DESIGN OBJECTIVES

Table 3.1
2 of 4

	BACKFILL DESIGN OBJECTIVES			PERIOD OF CONCERN		
	Scale	Code	Objective	-1) During Retrieval Period	-2) Post Decommissioning To Resaturation	-3) Post Resaturation
MECHANICAL CHARACTERISTICS	Room Scale	bmr1	[Minimize] integrity (compaction) of backfill (room scale) (if placed, during retrieval period)	●		
		bmr2a	[Maximize] support pressure (or structural support) provided by backfill (room scale)	●		
		bmr2b	[Maximize] increase in support pressure (or structural support) provided by backfill (room scale)		●	●
		bmr2c	[Minimize] decrease in support pressure (or structural support) provided by backfill (room scale)		●	●
		bmro2a	[Minimize] support pressure (or structural support) provided by backfill (room scale)	●		
		bmro2c	[Maximize] decrease in support pressure (or structural support) provided by backfill (room scale)		●	●
	Waste Package Scale	bmh1	[Minimize] stress transfer through backfill around waste package	●	●	●
		bmh2a	[Minimize] swelling pressure of backfill around waste package	●		
		bmh2b	[Minimize] increase in swelling pressure of backfill around waste package		●	●
THERMAL CHARACTERISTICS	Room Scale	btr1	[Maximize] insulation of waste package from rock mass around underground opening (room scale)	●	●	●
		btro1	[Minimize] insulation of waste package from rock mass around underground opening (room scale)	●	●	●
	Waste Package Scale	bth1	[Maximize] insulation of waste package from rock mass around emplacement hole	●	●	●
		bthol	[Minimize] insulation of waste package from rock mass around emplacement hole	●	●	●

(SEE KEY AT END OF TABLE)

SUMMARY OF BACKFILL DESIGN OBJECTIVES

Table 3.1
3 of 4

	BACKFILL DESIGN OBJECTIVES			PERIOD OF CONCERN		
	Scale	Code	Objective	-1) During Retrieval Period	-2) Post Decommissioning To Resaturation	-3) Post Resaturation
HYDROLOGIC CHARACTERISTICS	Room Scale	bhr1a	[Minimize] hydraulic conductivity (and effective porosity) of backfill and interface (room scale)	●	●	●
		bhr1b	[Maximize] decrease in hydraulic conductivity (and effective porosity) of rock mass (room scale) (i.e., sealing/filling of discontinuities) by backfill			●
		bhr2	[Maximize] porosity of backfill (room scale)	●	●	
	Room and Waste Package Scale	bh1	[Maximize] distance from waste package through repository along flow path due to backfill			●
GEOCHEMICAL CHARACTERISTICS	Room Scale	bgr1	[Maximize] protection of exposed rock surface underground (room scale) by backfill	●	●	●
		bgr2	[Maximize] thickness/adsorption of backfill (room scale)	●		
	Waste Package Scale	bgh1	[Maximize] mitigation of corrosive groundwater by backfill **(waste package scale)**	●	●	●
		bgh2	[Maximize] thickness/adsorption of backfill around waste package	●		
	Room and Waste Package Scale	bg1	[Maximize] length of flow path from waste package through backfill adsorbing material			●
		bg2	[Maximize] cross-sectional area of flow path from waste package through backfill adsorbing material (i.e., maximize volume of backfill)			●
		bg3	[Maximize] surface area per unit volume of backfill adsorbing material along flow path from waste package			●
		bg4	[Maximize] adsorption potential of backfill along flow path from waste package to accessible environment			●

(SEE KEY AT END OF TABLE)

KEY FOR CODE:

	Subject of Concern	Scale	Opposite to Identifier No.	Identifier No.	Similarity with Identifier No.		Time Period
b	s-schedule p-procedure m-mechanical t-thermal h-hydrologic g-geochemical	r-room scale h-waste package scale blank-room and waste package scale	blank o-opposite objective	1 2 3 . . .	blank a-similar b- " c- " . .	-	1-during retrieval period 2-post decommissioning to resaturation 3-post resaturation

For example:

b s r 1 a - 1

Note: These backfill design objectives have been explicitly derived from the repository system performance objectives (Figure 3.2) (see Appendix A). This development has been based on preconceived repository design concepts (specifically vertical waste emplacement) and performance assessment methodology (Section 2). Backfill design objectives may be slightly different for horizontal waste emplacement (see Section 6.5).

This development has been based on preconceived repository design concepts (specifically vertical waste emplacement) and performance assessment methodology (Section 2). Backfill design objectives may be slightly different for horizontal waste emplacement (see Section 6.5).

The backfill design objectives (Table 3.1) have been categorized in terms of the subject of concern (i.e., schedule, procedures, mechanical characteristics, thermal characteristics, hydrologic characteristics, or geochemical characteristics), the scale of concern (i.e., room scale, waste package scale, or both), and the period of concern (i.e., during the retrieval period, post-decommissioning to resaturation, or post-resaturation). Many of the more significant backfill design objectives can be summarized as relating to the primary objectives of providing structural support, water flow attenuation, or radionuclide transport attenuation.

It should be noted that some backfill design objectives are contradictory, e.g., maximize versus minimize time to placement of backfill, because for different reasons each has an advantage. In addition, some backfill design objectives will subsequently prove to be relatively insignificant. The significant backfill design objectives should form the basis for backfill design, and the subsequent evaluation of that design and its implementation with regard to achieving the repository system performance objectives. Hence, in this study, alternative backfill schemes will be evaluated solely with respect to achieving these significant backfill design objectives.

3.4 WEIGHTING OF BACKFILL DESIGN OBJECTIVES

Each of the identified backfill design objectives (Table 3.1) has a different significance or relative "weight" in contributing to the achievement of the repository system performance objectives. These relative weights must be assessed in order to identify those backfill design objectives which are most significant, and to then either:

- Optimize among the competing significant backfill design objectives for design purposes

- Evaluate a given scheme with respect to the significant backfill design objectives for comparison with other alternatives.

However, it is not within the scope of this study, nor has it been intended, to develop a backfill design basis sufficient for the purposes of design; rather, a reasonable comprehensive design basis sufficient only for comparative evaluations of alternative backfill schemes is required.

The weights of the previously identified backfill design objectives, with respect to achieving the repository system performance objectives, have been subjectively but explicitly derived (see Appendix B) and summarized (see Table 3.2). In this way, the significance of each backfill design objective with respect to achieving the repository system performance objectives has been clearly established within the context of backfill as an integral part of the repository system. This development has been based on preconceived repository design concepts (specifically vertical waste emplacement), performance assessment methodology, and generic site conditions (Section 2). Should these premises change, the weights may change. For example, the relative weights for backfill design objectives assuming horizontal waste emplacement may be slightly different (see Section 6.5), as may be the weights for different specific media/sites.

The relative weights have been subjectively assessed for generic site conditions, and thus should be considered as only indicators of relative significance. Although outside the scope of this report, the sensitivity in these resultant weights to the possible range in subjective assessments should be evaluated. This could be done, for example, by assessing a probability distribution for the relative weight of each subobjective in the hierarchy with respect to its immediate sovereign subobjective and the correlation between values of each member in the set. A probability distribution could then be derived for the relative weight of each backfill design objective by compounding down through the hierarchy. This analysis would be facilitated by computerizing the compounding portion of the analysis. Also, updating and/or other modifications (such as media/site specific evaluations) could be more easily accomplished if the compounding portion of the analysis were computerized.

The set of weighted backfill design objectives (Table 3.2) should form the basis for backfill design, and the subsequent evaluations of that design and its implementation/verification with regard to optimization in achieving the repository system performance objectives. Hence, in this study, alternative backfill schemes will be evaluated solely with respect to these weighted backfill design objectives (see Section 4). However, although deemed sufficient for the purposes of this study (i.e., for comparative evaluations of alternative backfill schemes), this generic design basis would have to be refined on a site-specific basis by quantitative performance assessment prior to any use (which has not been intended here) in guiding backfill design. The natural variability of site conditions, as they pertain to backfill, must be assessed and considered in such a refinement.

It is interesting to note that the total potential contribution of backfill to achieving the repository system performance objectives, which is determined by summing the weights of all the backfill design objectives (Table 3.2), has been roughly assessed to be about 16 percent for generic site conditions. If the hierarchy of subobjectives were completely developed, the total potential contribution of other aspects of repository design/construction/operation, as well as site screening/selection, could be determined and compared. This would provide a focus on which repository variables will be most important and thus warrant the most emphasis in design, implementation, and verification.

SUMMARY OF WEIGHTED BACKFILL DESIGN OBJECTIVES

Table 3.2
1 of 5

(Listed in approximate decreasing order of significance)

Code	Objective (see Table 3.1)	Relative Weight*
bg4-3	[Maximize] adsorption potential of backfill along flow path from waste package to accessible environment (post resaturation)	A
bsrolc-1	[Maximize] time to start resaturation process (i.e., maximize time to placement of backfill, room scale, while dewatering) (during retrieval period)	A
bhrla-3	[Minimize] hydraulic conductivity (and effective porosity) of backfill and interface (room scale) (post resaturation)	A
bhl-3	[Maximize] distance from waste package through repository along flow path due to backfill (post resaturation)	A
bgl-3	[Maximize] length of flow path from waste package through backfill adsorbing material (post resaturation)	B
bg2-3	[Maximize] cross-sectional area of flow path from waste package through backfill adsorbing material (i.e., maximize volume of backfill) (post resaturation)	B
bp2-1	[Maximize] monitoring of potentially hazardous underground conditions as backfilling occurs (during retrieval period)	B
bp3-1	[Maximize] quick and efficient mitigation of detected underground hazards as backfilling occurs (during retrieval period)	B
bhrla-2	[Minimize] hydraulic conductivity (and effective porosity) of backfill and interface (room scale) (post decommissioning to resaturation)	B
bg3-3	[Maximize] surface area per unit volume of backfill adsorbing material along flow path from waste package (post resaturation)	B
bpl-1	[Maximize] use of safe/reliable equipment for backfilling (during retrieval period)	B
bghl-3	[Maximize] mitigation of corrosive groundwater by backfill (waste package scale) (post resaturation)	B
bsrla-1	[Minimize] time to placement of backfill (room scale) (during retrieval period)	B

SUMMARY OF WEIGHTED BACKFILL DESIGN OBJECTIVES

Table 3.2
2 of 5

(Listed in approximate decreasing order of significance)

Code	Objective (see Table 3.1)	Relative Weight*
bhr2-1	[Maximize] porosity of backfill (room scale) (during retrieval period)	B
bhr2-2	[Maximize] porosity of backfill (room scale) (post decommissioning to resaturation)	B
bmr2a-1	[Maximize] support pressure (or structural support) provided by backfill (room scale) (during retrieval period)	B
bp4-1	[Minimize] personnel requirements for backfilling (i.e., maximize mechanization and remote operations) (during retrieval period)	B
bhrlb-3	[Maximize] decrease in hyraulic conductivity (and effective porosity) of rock mass (room scale) (i.e., sealing/filling of discontinuities) by backfill (post resaturation)	B
bmhl-3	[Minimize] stress transfer through backfill around waste package (post resaturation)	B
bthol-3	[Minimize] insulation of waste package from rock mass around emplacement hole (post resaturation)	B
bghl-1	[Maximize] mitigation of corrosive groundwater by backfill (waste package scale) (during retrieval period)	B
bgr2-1	[Maximize] thickness/adsorption of backfill (room scale) (during retrieval period)	B
bghl-2	[Maximize] mitigation of corrosive groundwater by backfill (waste package scale) (post decommissioning to resaturation)	B
bp5-1	[Minimize] total effort required for backfilling (e.g., no backfilling) (during retrieval period)	C
bgh2-1	[Maximize] thickness/adsorption of backfill around waste package (during retrieval period)	C
bmhl-1	[Minimize] stress transfer through backfill around waste package (during retrieval period)	C
bprl-1	[Minimize] volume of backfill (room scale) (if placed, during retrieval period)	C
bmh2b-3	[Minimize] increase in swelling pressure of backfill around waste package (post resaturation)	C
bshol-1	[Maximize] time to placement of backfill around waste package, and ventilate (during retrieval period)	C

SUMMARY OF WEIGHTED BACKFILL DESIGN OBJECTIVES

Table 3.2
3 of 5

(Listed in approximate decreasing order of significance)

Code	Objective (see Table 3.1)	Relative Weight*
bshl-1	[Minimize] time to placement of backfill around waste package (during retrieval period)	C
bmhl-2	[Minimize] stress transfer through backfill around waste package (post decommissioning to resaturation)	C
bthol-2	[Minimize] insulation of waste package from rock mass around emplacement hole (post decommissioning to resaturation)	C
bsrola-1	[Maximize] time to placement of backfill (room scale) (during retrieval period)	C
bmh2a-1	[Minimize] swelling pressure of backfill around waste package (during retrieval period)	C
bsrolb-1	[Maximize] time to placement of backfill,and ventilate (room scale) (during retrieval period)	C
bmrl-1	[Minimize] integrity (compaction) of backfill (room scale) (if placed, during retrieval period)	C
bthol-1	[Minimize] insulation of waste package from rock mass around emplacement hole (during retrieval period)	C
bsrlb-1	[Delay and minimize] backfilling of tunnels along possible egress routes (room scale)(during retrieval period)	C
bmro2a-1	[Minimize] support pressure (or structural support) provided by backfill (room scale) (during retrieval period)	C
btrl-1	[Maximize] insulation of waste package from rock mass around underground opening (room scale) (during retrieval period)	C
bmh2b-2	[Minimize] increase in swelling pressure of backfill around waste package (post decommissioning to resaturation)	C

SUMMARY OF WEIGHTED BACKFILL DESIGN OBJECTIVES

Table 3.2
4 of 5

(Listed in approximate decreasing order of significance)

Code	Objective (see Table 3.1)	Relative Weight*
bmr2c-3	[Minimize] decrease in support pressure (or structural support) provided by backfill (room scale) (post resaturation)	D
btrol-1	[Minimize] insulation of waste package from rock mass around underground opening (room scale) (during retrieval period)	D
bhrla-1	[Minimize] hydraulic conductivity (and effective porosity) of backfill and interface (room scale) (during retrieval period)	D
bmr2c-2	[Minimize] decrease in support pressure (or structural support) provided by backfill (room scale) (post decommissioning to resaturation)	D
bmr2b-3	[Maximize] increase in support pressure (or structural support) provided by backfill (room scale) (post resaturation)	D
bthl-3	[Maximize] insulation of waste package from rock mass around emplacement hole (post resaturation)	D
bthl-1	[Maximize] insulation of waste package from rock mass around emplacement hole (during retrieval period)	D
bmr2b-2	[Maximize] increase in support pressure (or structural support) provided by backfill (room scale) (post decommissioning to resaturation)	D
bthl-2	[Maximize] insulation of waste package from rock mass around emplacement hole (post decommissioning to resaturation)	D
btrl-2	[Maximize] insulation of waste package from rock mass around underground opening (room scale) (post decommissioning to resaturation)	D
btrl-3	[Maximize] insulation of waste package from rock mass around underground opening (room scale) (post resaturation)	D
bgrl-1	[Maximize] protection of exposed rock surface underground by backfill (room scale) (during retrieval period)	D
bmro2c-2	[Maximize] decrease in support pressure (or structural support) provided by backfill (room scale) (post decommissioning to resaturation)	E

SUMMARY OF WEIGHTED BACKFILL DESIGN OBJECTIVES

Table 3.2
5 of 5

(Listed in approximate decreasing order of significance)

Code	Objective (see Table 3.1)	Relative Weight*
bgrl-3	[Maximize] protection of exposed rock surface underground by backfill (room scale) (post resaturation)	E
bgrl-2	[Maximize] protection of exposed rock surface underground by backfill (room scale) (post decommissioning to resaturation)	E
bmro2c-3	[Maximize] decrease in support pressure (or structural support) provided by backfill (room scale) (post resaturation)	E
btrol-2	[Minimize] insulation of waste package from rock mass around underground opening (room scale) (post decommissioning to resaturation)	E
btrol-3	[Minimize] insulation of waste package from rock mass around underground opening (room scale) (post resaturation)	E

*The relative weight of each backfill design objective has been explicitly assessed with respect to its perceived contribution, relative to all other repository variables, to achieving the repository system performance objectives (see Appendix B). This assessment has been based on preconceived repository design concepts (specifically vertical waste emplacement), performance assessment methodology, and generic site conditions (Section 2); should these premises change, the weights may change. For example, the relative weights for backfill design objectives assuming horizontal waste emplacement may be slightly different (see Section 6.5), as may be the weights for different specific media/sites. Also, this assessment entails significant subjectivity, so that these weights should be considered only as approximate indicators of relative significance. Although deemed sufficient for the purposes of this study (i.e., a design basis for comparative evaluations of alternative backfill schemes), this generic design basis would have to be refined on a site-specific basis by quantitative performance assessment prior to any use (which has not been intended here) in guiding or rigorously evaluating backfill design.

The key used to denote the relative weights is:

A $10^{-2} <$ Relative Weight (most significant)
B $10^{-3} \leq$ Relative Weight $< 10^{-2}$
C $10^{-4} \leq$ Relative Weight $< 10^{-3}$
D $10^{-5} \leq$ Relative Weight $< 10^{-4}$
E Relative Weight $< 10^{-5}$ (least significant)

4. BACKFILL EVALUATION METHODOLOGY

Alternative backfill schemes (i.e., materials/additives, procedures, and schedule) must be comparatively evaluated in order to focus on those which will be optimum with respect to achieving the repository system performance objectives. A simple methodology for evaluating each backfill scheme with respect to achieving the generic backfill design basis (Section 3.0), and thereby the repository system performance objectives, is sufficient for these purposes; explicit overall system performance assessment, although necessary to predict actual performance and assess the adequacy of any scheme, is not required for such comparative evaluations and, in any case, is outside the scope of this study. This methodology essentially consists of subjectively assessing each backfill scheme's perceived relative contribution to achieving the repository system performance objectives by:

1) Subjectively evaluating the percentage of each significant backfill design objective perceived to be achieved by that scheme's expected performance, based on experience.

2) Multiplying the backfill scheme's assessed percentage of achieving each backfill design objective by that objective's previously determined relative weight (or significance) with respect to achieving the repository system performance objectives.

3) Summing the products of achievement percentage and relative weight for all backfill design objectives.

The estimated cost of each backfill scheme could then be compared to its relative contribution to achieving the repository system performance objectives, and an indication of each backfill scheme's cost-effectiveness thus derived. However, estimates of backfill costs are outside the scope of this study, and thus have not been considered further.

The evaluation methodology has been quantified, and consists of the following sequence of activities and definitions (see Table 4.1):

- Subjective assessment, for each backfill scheme (j), of the percentage (Pji) of each significant backfill design objective (i) perceived to be achieved by that scheme's expected performance, rated from Pji = 0.0 (no potential for achievement of objective) to Pji = 1.0 ("guaranteed" total achievement of objective).

- Determination of the perceived contribution (Qji) each backfill scheme (j) would make through achieving each backfill design objective (i) by multiplying the scheme's achievement percentage (Pji) for that objective times that objective's previously established relative weight (Wi) with respect to achieving the repository system performance objectives, i.e.:

  Qji = (Pji) (Wi)

COMPARATIVE EVALUATION METHODOLOGY: DEFINITION OF COMPONENTS

Table 4.1

Parameter	Definition
i	Specific backfill design objective (see Table 3.1)
Wi	Assessed relative weight of specific backfill design objective (i) (see Table 3.2)
j	Specific backfill scheme
Cj	Estimated cost of specific backfill scheme (j)
Pji	Percentage of specific backfill design objective (i) which is perceived to be achieved by expected performance of specific backfill scheme (j)
$Qji=(Pji)(Wi)$	Perceived contribution of specific backfill scheme (j) through achieving specific backfill design objective (i)
$Qj=\sum_{i}(Qji)$	Perceived contribution of specific backfill scheme (j) to achieving the repository system performance objectives
$Ej=Qj/[\sum_{i}(Wi)]$	Perceived effectiveness of specific backfill scheme (j) to achieving the backfill desigh basis
$Sj=(Ej)/(Cj)$	Perceived cost-effectiveness (i.e., benefit to cost ratio) of specific backfill scheme (j) in achieving the backfill design basis
$Tj=(Qj)/(Cj)$	Perceived cost-effectiveness (i.e., benefit to cost ratio) of specific backfill scheme (j) in achieving the repository system performance objectives.

Note: For comparison of alternative backfill schemes on solely a technical basis, Q or E-values would be compared, and on both a technical and cost basis, S or T-values would be compared. For comparison of alternative backfill schemes with other repository variables on solely a technical basis, Q-values would be compared, and on both a technical and cost basis, T-values would be compared. It should be remembered, however, that there is inherent uncertainty in these values due to the uncertainty in the subjective assessments of Wi, Cj, and Pji. Costs are outside of the scope of this study.

- Determination of the perceived contribution (Qj) each backfill scheme (j) would make to achieving the repository system performance objectives by summing that scheme's perceived contributions (Qji) through achieving each backfill design objective (i), i.e.:

  $Qj = \sum_i Qji$

  The Q-value would thus give an indication of the backfill scheme's expected contribution to achieving the repository system performance objectives. A backfill scheme's contribution could be compared to the contributions of other backfill schemes in order to rank them approximately on a technical basis; e.g., $Q1>Q2$ would indicate that Backfill Scheme 1 would have a generally higher probability of achieving the repository system performance objectives than Scheme 2. In fact, a backfill scheme's contribution could be compared with the analogous contribution of any other repository design component in order to assess that scheme's relative contribution as part of the system; e.g., a very low value of $Q1$ would indicate that Backfill Scheme 1 would contribute very little to achieving the repository system performance objectives and that a design component with a significantly higher analogous Q-value would be more effective. Although valuable for repository optimization, the assessment of design components other than backfill is outside the scope of this study and has not been considered further.

- Determination of "effectiveness" (Ej), similar to Qj, for each backfill scheme (j) by dividing the scheme's contribution (Qj) by the maximum possible contribution of backfill ($\sum_i Wi$):

  $Ej = Qj/[\sum_i(Wi)]$ where $\sum_i(Wi) \simeq 0.16$ for generic site conditions (see Section 3.4)

  The E-value would thus give an indication of each backfill scheme's effectiveness in achieving the backfill design basis. Again, a backfill scheme's effectiveness could be compared to the effectiveness of other backfill schemes in order to rank them on a technical basis; e.g., $E1 > E2$ would indicate that Backfill Scheme 1 would have a generally higher probability of achieving the backfill design basis than Scheme 2. Clearly, there is a linear relationship between the Q- and E-values for backfill, and either could be used for comparative studies, although the E-values might be easier to visualize.

The evaluation methodology could easily be expanded to incorporate cost considerations, which are presently outside the scope of this study, as follows:

- Estimation of cost (Cj) of each backfill scheme (j), which would inherently take into consideration feasibility and availability of material.

- Determination of "cost-effectiveness" (Sj) for each backfill scheme (j) by dividing the scheme's effectiveness by its estimated cost (Cj):

  $$Sj = (Ej)/(Cj) = [Qj/\sum_{i}(Wi)]/(Cj)$$

  The S-value would thus give an indication of each backfill scheme's cost-effectiveness in achieving the backfill design basis, i.e., a benefit-to-cost ratio. A backfill scheme's cost-effectiveness could then be compared to the cost-effectiveness of other backfill schemes in order to rank them on a cost, as well as technical, basis; e.g., $S1 > S2$ would indicate that Backfill Scheme 1 would generally be more cost-effective than Scheme 2 in achieving the backfill design basis. However, the S-value would provide only an indication of cost-effectiveness and would not indicate acceptability; i.e., a minimum acceptable value of Ej might exist, so that Sj would only become important for schemes with Ej higher than that minimum.

  Similar to the S-value, the backfill scheme's contribution (Qj) to achieving the repository system performance objectives could be divided by the scheme's estimated cost (Cj). The resulting value (Tj) would clearly be proportional to the S-value. The T-value would give an indication of each backfill scheme's cost-effectiveness in achieving the repository system performance objectives, i.e., a benefit-to-cost ratio. Such a backfill scheme's T-value could be compared with the analogous T-value of any other repository design component in order to assess that scheme's relative cost-effectiveness as part of the system; e.g., a value of $T1$ which is low compared to the analogous T-value of another design component would suggest that Backfill Scheme 1 would not be as cost-effective. Although clearly valuable for repository optimization, the assessment of design components other than backfill, as well as costs, is outside the scope of this study and has not been considered further.

The methodology developed herein would thus provide an explicit evaluation of alternative backfill schemes, with respect to the backfill design basis and hence the repository system performance objectives. The evaluation procedure would be clearly exposed so that areas of technical disagreement in the evaluation of any backfill scheme could be identified and resolved, e.g., by modifying the assessed potentials for achieving any backfill design objective. The effectiveness in achieving the backfill design basis (E-value) could be compared for the various alternative backfill schemes; the backfill scheme with the highest E-value would generally be the best on a technical basis (without considering cost). The contribution to achieving the repository system performance objectives (Q-value) could similarly be compared for the various alternative backfill schemes and also with the analogous Q-value (if available) of other repository design components; the backfill scheme or repository component with the highest Q-value would generally be the best on a technical basis (without considering cost).

However, it should be remembered that there will be significant inherent uncertainty in the determination of the E- or Q-values. This uncertainty will be due to the subjective evaluations involved, and will be a function of the uncertainty inherent in the assessment of:

- The relative weights of the backfill design objectives (Section 3.4)
- A scheme's perceived potential in achieving each backfill design objective.

It is felt that neglecting the inherent uncertainties in subjective assessment will probably not have a major effect on the results of the comparative evaluations of alternative backfill schemes. However, due to this uncertainty, the E- or Q-values should be considered as only rough indicators of relative merit, which although suitable for the purposes of this study, may be insufficient for other purposes, e.g., design. These uncertainties should be assessed at some point and subsequently incorporated in the evaluation methodology, in order to support the results of this study and provide a more useful evaluation tool for the NRC in their design review process. These uncertainties could be incorporated by assessing probability distributions for both the relative weights of each backfill design objective (Section 3.4) and the potential in achieving each backfill design objective, with correlations between objectives. These distributions could then be combined to achieve probability distributions for each Qji, and thereby Qj and Ej. Probability distributions could also be established for each Cj, and thereby Sj and Tj. This analysis would be facilitated by computerizing the computational portion of the methodology to allow for ease in modifications.

Although this subjective evaluation methodology is deemed sufficient for the purposes of this study (i.e., comparatively evaluating alternative backfill schemes), quantitative performance assessment (which is outside the scope of this study) would also be sufficient for this purpose and, in any case, will be required to evaluate the adequacy of any design. However, for comparatively evaluating many alternatives, quantitative performance assessments of each may not be feasible, so that the approach taken here is appropriate.

5. ALTERNATIVE BACKFILL SCHEMES

5.1 INTRODUCTION

The overall purpose of Task 5 is to provide the U.S. Nuclear Regulatory Commission (NRC) with sufficient information regarding backfill construction and testing with which to review Site Characterization Reports and License Applications. This technical assistance has been in the form of identifying and discussing alternative backfill materials/additives and related procedures of construction and testing, with respect to satisfying a given backfill design basis.

A generic backfill design basis (Section 3) and a subjective evaluation methodology (Section 4), which are sufficient for the purposes of this study, have been developed. In this section, a set of alternative backfill schemes is identified. These identified alternative backfill schemes will subsequently be evaluated (see Section 5). The backfill materials/additives perceived to have the highest potential for achieving the backfill design basis will be selected as a result of preliminary evaluations, and appropriate procedures for these selected materials/additives, as well as test programs, will be discussed (see Section 6).

For this study, backfill has been limited by definition to material placed in waste emplacement holes and underground excavations (rooms, corridors, etc.), which do not include shafts or boreholes or material placed as bulkheads or plugs. Backfill in these waste emplacement holes has been further limited to material placed prior to or after waste emplacement and does not include backfill buffer material as part of the waste package.

A backfill scheme (as used in this report) is comprised of the following components:

- Backfill materials/additives
- Procedures and equipment used to construct the backfill
- Backfilling schedule.

Backfill schemes have been identified in terms of these components, with additional attention given to the objectives of the backfill and the expected environmental conditions to which the backfill will be subjected. Testing for design verification has also been identified.

A collection of alternative backfill schemes have been identified and summarized (see Section 5.5). Three sources have been used in identifying these schemes:

- U.S. Department of Energy (DOE) proposed backfill schemes (see Section 5.2)
- Industry-typical backfill schemes (see Section 5.3)

- Backfill schemes identified by Golder Associates under an ongoing project with the NRC entitled "Performance of Engineered Barriers in a Geologic Repository," Contract No. NRC-02-81-027 (see Section 5.4).

All backfill schemes identified in DOE design publications have been included as alternative backfill schemes even though some may have been (or will be) superceded. All routinely used industry-typical backfill schemes have been included in the study. The work on the "Engineered Barriers Contract" is currently limited to a set of six alternative backfill materials/ additives.

5.2 DEPARTMENT OF ENERGY (DOE) PROPOSED BACKFILL SCHEMES

5.2.1 Introduction

Backfill schemes classified as DOE-proposed backfill schemes are those schemes specified in repository design publications authored by DOE contractors. The design publications have been primarily identified utilizing a literature data base developed by SAI (1981). All backfill schemes specified in these design publications have been included in this study. A total of 11 design studies (see Table 5.1, Study Nos. 1-11) have been individually summarized (see Appendix C).

These design publications vary from preconceptual to conceptual in nature; no final designs are currently available. In addition, of the four specified geologic media (basalt, salt, granite, and tuff), no design studies are currently available for repositories sited in tuff and only one is available for repositories sited in granite; however, two non-design reports (Table 5.1, Study Nos. 12 and 13) have been identified which provide an indication of the backfill materials presently being considered for tuff. It is evident that certain factors upon which the designs depend have been modified throughout the years, e.g., requirements for retrievability. Thus, some of the backfill schemes have been superceded.

The set of DOE-proposed backfill schemes have been categorized in terms of geologic media. The schemes have been described in terms of location, backfill materials/additives, source of material, preparation, storage and placement procedures, testing to assess backfill characteristics, and expected environmental conditions during and after backfilling. Brief summaries have been provided for each medium; each study referred to in the following sections has been numbered for easy reference (Table 5.1).

5.2.2 Proposed Backfill Schemes in Basalt

Five design studies, dated from April 1978 to March 1982, related to backfilling in basalt have been identified and briefly summarized (see Table 5.2 and Appendix C).

SUMMARY OF REFERENCED DOE DESIGN PUBLICATIONS RELATED TO BACKFILL

Table 5.1

Study No.	Reference(s)		Applicable Media
1)	Parsons et al	(1978c)	Basalt
2)	BWIP	(1980)	Basalt
3)	Kaiser et al	(1980)	Basalt
4)	Kaiser et al	(1982)	Basalt
5)	Westinghouse	(1981a)	Basalt
6)	Parsons et al	(1978a)	Salt
7)	Stearns-Roger Stearns-Roger Stearns-Roger Woodward-Clyde	(1978) (1979a) (1979b) (1978)	Domal salt
8)	Kaiser Kaiser	(1978a) (1978b)	Bedded salt
9)	Bechtel	(1979)	Domal salt
10)	Westinghouse	(1981b)	Salt
11)	Parsons et al	(1978b)	Granite
12)	DOE/NNWSI	(1981)	Tuff
13)	Langkopf	(1981)	Tuff

Note: The aspects of each of the studies (1) through (11) related to backfill have been summarized individually in Appendix C. In addition to these design studies, two non-design reports (12) and (13) provide an indication of the backfill materials presently being considered for tuff.

Table 5.2
1 of 3

BRIEF SUMMARY OF BACKFILL SCHEMES PROPOSED BY DOE - BASALT

REFERENCE NO.	LOCATION	MATERIAL	PLACEMENT	STATED OBJECTIVE	STATED ANTICIPATED CONDITIONS	COMMENTS
(1) Parsons et al (1978c) No repository location (see Appendix C. Section C.1)	Room	Crushed Basalt	Front-end loader will place to within 5 ft. of ceiling.	Not specified	- Relatively impermeable basalt **with flows into** repository of 265 gpm - Increased temperatures - Increased rock stress.	- Preconceptual Design Report - Backfill will be placed after retrievability period (5 years after first waste placement) - 25 year retrievability also considered.
	Waste Emplacement Hole	None	NA	NA	As above	
(2) BWIP (1980) Site is at Hanford, WA (see Appendix C. Section C.2)	Waste Emplacement Hole	Grout around steel cylinders	Pump grout into place	Not specified	- Groundwater expected - High temperatures - Stresses in rock will be below acceptable limits.	- Preconceptual Design Report - Horizontal holes used to store waste - Placement rooms will be backfilled after operational period (one to two years).
	Room	Lower 2/3 of room crushed basalt; upper 1/3 of room concretious mixtures; Note: Expansive clay was being considered.	Lower 2/3: mechanical placement & compaction; upper 1/3: pneumatic placement.	- Low permeability and stable with time - Ion-exchange capability equal to that of basalt - Passive support for rock mass - Be deformable to accomodate moderate strains.	As above	

BRIEF SUMMARY OF BACKFILL SCHEMES PROPOSED BY DOE - BASALT

Table 5.2
2 of 3

REFERENCE NO.	LOCATION	MATERIAL	PLACEMENT	STATED OBJECTIVE	STATED ANTICIPATED CONDITIONS	COMMENTS
(3) Kaiser et al (1980) Site at Hanford, WA (see Appendix C, Section C.3)	Within waste package	Bentonite contained by aluminum sleeve	Not specified	Perform as engineered barrier	- High temperatures - Corrosion implying presence of groundwater.	
	Between waste package and emplacement hole walls	Bentonite around waste package; zircon sand on top.	Not specified	As above	As above	
	Room	50% crushed basalt 40% bentonite powder 10% bentonite pellets	Not specified	Provide permanent support and act as a chemical and physical barrier against radionuclide migration.	As above plus - rock displacements.	Backfill in room will begin after retrievability period (25 years after waste emplacement).
(4) Kaiser et al (1982) Site at Hanford, WA (see Appendix C, Section C.4)	Within waste package	Bentonite within aluminum sleeve	Not specified	Isolation of radionuclides via low permeability and ion-exchange	- High temperatures - Slow movements of groundwater in basalt.	
	Between waste package and emplacement hole walls	Bentonite around waste package; top portion of annulus filled with zircon sand.	Not specified	As above	As above	

BRIEF SUMMARY OF BACKFILL SCHEMES PROPOSED BY DOE - BASALT

Table 5.2
3 of 3

REFERENCE NO.	LOCATION	MATERIAL	PLACEMENT	STATED OBJECTIVE	STATED ANTICIPATED CONDITIONS	COMMENTS
(4) (Cont'd)	Room	50% crushed basalt 50% bentonite (40% powder-10% pellets)	- Trucks and bulldozers for backfill to 10 ft. in height - Trucks and low profile equipment for backfill to 14 ft. in height - Travelling shield apparatus with automatic feed to complete backfilling of room .	As above	As above	- Travelling shield equipment is not currently used - Room is pre-cooled to 27°C - Room is backfilled after retrievability period (25 years after waste emplacement).
(5) Westinghouse (1981) No repository location (see Appendix C, Section C.5)	Waste Emplacement Hole	Pre-formed bentonite shapes with crushed basalt at bottom of hole and around bentonite outside edges	Bentonite: lowered into hole prior to canister Basalt: poured into hole	- Control groundwater - Radiation shielding.	- Presence of water - High temperatures - Radiation above waste package in room.	- Also givesalternative of self-shielded designs of waste packages placed on tunnel floor - Waste emplacement hole backfill is placed at time of waste emplacement - Backfilling of room is scheduled as soon as reasonably possible after the last emplacement made and before the bentonite absorbs significant quantities of water .

5.2.2.1 Backfill Material/Additive Types - Basalt

Materials which have been proposed for backfill around the waste package include crushed basalt, a type of grout, bentonite topped by zircon sand or pre-formed bentonite rings surrounded by crushed basalt on the outside surfaces.

Materials which have been proposed for the room backfill include crushed basalt, crushed basalt topped by a "concretious" mixture, and a mixture of crushed basalt and bentonite.

In the case of bentonite topped by zircon sand, the consistency of the bentonite has not been specified, i.e., it is uncertain if bentonite would be wet or dry, pellets or powder. The mixture of crushed basalt and bentonite would be prepared at 10 to 15 percent moisture content and would include 50 percent crushed basalt plus 40 percent bentonite powder and 10 percent bentonite pellets. The crushed basalt has frequently been specified as being sized with gradations varying from less than 3-inch to silt size particles. The source of crushed basalt would be from the excavation of underground openings. This muck might be processed, crushed and screened prior to use in backfill. In some cases, the basalt would be used as excavated. Sources for the bentonite, zircon sand and grout have not been specified.

5.2.2.2 Backfilling Procedures - Basalt

Preparation of the backfill material/additive would vary with the material being specified and with the location for the backfill (i.e., waste emplacement hole or room). Typical preparation activities would include:

- For crushed basalt, the excavated basalt might have to be crushed and/or screened to achieve the desired gradation. The requirement of crushing and screening would partially depend on the excavation method used.

- Mixing the various percentages of basalt, grout and/or bentonite could be conducted either underground or at the ground surface, depending on mining activities and underground space.

- Storage of mixtures may be required. Re-mixing of backfill may be required immediately prior to placement.

- In the case of the pre-formed bentonite shapes, the pressing and the forming of the shapes would be conducted at the surface prior to placement. The bentonite would also have to be stored in acceptable atmospheric conditions so that excessive moisture would not be absorbed.

- Storage of raw backfill materials (e.g., crushed basalt) would probably be required, depending on the sequence of mining and backfilling.

Storage and transportation of materials at processing and mixing locations would require a variety of equipment and methods (depending on logistics), such as shuttle cars, skips, hoists, conveyor belts, surge bins, batch plants, mixers, and rail haulage system.

The various proposed placement procedures for backfilling include:

- For backfilling the waste emplacement hole
  - Grouting of steel cylinders (into horizontal boreholes) (2- BWIP, 1980)
  - Mechanized placement of pre-formed bentonite shapes into a waste emplacement hole after a level pad has been prepared with crushed basalt. The backfill would be placed prior to waste package emplacement. The outside annulus of the bentonite shapes would then be filled with crushed basalt (5- Westinghouse, 1981a).
- For backfilling the room
  - Trucks and unspecified transport equipment would deliver backfill to rooms to within 5 feet of the ceiling using a front-end loader. Backfill would commence after the retrievability period (5 years in this case) (1- Parsons et al, 1978c).
  - Placement of crushed basalt by trucks and dozers would occur in the lower two-thirds of room. Mechanical compaction would be performed. The upper one-third of the room would be backfilled by pneumatic placement of a concretious mixture. Backfilling would utilize conventional equipment and commence after the operational period of waste emplacement (one to two years) (2- BWIP, 1980).
  - Placement of 50% crushed basalt, 40% bentonite powder, and 10% bentonite pellets would occur in three stages after the room has been pre-cooled to 27°C. The backfill would be hauled and dumped into the room by normal equipment and spread by a bulldozer in 8-inch lifts. Compaction would be performed using normal size equipment until backfill has reached a 10 foot height (Stage 1). The next 4 feet would be placed and compacted similarly, but utilizing low profile equipment (Stage 2). The final stage of placement would be performed using a traveling shield which compresses the backfill against a fill fence (bulkhead). The backfill would enter into the space through a hole in the top of the traveling shield. Backfill would commence after the retrievability period (25 years in this case) (4- Kaiser et al, 1982).

The few details available on specific test programs to establish the in-place performance of the backfill (waste emplacement hole or room) include:

- The establishment of a testing program to demonstrate the ability of the backfill to provide structural support and inhibit groundwater migration (2- BWIP, 1980)

- An experimental panel to examine design alternatives, as well as backfill procedures (3- Kaiser et al, 1980 and 4- Kaiser et al, 1982)

- The need for mock fabrication and emplacement tests for the preformed bentonite backfill, and the need for definitive material properties (5- Westinghouse, 1981a).

5.2.2.3 Expected Environmental Conditions - Basalt

Environmental conditions existing at the site will have a considerable influence on the construction and performance of the backfill. These conditions will be a function of the site characteristics and repository design (Section 2).

The expected conditions for a repository in basalt have been discussed in various levels of detail in the design reports, and can be summarized as:

- During backfilling of waste emplacement hole
  - Presence of water - amounts may depend on the degree of disturbance during excavation
  - Possible increased temperatures - this may depend on the age of waste and the degree of shielding in the waste package, and the time elapsed since placement
  - Possible radiation - this will depend on the degree of shielding in the waste package
  - Increased stresses in basalt around openings.
- During backfilling of room
  - Presence of water - amount of water may be additionally affected by thermal gradients
  - Elevated temperatures - if backfilling of the room commences after a delay for retrievability purposes, temperatures in the surrounding rock will likely increase due to temperatures in the waste package. The degree of increase will depend partially on the waste package and waste emplacement hole backfill design
  - Possible radiation - levels of radiation at this stage will likely be less than at waste emplacement hole backfilling, based on increased shielding by waste emplacement hole backfill and the shield plug
  - Increased stresses in basalt around openings.

5.2.3 Proposed Backfill Schemes in Salt

Five design studies, dated from April 1978 to November 1981, related to backfilling in salt have been identified and briefly summarized (see Table 5.3 and Appendix C). For the purposes of this section, bedded and domal salt have been combined into one category.

5.2.3.1 Backfill Material/Additive Types - Salt

Materials which have been proposed for waste emplacement hole backfill materials/additives include excavated or crushed salt, crushed salt around a steel sleeve, and bentonite topped by crushed salt. In the case of crushed salt around the steel sleeve, the sleeve would be provided only to enhance retrievability. Bentonite/montmorillonite has also been suggested as a possible backfill for the waste emplacement hole (7- Stearns-Roger, 1978, etc.).

Excavated or crushed salt has been proposed for room backfill in all cases. The source of the excavated or crushed salt would be from excavation of underground openings. Gradations of salt, either as excavated or required, have not been given, and thus it is not clear when or how much crushing would be necessary.

5.2.3.2 Backfilling Procedures - Salt

The preparation of the salt backfill would involve crushing, but no details or gradations have been given. Transportation of the excavated salt to surface or underground storage and/or processing stations would be required and would often utilize conventional construction equipment (trucks, front-end loaders, etc., with crushers, conveyor belts, surge bins, skip and hoist systems, and shuttle cars).

In backfilling of the waste emplacement hole, it has been proposed that crushed salt be initially poured into the hole to level the bottom for receipt of the waste package. The next stage would be the placement of a steel sleeve and/or the waste package into the hole. The sleeve might be suspended from the top of the hole and no backfill placed around the sleeve (8- Kaiser, 1978a and 1978b). Alternatively, backfill could be placed around the sleeve (9- Bechtel, 1979). The salt backfill around the sleeve would be poured into place and vibrated. The sleeve might no longer be required after the initial retrievability period and the placement of the waste package would then require salt to be placed around the waste package (8- Kaiser, 1978a and 1978b). Salt might be placed only on top of the waste package during the post-retrieval period (9- Bechtel, 1979 and 10- Westinghouse, 1981b).

Placement of salt into the waste emplacement hole would generally utilize the same equipment as used to place the sleeve or waste package, and would require a salt storage bin and a method to place and perhaps, as suggested in one case, vibrate the salt. No details of the bentonite

BRIEF SUMMARY OF BACKFILL SCHEMES PROPOSED BY DOE - SALT

Table 5.3
1 of 3

REFERENCE NO.	LOCATION	MATERIAL	PLACEMENT	STATED OBJECTIVE	STATED ANTICIPATED CONDITIONS	COMMENTS
(6) Parsons et al (1978a) No repository location (see Appendix C, Section C.6)	Waste emplacement hole with sleeve (retrievability period)	Excavated salt around sleeve	Not specified	To ensure that sleeve and canister remain plumb during placement process and retrievability period.	- No water inflow into repository provided no major disturbance of salt - Increased temperature - Increased rock stress.	
	Waste emplacement hole without sleeve (after retrievability period)		NA	NA		
	Room	Excavated salt	Conveyors place salt to within 2 ft. of ceiling	Not specified	Not specified	Backfilling of room will begin after retrievability period (first 5 years of operation). 25 year retrievability also considered.
(7) Stearns-Roger (1978) Stearns-Roger (1979a) Stearns-Roger (1979b) Woodward-Clyde (1978) Domal Salt No repository location (see Appendix C, Section C.7)	Waste emplacement hole	Suggest bentonite between hole wall and canister; salt on top portion of hole.	Not specified	To prevent corrosion	-High temperatures -Salt brine.	Suggest 250' deep waste emplacement holes.
	Room	Excavated salt	Centrifugal thrower	Not specified	As above	Backfilling of room will begin after first 5 years of operation.

BRIEF SUMMARY OF BACKFILL SCHEMES PROPOSED BY DOE - SALT

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REFERENCE NO.	LOCATION	MATERIAL	PLACEMENT	STATED OBJECTIVE	STATED ANTICIPATED CONDITIONS	COMMENTS
(8) Kaiser (1978a and b) Bedded Salt No repository location (see Appendix C, Section C.8)	Waste emplacement hole with sleeve (retrievability period)	None	NA	NA	- High temperatures - Salt creep - Low moisture in salt - Water migration due to thermal gradient.	
	Waste emplacement hole without sleeve (after retrievability period)	Crushed salt (no gradation given)	Modified transporter will place salt on top of waste package.	Radiation shielding	As above	
	Room	As above	Trucks, dozers and low-profile teletrams fitted with blades will place salt.	Not specified	As above	Backfilling of room will begin after retrievability period (first 5 years of operation).
(9) Bechtel (1979) Domal Salt No repository location (see Appendix C, Section C.9)	Waste emplacement hole with inner sleeve (retrievability period)	Crushed salt (no gradation given)	Mechanically poured into waste emplacement hole and on top of package	Heat transfer	- High temperatures - Salt creep - Presence of moisture and corrosion of canister.	
	Waste emplacement hole without inner sleeve (recovery period)	As above	Mechanically poured on top of package	Heat transfer	As above	

Table 5.3
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BRIEF SUMMARY OF BACKFILL SCHEMES PROPOSED BY DOE - SALT

REFERENCE NO.	LOCATION	MATERIAL	PLACEMENT	STATED OBJECTIVE	STATED ANTICIPATED CONDITIONS	COMMENTS
(9) (Cont'd)	Room	As above	Centrifugal thrower at end of conveyor belt	To avoid permanent support during retrievability period	As above	Backfill of room will begin after retrievability (5 years after first waste emplacement).
(10) Westinghouse **(1981b)** No repository location **(see Appendix C, Section C.10)**	Waste emplacement hole (on top of package and at base of hole)	Crushed salt (no gradation given)	Mechanically poured into waste emplacement hole	Radiation shielding; level hole bottom.	- High temperatures - Salt creep (closure of waste emplacement holes, tunnel) - Small quantities of groundwater/brine - Radiation in room above waste package.	Vertical waste emplacement hole summarized. Self-shielded designs also given in report.
	Room	As above	Not specified	Not specified	As above	Backfilling of room will begin 6 months to 1 year after waste package emplacement.

backfill placement around the waste package have been given. The schedule for backfill placement in the waste emplacement hole would generally be immediately after sleeve or waste package placement.

Three different methods have been proposed to place the excavated salt in rooms. One method would utilize a conveyor suspended from the ceiling to place the salt to within 2 feet of the ceiling. A second method would utilize trucks and bulldozers to fill the room halfway in height. The remaining part of the room would be filled utilizing low-profile teletrams fitted with bulldozer blades. The third option would transport salt on a conveyor to a centrifugal thrower, which would then project the salt into the room.

Regarding proposed backfilling schedules, in every case (except one) room backfilling would commence after the retrievability period (either 5 or 25 years). Alternatively, backfilling would commence six months to one year after waste emplacement (10- Westinghouse, 1981b).

No details regarding anticipated performance testing of the backfill (waste emplacement hole or room) have been given. However, instrumentation has been proposed to monitor repository performance, which includes room closure and creep, radiation levels, and salt temperature levels (8- Kaiser, 1978a and 1978b, and 9- Bechtel, 1979).

5.2.3.3 Expected Environmental Conditions - Salt

Environmental conditions existing at the site will have a considerable influence on the construction and performance of the backfill. These conditions will be a function of the site characteristics and repository design (Section 2).

The expected conditions for a repository in salt, as mentioned in the design publications, can be summarized as:

- During backfilling of waste emplacement hole
  - Presence of water - water as well as brine is expected in small quantities in the salt. Thermal gradients will affect water/brine migration
  - Possible increased temperatures - the magnitude of increase may depend on the age of waste and the degree of shielding of the waste package
  - Possible radiation - the amount of radiation will depend on the degree of shielding in the waste package
  - Closure (creep) of waste emplacement hole and room.
- During backfilling of room (in addition to the above conditions)
  - Temperatures will likely be even greater

- Creep displacements will likely be larger
- Radiation levels may be less if borehole plugs and sufficient waste emplacement hole backfill have been used.

5.2.4 Proposed Backfill Schemes in Granite

Only one publication, dated April 1978, related to backfilling in granite has been identified and briefly summarized (see Table 5.4 and Appendix C).

5.2.4.1 Backfill Material/Additive Types - Granite

No details for waste emplacement hole backfill have been given. Sleeves would be used to enhance retrievability during the first 5 years, and presumably no backfill would be placed around the waste package after that time.

Crushed granite has been proposed for room backfill, although no gradation has been specified.

5.2.4.2 Backfilling Procedures - Granite

Preparation of crushed granite would include transportation of the material and crushing of the granite. It has been proposed that these activities occur underground. Equipment required would include trucks, rail cars, conveyor belts, storage bins and a crusher.

The crushed granite would be placed within 5 feet of the room ceiling using a front-end loader. The schedule for backfilling of the rooms in the case of spent fuel would be after the 5 year retrievability period. No testing or monitoring program has been mentioned.

5.2.4.3 Expected Environmental Conditions - Granite

Environmental conditions existing at the site will have a considerable influence on the construction and performance of the backfill. These conditions will be a function of the site characteristics and repository design (Section 2). The expected conditions for a repository in granite, as mentioned in the design document, can be summarized as:

- Increased temperatures
- Increased rock stresses
- Minimal water flow into the repository.

5.2.5 Proposed Backfill Schemes in Tuff

No published design studies for a waste repository in tuff are currently available. However, an indication of materials being considered as

BRIEF SUMMARY OF BACKFILL SCHEMES PROPOSED BY DOE - GRANITE

Table 5.4

REFERENCE NO.	LOCATION	MATERIAL	PLACEMENT	STATED OBJECTIVE	STATED ANTICIPATED CONDITIONS	COMMENTS
(11) Parsons et al (1978b) No repository location (see Appendix C, Section C.11)	Room	Crushed granite	Front-end loader will place to withir 5 feet of ceiling.	Not specified	- Minimal water flow into repository - Increased temperatures - Increased rock stress.	- Backfill will begin after retrievability period (approximately 5 years after first waste emplacement). - 25 year retrievability also considered.
	Waste emplacement hole	No backfill around steel pipe sleeve	Not mentioned	Not specified	As above	

backfill has been obtained from two non-design reports, dated June and December 1981, which have been briefly summarized (see Table 5.5).

Backfill associated with the waste package has been assumed to be 70 to 90% crushed tuff with 10 to 30% smectite clay (12- DOE/NNWSI, 1981). However, it is not clear if this backfill would be within the waste package or around it. Backfill in the room itself has been assumed to be crushed tuff (13- Langkopf, 1981).

Procedures have not been detailed, and expected environmental conditions have not been specifically discussed. The occurrence of elevated temperatures has been mentioned, with saturated conditions in the room considered as a possibility after backfilling of the room.

5.3 INDUSTRY - TYPICAL BACKFILL SCHEMES

5.3.1 Introduction

Backfill is commonly used in a routine manner in mining and civil engineering projects. Design procedures for these backfilling operations are generally empirical but nevertheless satisfactory and adequate for the particular applications and objectives. Such backfill operations involve the filling of large voids, caverns, pits or openings and would thus be most applicable to the backfilling of waste emplacement rooms. This section reviews the construction and operation aspects of industry-typical backfills. A considerable potential cross-application of a well-developed technology to repository backfilling is evident.

5.3.2 Backfill Schemes Used in Mining

Backfilling is utilized in underground mining primarily for the purpose of wall and roof support of mined areas. Other uses of backfilling are to provide a working platform for miners and equipment when working up a stope and for disposal of mine/mill waste.

Three methods are currently used for placing backfill:

1) mechanical - dumped from truck or conveyor belts
2) pneumatic - by compressed air
3) hydraulic - placed as a water-saturated slurry.

Site conditions, the availability of materials and the purpose of the backfill generally determine which method is used. If the primary purpose is structural support of walls and/or roofs in a mine, special procedures are required with all three methods to maximize the as-placed density and stiffness of the backfill. Maximum densities are achieved by using selected backfill materials, compaction procedures and/or the incorporation of additives such as cement or fly ash in the backfill. With proper placement, a high modulus backfill can be developed to significantly reduce the instability of mine openings and to permit otherwise unacceptable mining methods to be applied.

Table 5.5

BRIEF SUMMARY OF BACKFILL SCHEMES PROPOSED BY DOE - TUFF

REFERENCE NO.	LOCATION	MATERIAL	PLACEMENT	STATED OBJECTIVE	STATED ANTICIPATED CONDITIONS	COMMENTS
(12) DOE/NNWSI (1981)	Waste emplacement hole	70% to 90 crushed tuff and 10% to 30 smectite clay	Not mentioned	Not mentioned	- High temperatures	-Recommendations on canister loading are to be made based on perceived importance of waste package. -Temperatures within waste package are in excess of stability limits for the clay unless reduced canister loading is achieved.
(13) Langkopf (1981)	Room	Crushed tuff	Not mentioned	Not mentioned except that crushed tuff was modeled as having same properties as in-place tuff.	- High temperatures - Saturated conditions possible.	Low thermal conductivity backfill for waste package was mentioned as being considered.

In surface mining, backfilling is often used for waste disposal or engineering purposes, e.g., haul roads and ramps. When used for waste disposal, little control of material content or method of placement is exercised with the exception of slope stability concerns. When used for engineering purposes, it is typically subject to strict quality control and emplacement treatment, similar to surface civil engineering (see Section 5.3.3). The remainder of this section will be concerned with backfilling in underground mines.

5.3.2.1 Mechanical Placement of Backfill

Mechanically placed backfill normally consists of waste rock derived from underground mining. In some cases, however, the necessity to attain certain properties for the in-place fill requires that the waste rock be derived from a specially developed quarry. Such backfill material is usually blocky and angular, with a wide range of gradations. Generally, waste rock is unsuitable for structural backfill, as both the large size of the rock and the placement methods often result in portions of the opening not being completely filled. Occassionally, crushed and sized material from the surface is placed mechanically. Grouting or gravity percolation of voids with a cemented slurry is sometimes used to provide more rigid support and to render the fill less permeable.

The placement of backfill by mechanical methods in mining applications is ordinarily accomplished by transporting the material by trucks, bulldozers or conveyor belts to the area to be backfilled and dropping or dumping the material into the opening. Compaction of the backfill is achieved by the impact of the falling material. Further compactive effort is sometimes applied by construction equipment, if warranted.

Waste rock fill can be placed from the surface through a fill pass (i.e., a shaft created for gravity feeding the rock fill, usually by a choked draw, to the required stope) (Kerr, 1978). This is a common practice with coarse-grained waste disposal.

For the transport and placement of fill, some specialized equipment not otherwise employed in the operation of the mine is often required, especially if a large scale filling program is in operation. This equipment includes surface dump trucks, raise borers for constructing fill passes, horizontal belt conveyor, centrifugal throwers, load-haul dump trucks or compaction machines.

5.3.2.2 Pneumatic Placement of Backfill

Material for pneumatic placement of backfill has specific gradation requirements. Equipment capable of handling particles up to 1 1/2 inches is common, although special equipment may be available for up to 3 inch maximum particle size. The minimum size of material is less critical, but high percentages of the fine-grained material often create dust problems. Dust can be minimized by misting water into the system just prior to discharge. Mineralogical content is unimportant except for abrasion considerations for equipment. Additives that require moisture are not favored since low moisture content is critical to transport by pneumatic methods.

Sources of backfill are usually mine waste rock. However, other materials have been used. For example, one mine has successfully used desert sand, available at the site, for pneumatic backfill (Soderberg and Corson, 1976).

Pneumatic placement of backfill is accomplished by placing the backfill material with compressed air. The procedure requires that the properly sized material be within a certain desired water content (5-8%). The material is loaded into a feed hopper and blown into place through an injection nozzle. An operator directs the placement of material by aiming the nozzle and filling the openings. The density of the material is determined solely by the placement of the material, as no compaction is generally performed.

The equipment needed for pneumatic placement of backfill consists of a blower unit, stower, drive unit and ancillary equipment. The blower is an air compressor, with sufficient capacity to propel the material. The stower is a rotary valve airlock which feeds backfill material into the high pressure pipeline. The drive unit supplies mechanical power to the blower and hydraulic power to the stower and nozzle directing equipment. Ancillary equipment consists of abrasion-resistant pipe, couplings and elbows to reach the placement site from the stower, the nozzle to direct the stream of backfill, and hydraulic controls for the nozzle. A tapered discharge is generally used to better direct placement of the backfill. Abrasion-resistant pipe is necessary for longer useful life, although it is more expensive. Design and specifications for all equipment are influenced by site specific criteria, such as maximum particle size, abrasion characteristics and required filling rate.

5.3.2.3 Hydraulic Placement of Backfill

Particle size distribution, slurry water content, and discharge distance are the main parameters for selection of materials in the hydraulic placement of backfill. The material is placed as a slurry, so that transportation of material is usually via pipe or with gravity feed. The pipe diameter controls the maximum particle size that can be used.

Very small particles may drain off with the decant water, while very large particles may settle in the piping system (depending on flow velocities). The slurry water content desired affects the types of materials able to be transported. The size of the opening or discharge distance affects segregation of the material. The coarsest materials sediment first, leaving fine-grained materials in suspension. A considerable variation in fill properties across the room and with elevation results. The segregation-related structure in the fill markedly influences its hydrologic and mechanical behavior.

Hydraulic backfills are typically loose, as deposited, and thus the modulus of the backfill is relatively low. Compaction of hydraulic backfill is seldom performed. If the backfill is subject to densification by vibrations, gaps may occur in the top of the opening.

Additives that are used in hydraulic backfilling include:

- Cement grout, fly ash, or slags to bind particles together and fill voids
- Flocculants to improve settling of the fine-grained materials at the decant location
- Dispersants to reduce flocculated structure in backfilled areas.

A frequent source of hydraulic backfill material is mill tailings, which primarily consist of sand- and silt-sized particles. The advantage of tailings is their availability, their pre-existence in slurry form, the need to dispose of the tailings, and suitable grain size distribution. Other material sources are sometimes used, but these require crushing and screening prior to slurry preparation.

Assuming a suitable slurry is available, hydraulic backfilling is accomplished by the following typical method. Fill fences or bulkheads are constructed across any openings in the stope. The fill fences serve to contain the backfill within the stope to be filled and provide drainage for the slurry water. The slurry is fed to the stope from the surface through pipes along existing shafts, tunnels or drillholes, as necessary. It is usually freely discharged into the stope from the top. The additives are added to the slurry, as required, either at the surface or underground, prior to discharging the slurry into the stope. If compaction is employed, the stope may be filled in lifts. The stope is filled to the desired level and the slurry water is decanted through the fill fences and pumped out of the mine. The slurry is transported by gravity, thereby avoiding the need for pumps. In some cases, the tailings slurry is cycloned to remove some of the fines and reduce siltation of the decant water pumps. In situations where mining is to be done above the backfill, a working surface is created by placing the last six inches as a layer of cemented slurry backfill.

Two types of compaction techniques are available: vibratory compaction and electro-osmosis. Vibratory compaction is accomplished by vibrating the backfill after it has been placed. The vibration causes densification of the loose structure of the material. Electro-osmosis uses negatively charged cathodes placed near drains to encourage the flow of water towards the discharge points, which promotes dewatering in low permeability backfills. The loss of water causes consolidation (densification) of the backfill. Various configurations of electrodes and current application are used, according to specific site conditions, to obtain the best results.

Exclusive of surface equipment to produce the slurry, the necessary equipment for hydraulic backfill is relatively simple. Transporting the slurry from the surface down to the stope requires only pipes, fittings and valves which are simple to assemble and dissassemble (for set up at another backfill site). Abrasion is not as critical as in pneumatic backfilling, so no special requirements are needed for the pipe. In some situations, the backfill is simply poured down drill holes which exit into the stope. The fill fences are typically constructed with timbers and are rock bolted or otherwise braced to support the load from the backfill. They are backed (on the backfilled side) with burlap, or an acceptable geotextile, which allow flow of water through spaces between the timbers but retain the backfill. Decant sumps collect the water, which is then pumped out of the mine.

Concrete vibrators are sometimes used to vibrate the backfill when placed in lifts, but an immersion type vibrator can be used while backfilling is taking place and has the added capability of being operated remotely, thereby reducing risk to mine personnel. The electro-osmosis process requires a high voltage D.C. power source (on the order of 225 volts), connecting cables and electrodes (preferably made of lead but iron is acceptable). The electrodes need to be placed prior to backfilling in order to locate them properly.

In spite of the seemingly simple equipment necessary for hydraulic backfilling, very complex systems are used for the most successful utilization of the method. These systems involve remote sensing instrumentation, slurry-density monitoring systems, rate and volume control systems, sophisticated batching plants, and safe and detailed construction of fill fences.

5.3.2.4 Hybrid Backfill Schemes

In any one of the aforementioned schemes, diverse techniques are associated with the transportation, placement and compaction of backfill. It is conceivable that a hydrid backfill scheme could be devised that would utilize techniques from several backfill schemes. For example, if mill tailings are the backfill material, the tailings could be transported to the opening in a slurry, as in hydraulic backfill, but might be dewatered underground and placed pneumatically. Possible hybrid backfill schemes will subsequently be considered in the preliminary evaluation of the select set of alternative schemes for further study.

5.3.2.5 Discussion

So as to place these three types of mine backfill methods into perspective as potential backfilling techniques for waste emplacement rooms, it is instructive to review the relevant characteristics of these methods, and in particular, their advantages and disadvantages.

For <u>mechanical placement of backfill</u>:

- Advantages include
  - Equipment already on hand to remove muck can be utilized to place backfill, thus minimizing the purchase of new equipment
  - Larger rock particles can be used to increase the bulk of the material, thereby reducing cost, and also to improve the stiffness of the fill.
- Disadvantages include
  - The backfill hauling equipment may interfere with other operations
  - As openings are backfilled, they must be entered by miners, which requires keeping the area ventilated during operations
  - Entry into openings by miners during backfilling of openings exposes them to the possibly unsupported roof and walls
  - Conveyors and passes are difficult to set up and remove, making the transport system inflexible
  - Depending on exact method of mechanical placement, it may be difficult to achieve a homogeneous backfill
  - Mechanical placement methods need access room, making complete backfilling against the roof difficult.

For <u>pneumatic placement of backfill</u>:

- Advantages include
  - A wide range of material particle sizes from 1 1/2 inches to silt-size can be handled
  - Significant quantities of water are not introduced underground
  - The system is capable of completely filling the opening up to the roof.
- Disadvantages include
  - Dust is produced during backfill operations
  - Operating costs for the compressor, stower and hydraulic systems are high
  - Dry backfill is very abrasive and results in considerable wear of equipment
  - Depending on material, the backfill may experience settlement upon wetting

  - Adequate density and stiffness of the backfill may be difficult to achieve.

For hydraulic placement of backfill:

- Advantages include
  - Energy requirements are low, as slurry can be delivered through a gravity piping system
  - There is minimal interference with other operations underground
  - Material can flow into inaccessible areas, including cracks that might not otherwise be backfilled.
- Disadvantages include
  - Dewatering is required, as water used in the slurry must be decanted and removed from underground
  - Unless compacted or treated with additives, the density is generally lower than that obtained by other methods
  - Potential for serious accidents exists should fill fences fail before backfill is dewatered
  - Continued drainage is required to provide safety against liquefaction
  - It is difficult to maintain dry conditions in other areas underground
  - Complete filling to the roof of the opening is difficult to achieve
  - Large post-filling settlement prevents reliable estimation of roof support.

5.3.3 Backfill Schemes Used in Surface Civil Engineering

Backfill used in civil engineering projects can be categorized under two basic headings: structural and hydrologic. Structural backfills are used to provide support/bearing and hydrologic backfills are used to either promote or retard the flow of water. In some instances, a backfill may be designed to serve both purposes.

5.3.3.1 Structural Backfill

Properties required of structural backfill include a high resistance to deformation under load (high modulus) and sufficient strength to prevent shear failures (bearing capacity and slope stability). These requirements place certain constraints on the types of material used and the techniques used to place and compact them. Selection of a material type also depends on availability of materials, environmental concerns (rainfall, drainage, etc.), and other uses of the fill beyond structural needs.

Generally, the mechanical properties of backfill are a function of the type of material (grain size distribution, shape of particles, and moisture content) and density (achieved by compaction). Coarse-grained soils generally offer a higher modulus and strength than fine-grained soils (silt and clay). Also, loose fills generally undergo greater displacement under load and exhibit a lower strength than dense soils. The behavior of coarse- and fine-grained soils at failure differs. For example, considering the case of shallow foundation bearing capacity, failure in clean, coarse-grained soils is likely to be manifested as gradually increasing settlements whereas a failure in soils containing a significant portion of fine-grained material is likely to be manifested as a sudden shear displacement. Thus, the potential significance of the failure characteristics of the backfill to the performance of the structure under the anticipated loading conditions should be considered in the selection of a backfill material.

Soil used for structural backfill is usually compacted in order to densify the soil and achieve adequate behavior. In cohesionless soils, the ease of compaction is relatively insensitive to the moisture content. However, the compactibility and behavior of fine-grained soils, or soils with a significant percentage of fine-grained material, depends greatly on the compaction water content. In general terms, the strength is maximized near the optimum water content, i.e., that water content which produces maximum density; however, the modulus decreases with increasing water content. Volume change during saturation or the introduction of water to the soils is greater for water contents on the dry side of optimum water content.

Procedures for compaction vary with the gradation of the material. Specifications for compaction generally require that maximum densities be determined by laboratory tests. Moisture contents related to the maximum density are also determined, if appropriate. Standard procedures for these determinations exist (e.g., ASTM Annual Book of Standards, Part 19, Soil and Rock, Building Stones). The backfill is frequently tested for as-compacted density in the field and compared with the specified density and water content.

Material is most commonly compacted in lifts, the thickness of which is controlled by the maximum particle size, the type of structure to be founded on the backfill, and the degree of compaction sought.

In general, clean, coarse-grained materials can be compacted with heavy smooth-drum rollers (often with vibratory effort), rubber-tired rollers (primarily on sand) and construction traffic (such as bulldozers, haul trucks). Soils with a high percentage of fine-grained material generally require sheepsfoot rollers, although smooth-drum or rubber-tired rollers can also be satisfactory.

Smooth-drum rollers provide compactive effort through the weight of the drum and associated equipment. Vibrating rollers, weighing from 5 to 15 tons and vibrating at approximately 1500 cycles per minute, are often utilized with cohesionless material. In tight areas where large vibrating rollers cannot operate, hand-operated, self-propelled vibratory compactors can be used. The depth to which compaction takes place depends on the weight of the roller, frequency of vibration, number of passes, type of material, and depth of each lift.

In cohesive material, compaction in layers by heavy rollers is most often used without vibration, as vibration is less effective; even so, vibration is sometimes utilized. The types of rollers most frequently used are rubber-tired and sheepsfoot rollers. Rubber-tired rollers range from 25,000 pounds to over 100 tons in weight. The weight can be varied by adding or removing ballast from the boxes, and the load transmitted to the backfill can be varied by changing the weight and inflating or deflating the rubber tires. The compacting action is a combination of tire load and the kneading action between the tires.

The sheepsfoot roller is a drum to which numerous projections or feet are attached. These feet serve to transmit the weight of the drum through a small surface area to the backfill, thus increasing the applied surface pressure. The weight of the drum can be varied by filling or emptying the drum with sand or water. The action of the feet tend to impart a kneading action on the soil. The sheepsfoot roller is especially effective in bonding compaction layers together.

5.3.3.2 Hydrologic Backfill

Material requirements for hydrologic backfill depend on whether the purpose is to promote or retard the flow of water. If drainage is desired, pervious material is used and specific grain size requirements must be met. In general, the material needs to be sand sized or larger to have sufficiently high permeability. Alternatively, for retarding the flow of water, impervious material with a high content of fine-grained material is used.

For impervious backfills, both non-swelling and swelling clays (bentonite) are often used, since they have low permeability. The swelling potential of bentonite can be very beneficial since, if the swelling is confined, even lower permeabilities develop. One problem that can occur, however, is that if the clay dries, desiccation cracks can develop and the permeability is increased, often severely, especially if coarse-grained material falls in the cracks. Silts are sometimes used as impervious materials, as in dams, but generally they are more permeable and erodible than clays. It should be noted that concrete and some bituminous materials may also be used as impervious material.

Mineralogical considerations may be important in the selection of backfill materials, since some materials may alter or weather when in contact with water. A common product of alteration is clay, which would reduce the permeability of a drainage backfill. Additionally, some clays which are dispersive erode easily when in contact with flowing water. Other materials degrade with time, e.g., clay shales.

Where flow occurs through a fill, graded filters are necessary to prevent erosion and piping. Filters can be designed using grain size relationships to prevent loss of material from specified layers.

Procedures for placing and compacting (if required) backfill for hydrologic purposes are typically the same as for structural backfill (Section 5.3.3.1).

An alternative method of providing an impervious cutoff for water flow is the slurry trench, which is excavated to a suitable depth or stratum to effect a barrier to migration of water. A clay slurry is utilized to keep the trench open. The clay slurry is eventually displaced partially by backfill (often coarse-grained), but slurry infiltrates the walls of the trench and the voids of the backfill rendering the trench relatively impermeable. However, the method of trenching limits the application of this method.

5.3.3.3 Summary

Backfill materials, related compaction procedures, and their suitability for use as structural and hydrologic backfill have been summarized (see Table 5.6) to serve as a general guideline for backfills utilized in civil engineering projects.

In addition to soils, concrete can be, and often is, used for structural and/or hydrologic backfill. Concrete is typically placed using mechanical or pumping techniques, and compacted using mechanical or vibratory techniques. When compacted by rollers, the concrete is termed "roll-crete" and has improved mechanical properties (i.e., higher strength and modulus). Roll-crete has been used for a variety of purposes, such as dams (e.g., Willow Creek Dam is a roll-crete dam being constructed by the Army Crops of Engineers in Heppner, Oregon).

5.4 "ENGINEERED BARRIERS CONTRACT" BACKFILL MATERIALS/ADDITIVES

Golder Associates is currently working on a complementary NRC project (NRC-02-81-027) entitled "Performance of Engineered Barriers in a Geologic Repository". This study has progressed to a point where a preliminary selection of six engineered barrier system concepts has been made from a comprehensive group of possible designs, including backfills, metal hole liners, grouted fracture zones, bulkheads, etc. The preliminary selection has been made by considering both the cost and performance (in terms of reducing radionuclide release) in a screening analysis. The preliminary selection has demonstrated that the greatest benefit can be realized from the proper choice of backfill materials

SUMMARY OF CIVIL ENGINEERING BACKFILL CHARACTERISTICS

Table 5.6

MATERIAL	RANGE OF GRAIN SIZES*	COMPACTION METHOD	STRUCTURAL SUITABILITY	HYDROLOGIC SUITABILITY	PERMEABILITY FOR COMPACTED, SATURATED FILL
Gravel	75 mm to 4.75 mm	Smooth drum or vibrating roller	High modulus	Good for drainage applications	Very high
Gravel & Sand	75 mm to .074 mm	Smooth drum or vibrating roller	High modulus	Good for drainage applications	High
Sand	4.75 mm to .074 mm	Smooth drum or vibrating roller	High to moderate modulus	Good for drainage applications	High
Sand & Silt	4.75 mm to .005 mm	Smooth-drum, rubber-tired or vibrating roller	Moderate modulus	Possibly acceptable for drainage applications	Moderate
Silt	.074 mm to .005 mm	Smooth-drum, rubber-tired or sheepsfoot roller	Moderate to low modulus	Possibly acceptable for impervious fill	Moderate to low
Sand Silt & Clay	4.75 mm to <.005 mm	Smooth-drum, rubber-tired or sheepsfoot roller	Moderate to low modulus	Possibly acceptable for impervious fill	Moderate to low
Silt & Clay	.074 mm to <.005 mm	Smooth-drum, rubber-tired or sheepsfoot roller	Low modulus, possible swelling or consolidation problems depending on environment	Possibly acceptable for impervious fill	Low
Clay	<.005 mm	Smooth-drum, rubber-tired or sheepsfoot roller	As above	Good impervious fill	Very low

*per 1982 Annual Book of ASTM Standards, Part 19, Soil and Rock; Building Stones themselves. The selected concepts represent a range of possible materials and additives and are not necessarily the optimum designs, but rather they exemplify the range of credible design possibilities. The concepts available to date are presented here as background information on potential backfill designs and serve as a basis for reviewing the available backfill concepts without the benefit of a detailed knowledge of their respective performance characteristics.

The six selected backfill concepts (see Table 5.7) have been identified in terms of their primary objectives, namely, providing attenuation of water flow (W) or attenuation of radionuclide migration (RN) by backfilling the waste emplacement hole or room. An additional concept, a concrete floor slab extending into the fracture-affected rock zone, may provide a further barrier to water flow and has been considered.

Within the present Engineered Barriers study, relevant properties have been assigned to the backfill materials for use in performance assessment; however, the procedures required to achieve these properties have not been addressed in that study.

5.5 SUMMARY OF ALTERNATIVE BACKFILL SCHEMES

5.5.1 Introduction

Backfill schemes proposed by DOE, schemes typically utilized in industry and other concepts being studied under Golder Associates' complementary "Engineered Barriers" NRC contract have been identified (Sections 5.2, 5.3, and 5.4, respectively). This section collectively appraises and presents in summary form a concise set of alternative backfill schemes representative of the wide range of practice reviewed. This set forms the basis for subsequent evaluations in terms of functional and constructional characteristics and their suitability to repository backfill application. The expected in-place properties of each alternative backfill scheme have been investigated and summarized (see Appendix D). However, due to the large number of potential variables, there is significant uncertainty in this assessment. These values are useful as indications of magnitude and also for comparing between alternative schemes, but are not sufficient (nor have they been intended to be) for design. Much work, which is outside the scope of this study, remains to be done in determining in-place backfill properties under repository conditions.

For discussion purposes, the set of schemes have been categorized in terms of location (waste emplacement hole or room) and then primary backfilling objectives (i.e., providing structural support, water flow attenuation or radionuclide attenuation). In this discussion, vertical waste emplacement and generic site conditions have been assumed; variations for horizontal waste emplacement and media/site specific conditions will be discussed later (see Sections 6.5 and 6.3, respectively). Also, while a large number of detailed backfill design objectives have been identified (Section 3), the alternative backfill schemes will be discussed in this section in terms of the three primary objectives. The three types of backfill, with respect to the primary objectives, can be defined as follows:

Table 5.7

"ENGINEERED BARRIERS CONTRACT" BACKFILL MATERIALS/ADDITIVES

BACKFILL CONCEPT NO.	PRIMARY OBJECTIVE(S) FOR BACKFILL CONCEPT*		ALTERNATIVE MATERIALS FOR PRIMARY OBJECTIVES	
	Waste Emplacement Hole Backfill	Room Backfill	Waste Emplacement Hole Backfill Materials	Room Backfill Materials
1	W	W	50% Bentonite/50% Basalt	50% Bentonite/50% Basalt
2	W	RN	Bentonite Bentonite Concrete	Clinoptilolite Illite clay Illite clay
3	W	RN	Bentonite)with concrete Bentonite)floor slab Concrete)	Clinoptilolite Illite clay Illite clay
4	W	No objective as barrier	Bentonite 10% Bentonite/90% Quartz Concrete 50% Bentonite/50% Basalt	Excavated Host Rock (Run of Mine)
5	RN	No objective as barrier	Clinoptilolite Synthetic Zeolite Illite Clay	Excavated Host Rock (Run of Mine)
6	No objective	RN	No Backfill	Clinoptilolite Illite clay

*<u>LEGEND</u>

W = Primary objective is attenuation of water flow

RN = Primary objective is attenuation of radionuclide migration

(From ongoing work being performed by Golder Associates for the U.S. Nuclear Regulatory Commission under Contract No. NRC-02-81-027.)

- Structural backfill limits displacements of the waste emplacement hole or room, or controls failure of the opening, i.e., prevents the development of unstable collapse mechanisms.

- Water flow attenuation backfill retards the seepage of water through the waste emplacement hole or room.

- Radionuclide transport attenuation backfill suppresses the transport of radionuclides wholly or partly by adsorption of radionuclides.

5.5.2 Waste Emplacement Hole Backfill

The materials, procedures and schedules for waste emplacement hole backfills have been summarized (see Table 5.8) and discussed, by primary backfill objective, in the following subsections.

5.5.2.1 No Backfill

The case of no backfill in the annulus between the emplacement hole and waste package may be desirable during the retrievability period when the need for removal of the waste package is regarded as a distinct possibility. No backfill may also be desirable if the engineered barrier and waste package scheme will not require the presence of backfill in terms of structural support, water flow or radionuclide transport attenuation, or other parameters. For example, no backfill after retrievability, allowing the in-place salt to creep towards the waste package, has been proposed for a salt repository (Parsons et al. 1978). Advantages of no backfill placed around the waste package include minimization of both waste package temperature (due to lack of insulation) and stress transferred from the host rock to the waste package.

5.5.2.2 Structural Backfill

Structural backfill in the annulus between the emplacement hole and waste package would serve to limit closure and stabilize the hole walls, and thereby maintain the integrity of the rock with respect to containment/isolation and facilitate subsequent removal of the waste package during retrievability (if required).

Materials with a relatively high modulus deemed suitable for structural backfill include:

- Crushed or excavated rock
- Sand-cement grout or concrete.

Placement procedures for crushed or excavated rock would depend on the size of the annulus and the particle size of the backfill. Crushing may be required if the rock particles are too large to be placed in the annulus. One method of placing the crushed or excavated rock backfill

SUMMARY OF ALTERNATIVE BACKFILL SCHEMES FOR WASTE EMPLACEMENT HOLES

Table 5.8
1 of 2

MATERIAL/ADDITIVE	PROCEDURES	SCHEDULE
1. NO BACKFILL	NA	NA
2. STRUCTURAL BACKFILL		
(a) Crushed or excavated rock	Placement: - poured around waste package after package emplacement - some rock may be required to level bottom of hole. Compaction: - vibration may be necessary.	After waste package emplacement
(b) Sand-cement grout or concrete	Placement: - pumped into annulus surrounding waste package. Compaction: - depending on consistency of grout or concrete, vibration of mixture may be necessary.	After waste package emplacement
3. WATER FLOW ATTENUATION BACKFILL		
(a) Pre-formed bentonite shapes (sand or crushed rock may be used to complete backfill <u>above</u> the waste package and/or to level bottom of waste emplacement hole)	Placement: - crushed rock is poured in hole to level bottom - pre-formed bentonite shapes are lowered into hole. Compaction: - compaction at time of backfill placement in hole is not required.	Prior to waste package emplacement
(b) Bentonite or bentonite/crushed rock mixtures (amount of crushed rock will depend on hydraulic conductivity required) (sand or crushed rock may be used to complete backfill above the waste package and/or to level bottom of waste emplacement hole)	Placement: - crushed rock is poured in hole to level bottom of the hole. - bentonite or mixture is poured around waste package in relatively dry state.	After waste package emplacement

SUMMARY OF ALTERNATIVE BACKFILL SCHEMES FOR WASTE EMPLACEMENT HOLES

Table 5.8
2 of 2

MATERIAL/ADDITIVE	PROCEDURES	SCHEDULE
(b) (cont'd)	Compaction: - mechanical compaction would be difficult - vibrating of the mix would have limited success.	
(c) Sand-cement grout or concrete	See 2 (b) Exception: For water flow attenuation purpose, a second stage of grout may be necessary to fill shrinkage cracks.	After waste package emplacement
4. RADIONUCLIDE TRANSPORT ATTENUATION BACKFILL (a) Illite (b) Clinoptilolite (c) Zeolite (synthetic)	Placement: - material is poured into annulus surrounding waste package - material should be in relatively dry state. Compaction: - mechanical compaction would be difficult - vibration may be able to densify clinoptilolite or zeolite.	After waste package emplacement

would be to pour the crushed rock around the waste package. Adequate compaction may be achieved by vibration. The backfill placement would occur after the waste package has been placed; however, some backfill may be needed prior to package placement to level the bottom of the hole and/or provide the specified depth of emplacement.

Sand-cement grout or concrete would be pumped into place around the waste package and thus must occur after placement of the waste package. Vibration of the grout or concrete may or may not be necessary, depending on its consistency.

5.5.2.3 Water Flow Attenuation Backfill

Water flow attenuation backfill in the annulus between the emplacement hole and waste package would serve to limit water migration in the area of the waste emplacement hole, primarily to reduce transport of released radionuclides, but also to reduce corrosion of the waste package.

Materials with a low value of hydraulic conductivity deemed suitable for water flow attenuation backfill include:

- Pre-formed bentonite shapes
- Bentonite with or without crushed rock
- Sand-cement grout or concrete.

The placement procedure envisaged for the pre-formed bentonite shapes would be as follows. After the waste emplacement hole has been dewatered, a small amount of crushed rock would be placed in the bottom of the hole to provide a level, raised bearing surface. The bentonite shapes would then be placed in the hole to form a base pad and annulus for the placement of the waste package. After placement of the waste package, sand or crushed rock may be poured above and around the outside edges of the bentonite to complete the backfill in the waste emplacement hole.

The placement of bentonite, with or without crushed rock, would take place after the waste package has been positioned. The bentonite in this mixture would be either pellets, powder or a combination of the two. The mixture of bentonite (pellets and/or powder) and crushed rock should be relatively dry so that it could be poured into place around the waste package. The waste emplacement hole should be dewatered prior to backfill placement. A small amount of crushed rock may be necessary to level the bottom of the hole prior to waste package placement. An additional amount of sand or crushed rock may be placed over the bentonite to complete the waste emplacement hole backfill.

Mechanical or vibratory compaction of the bentonite mixture in the hole would be difficult. However, the top of the waste emplacement hole should be completed in such a manner that the bentonite would be constrained when expansion takes place in the presence of water.

The placement of sand-cement grout or concrete would be identical to the procedure outlined for structural backfill in waste emplacement holes, with the exception that a second stage of grout may be necessary to fill temperature-induced shrinkage cracks. Open cracks would be more critical for water flow attenuation backfill than for structural backfill.

5.5.2.4 Radionuclide Transport Attenuation Backfill

Radionuclide transport attenuation backfill in the annulus between the emplacement hole and waste package would serve to retard the transport of radionuclides by adsorption of the radionuclides by the backfill.

Materials with adequate adsorption capability deemed suitable for radionuclide transport attenuation backfill include:

- Illite clay
- Clinoptilolite
- Zeolite (synthetic).

Placement procedures would be essentially identical for each material. The bottom of the waste emplacement hole may be leveled with crushed rock or the backfill itself. The annular backfill would be poured into place after the waste package has been positioned. The backfill should be relatively dry when placed. Mechanical compaction of the backfill would be difficult. Vibratory compaction may work well in clinoptilolite and zeolite, but have only limited success in illite.

5.5.3 Room Backfill

The materials, procedures and schedules for room backfills have been summarized (see Table 5.9) and discussed, by primary backfill objective, in the following subsections.

5.5.3.1 No Backfill

No backfill in the room may be justified if remining for retrievability would be considered to be difficult or expensive and if the structural support provided during excavation would be sufficient to support the room throughout the life of the repository. It would also be necessary that backfill in the room not be needed for water flow attenuation and/or radionuclide transport attenuation.

5.5.3.2 Structural Backfill

Structural backfill in the room would serve to limit deformation and control failure during the retrievability periods and/or during the remaining life of the repository.

Table 5.9
1 of 3

SUMMARY OF ALTERNATIVE BACKFILL SCHEMES FOR ROOMS

MATERIAL/ADDITIVE	PROCEDURES	SCHEDULE
1. NO BACKFILL	NA	NA
2. STRUCTURAL BACKFILL (a) Crushed or excavated rock	Placement: pneumatic - require crushing & grading of material hydraulic - also would require crushing & grading of material mechanical - conventional equipment - trucks, dozers, loaders - low profile equipment - travelling shield - centrifugal thrower - fill pass method - conveyor systems } crushing and grading of material may be required Compaction: (the requirement for compaction depends upon the designed in-place stiffness of the backfill to provide structural support) pneumatic placement: Compaction impractical unless pneumatic placement is in lifts (reduces effectiveness of method) hydraulic placement: Vibrating or electro-osmosis mechanical placement: Mechanical (vibrating or static) compaction in lifts using: - rollers (drum or rubber-tired), - construction traffic - travelling shield.	Options: 1. After retrievability period - currently considered to be 50 years after individual waste emplacement (TUCFR80) 2. After completion of waste placement in a given room or panel. Retrieval would require mining of backfill.

SUMMARY OF ALTERNATIVE BACKFILL SCHEMES FOR ROOMS

Table 5.9
2 of 3

MATERIAL/ADDITIVE	PROCEDURES	SCHEDULE
(b) Concrete	Placement: mechanical - conventional and low profile construction equipment (trucks, loaders, dozers) hydraulic - pumping equipment and pipes Compaction: - vibratory compaction if hydraulically placed - mechanical compaction ("roll-crete") if mechanically placed.	Option 1
(c) Sand-cement grout	Hydraulically pump grout using previously installed grout pipes. This grout is only intended to fill voids in or above backfill.	Option 1
3. WATER FLOW ATTENUATION BACKFILL		
(a) Pre-formed bentonite blocks	Placement: Machine-placement of various-sized pre-formed bentonite blocks, tightly placed in room with only small voids between blocks and room. Structural bulkheads must be placed at room outlets. Room must be dewatered at time of room backfill. Compaction: None required in the room. Bentonite is pre-compacted into required shapes.	Options 1 or 2

SUMMARY OF ALTERNATIVE BACKFILL SCHEMES FOR ROOMS

Table 5.9
3 of 3

MATERIAL/ADDITIVE	PROCEDURES	SCHEDULE
(b) Compacted bentonite soil with percentage of granular soil (0. to 50.)	Placement: mechanical - conventional and low profile equipment (trucks, loaders, dozers) - travelling shield apparatus - conveyor systems Compaction: mechanical - conventional or low profile equipment (sheepsfoot, rubber-tired or drum rollers; power tampers - portable or equipment mounted) - travelling shield apparatus.	Options 1 or 2
(c) Concrete	Identical to 2(b) With exception that secondary grouting may be required.	Option 1
4. RADIONUCLIDE TRANSPORT ATTENUATION BACKFILL (a) Illite (b) Clinoptilolite (c) Zeolite (synthetic)	Placement: mechanical (illite, clinoptilolite or zeolite): - conventional and low profile equipment (trucks, loaders, dozers) - conveyor systems - travelling shield - centrifugal thrower } illite must be relatively dry - fill pass method } illite must be relatively dry pneumatic - illite must be relatively dry hydraulic - clinoptilolite and zeolite only Compaction: Identical to 2(a).	Options 1 or 2

Materials with a relatively high modulus deemed suitable as structural backfill in rooms include:

- Excavated or crushed rock
- Concrete
- Sand-cement grout (only proposed to fill voids in placed rock backfill or between the top surface of backfill and the room ceiling).

Procedures to place and compact (if necessary) the backfill would vary with the material. The procedures would also be affected by the design criteria of the backfill. For example, if little or no roof displacements are desired, the backfill should be relatively stiff and completely fill the room. If higher strains can be tolerated, the backfill may be more deformable, although a placement procedure that completely fills the room would be preferred. These procedures can be summarized as:

- If little or no roof strain is desired:
  - Mechanical placement and compaction, with backfill completely filling room.
- If some roof strain can be tolerated:
  - Mechanical placement; compaction can be performed, if desired.
  - Hydraulic placement; vibratory compaction can be performed, if desired. However, large quantities of water may be introduced into the repository, which could be detrimental to repository operations.
  - Pneumatic placement. Operations of placement would no longer be continuous if compaction is performed. Only relatively dry backfills should be used with this procedure.

The backfill placement schedule would be partly influenced by the difficulty of remining for retrieval. That is, backfill may have to be removed for retrieval of waste packages if the backfill has already been placed. If it is especially difficult to remove or remine, the backfill should not be placed until after the retrievability period unless the openings will not stay open without it during the entire period.

Hence, crushed or excavated rock (without grout) may be placed prior to or after the retrievability period, depending on the difficulty of remining. Grout should only be injected or concrete backfill be placed after the retrievability period.

5.5.3.3 Water Flow Attenuation Backfill

Materials with a low value of hydraulic conductivity deemed suitable for water flow attenuation backfill in rooms include:

- Pre-formed bentonite blocks
- Compacted (in-place) bentonite, with or without crushed rock
- Concrete.

Placement procedures for the pre-formed bentonite blocks have only been considered subsequent to the manufacture and storage of the blocks. The criteria governing the use of preformed bentonite blocks would be that water entering the room not flow freely through the voids in the blocks and that such water be initially imbibed by the bentonite until all placement voids have been filled by the expanding clay. Thus, the blocks should be of various sizes such that, when placed, the room would be nearly filled. Structural bulkheads at openings breaching the room would be required, as the bentonite would be expected to expand considerably in the presence of water.

Procedures for placement and compaction of the bentonite, with or without crushed rock, should also intend to completely fill the room. Acceptable placement systems would include conventional and low-profile mining and construction equipment, conveyor belt systems and the traveling shield apparatus. In each case, the material would be placed and compacted in layers (either horizontal or inclined). The compaction procedures should consider the optimum moisture content of the backfill. Conventional compaction equipment would include sheepsfoot, rubber-tired or drum rollers, as well as power tampers (portable or equipment mounted).

Crushed rock could be added to the bentonite, as desired. However, crushed rock would change the backfill compaction and behavioral properties. Of most importance, the hydraulic conductivity of the backfill would usually increase with major additions of crushed rock.

Procedures for placement and compaction of concrete would include mechanical placement or pumping techniques, with mechanical or vibratory compaction techniques. Concrete could be compacted using rollers, which is then often referred to as "roll-crete". The concrete must completely fill the room to act as a water barrier. It may be necessary to grout shrinkage cracks that may occur in the concrete due to the increased temperatures in the room. The use of expansion grouts or low-heat concretes may significantly reduce the post-construction development of potential leakage paths.

5.5.3.4 Radionuclide Transport Attenuation Backfill

Materials with adequate adsorptive capability deemed suitable for radionuclide transport attenuation backfill in the room include:

- Illite clay
- Clinoptilolite
- Zeolite (synthetic).

The final selection of materials would depend on the radionuclides to be attenuated and whether or not the relative hydraulic conductivity of the room backfill significantly affects engineered barrier performance, since illite would probably be less permeable than clinoptilolite or zeolite.

Placement procedures would vary for the materials chosen, but mechanical, pneumatic and hydraulic placement procedures may be used for all three materials with the exclusion of hydraulic placement of the illite clay. Since the radionuclides would be expected to be transported by water flowing in voids, placement procedures should enable the room to be filled completely.

The use of hydraulic placement for clinoptilolite and zeolite may introduce unacceptably large quantities of water into the repository. Pneumatic placement procedures may be used on all three materials, but the illite must be relatively dry to be placed by this procedure. Possible mechanical placement procedures would include conventional and low profile equipment, conveyor systems, the travelling shield apparatus, centrifugal thrower and the fill pass method. However, the illite clay must be relatively dry in order to use the centrifugal thrower or the fill pass methods.

Compaction procedures would vary with the placement technique. Compaction would not likely be performed in conjunction with the centrifugal thrower, fill pass, pneumatic or hydraulic placement methods. If compaction is desired, the placement would most likely occur in lifts requiring interruptions to the above placement methods. The centrifugal thrower, fill pass, and pneumatic placement methods would then most likely utilize mechanical compaction procedures, whereas hydraulic placement would utilize vibratory compaction. Compaction of material placed by dozers or loaders would utilize mechanical compaction equipment (rollers or tampers).

Schedule of placement for all three of these materials may be prior to or after the retrievability period.

6. EVALUATION OF ALTERNATIVE BACKFILL SCHEMES

6.1 INTRODUCTION

Alternative backfill schemes, consisting of materials and additives (if any) and associated construction procedures, have been identified (Section 5), based on DOE-proposed backfill designs, industry (both mining and civil engineering) typical backfill schemes, and backfill concepts identified under Golder Associates' complementary "Engineered Barriers" NRC contract. In the following sections, these alternative backfill schemes will be summarized and subjectively evaluated in order to select several of the best backfill material/additive combinations, for which appropriate construction and testing procedures will then be identified and summarized. This will be accomplished by:

- Summarizing and then subjectively evaluating (in Section 6.2 and Appendix E), in a preliminary fashion, each of the alternative backfill schemes with respect to their perceived effectiveness in achieving the generic backfill design basis (Section 3) using a specific subjective evaluation methodology (Section 4).
- Identifying (in Section 6.3) the appropriate construction procedures for those combinations of waste emplacement hole and room backfill materials/additives which apparently are most effective in achieving the generic design basis, based on the preliminary evaluation.
- Identifying (in Section 6.4) the test procedures which are appropriate for assessing backfill, as constructed, and verifying that the design has been adequately implemented.
- Identifying (in Section 6.5) additional design and construction considerations for horizontal waste emplacement.

6.2 PRELIMINARY EVALUATION OF ALTERNATIVE BACKFILL SCHEMES

6.2.1 Alternative Backfill Schemes

A list of viable backfill materials includes none, concrete, muck, sand, bentonite, illite, and clinoptilolite/zeolite (synthetic). A list of potential backfill additives includes none, sand-cement grout, bentonite, illite, and clinoptilolite/zeolite (synthetic). The general viability of each potential combination of backfill material and additive, with respect to backfilling the waste emplacement hole or the room, has been assessed (see Table 6.1), based on previous discussions (Section 5) and judgement. The 12 most viable combinations have been identified and summarized with respect to their primary objectives (see Table 6.2); this study will subsequently be limited to consideration of these backfill materials/additives, which are perceived to be most viable. The general viability of each potential combination of the 12 selected backfill materials/additives in the waste emplacement hole and

VIABILITY OF POSSIBLE COMBINATIONS OF BACKFILL MATERIALS AND ADDITIVES

Table 6.1

MATERIAL	POTENTIAL ADDITIVE * (If any)			
	A. Sand-Cement Grout	B. Bentonite	C. Illite	D. Clinoptilolite/Zeolite (synthetic)
1. None				
2. Concrete	●			
3. Muck	●	●	○	○
4. Sand	●	●	○	○
5. Bentonite	○	—		
6. Illite	○		—	○
7. Clinoptilolite/Zeolite (synthetic)	○		○	—

(Room Scale or Waste Package Scale)

*Other secondary additives could be considered, e.g.:
fly ash
chemical mixtures
chemical grout
different concrete types

KEY:
● More viable combination
○ Less viable combination
— **Material and potential additive are identical**

SUMMARY OF ALTERNATIVE BACKFILL MATERIALS AND ADDITIVES

Table 6.2

Code		Primary Objectives		
Material Additive	Material/Additive (see Table 6.1)	Structural Support	Water Flow Attenuation	Radionuclide Transport Attenuation
1	None			
2	Concrete	x	o	
2A	Concrete with sand-cement grout	x	x	
3	Muck	x		
3A	Muck with sand-cement grout	x	x	
3B	Muck mixed with bentonite	x	x	
4	Sand	x		
4A	Sand with sand-cement grout	x	x	
4B	Sand mixed with bentonite	x	x	
5	Bentonite		x	
6	Illite		o	x
7	Clinoptilolite/Zeolite (synthetic)			x

(Room Scale or Waste Package Scale)
x = Principal objective of backfill material/additive
o = Secondary objective of backfill material/additive

the room (a total of 144 combinations) has been assessed (see Table 6.3), again based on previous discussions (Section 5) and judgement. The 60 most viable combinations have been identified and summarized (see Table 6.4); this study will subsequently be limited to consideration of these combinations of waste emplacement hole and room backfill materials/additives, which are perceived to be most viable. It is felt that these combinations offer a sufficiently large number and wide range of viable alternatives for further study.

6.2.2 Results of the Preliminary Evaluation

The 60 most viable combinations of waste emplacement hole and room backfill materials/additives (Table 6.4) have been subjectively evaluated, in a preliminary fashion, with respect to each one's perceived effectiveness in achieving the generic backfill design basis developed and used in this study (Section 3) (see Appendix E). This preliminary evaluation of apparent effectiveness has utilized a subjective but explicit evaluation methodology (Section 4), which essentially consists of:

- Subjectively assessing the contribution each alternative backfill scheme is perceived to have (relative to the other alternatives) through its expected performance in achieving each weighted backfill design objective, ranging from 0 (no contribution) to 1 (complete achievement).
- Multiplying the backfill scheme's perceived contribution towards achieving each backfill design objective by that objective's relative weight, and then summing the products for all objectives to determine the relative contribution of each backfill scheme towards achieving the backfill design basis and thereby the repository system performance objectives.

The results of this preliminary evaluation of the 60 most viable combinations of waste emplacement hole and room backfill materials/additives (Appendix E) have been summarized (see Table 6.5) in terms of the apparent effectiveness of each alternative.

As previously noted, there is significant uncertainty in these results due to the subjectivity in the assessments of both the relative weight of each backfill design objective (Section 3 and Appendix B) and the perceived relative contribution to achieving each objective by any backfill scheme (Appendix E). In addition to being subjective, both assessments have been made based on preconceived repository design concepts (specifically vertical waste emplacement), performance assessment methodology, and generic site conditions; should these premises change, the assessments may change. For example, the assessments may change slightly for horizontal waste emplacement (see Section 6.5) or for different specific site conditions. However, for the purpose of this study (i.e., a preliminary evaluation of alternatives for comparison and subsequent selection of several top ranking ones for

VIABILITY OF POSSIBLE COMBINATIONS OF WASTE EMPLACEMENT HOLE AND ROOM BACKFILL MATERIALS/ADDITIVES

Table 6.3

ROOM BACKFILL MATERIAL/ADDITIVE (See Table 6.2)

WASTE EMPLACEMENT HOLE BACKFILL MATERIAL/ADDITIVE (See Table 6.2)

	1	2	2A	3	3A	3B	4	4A	4B	5	6	7
1	●	○	○	●	○	○	○	○	○	○	○	○
2	●	●	●	●	●	●	○	○	○	○	○	○
2A	○	●	●	●	●	●	○	○	○	●	○	○
3	●	○	○	●	○	○	○	○	○	○	○	○
3A	●	○	○	●	●	○	○	○	○	○	○	○
3B	●	○	○	●	●	●	○	○	○	○	○	○
4	●	○	○	●	○	○	●	○	○	○	○	○
4A	●	○	○	●	●	○	○	●	○	○	○	○
4B	●	○	○	●	●	●	○	○	●	○	○	○
5	●	●	●	●	●	●	○	○	○	●	●	○
6	●	●	●	●	●	●	○	○	○	●	●	○
7	●	●	●	●	●	●	○	○	○	●	●	●

Key: ● More viable combination

○ Less viable combination

SUMMARY OF ALTERNATIVE BACKFILL SCHEMES

Table 6.4
1 of 3

CODE Waste Emplacement Hole Material/Additive Room Material/Additive	COMBINATION (see Table 6.3)	
1:1	no backfill around waste package	: no room backfill
1:3	no backfill around waste package	: room backfilled with muck
2:1	concrete around waste package	: no room backfill
2:2	concrete around waste package	: room backfilled with concrete
2:2A	concrete around waste package	: room backfilled with concrete & grouted
2:3	concrete around waste package	: room backfilled with muck
2:3A	concrete around waste package	: room backfilled with muck & grouted
2:3B	concrete around waste package	: room backfilled with muck mixed w/bentonite
2A:2	concrete around waste package & grouted	: room backfilled with concrete
2A:2A	concrete around waste package & grouted	: room backfilled with concrete & grouted
2A:3	concrete around waste package & grouted	: room backfilled with muck
2A:3A	concrete around waste package & grouted	: room backfilled with muck & grouted
2A:3B	concrete around waste package & grouted	: room backfilled with muck mixed w/bentonite
2A:5	concrete around waste package & grouted	: room backfilled with bentonite
3:1	muck around waste package	: no room backfill
3:3	muck around waste package	: room backfilled with muck
3A:1	muck around waste package & grouted	: no room backfill
3A:3	muck around waste package & grouted	: room backfilled with muck
3A:3A	muck around waste package & grouted	: room backfilled with muck & grouted

SUMMARY OF ALTERNATIVE BACKFILL SCHEMES

Table 6.4
2 of 3

CODE	
Waste Emplacement Hole Material/Additive Room Material/Additive	COMBINATION (see Table 6.3)
3B:1	muck mixed w/bentonite around waste package : no room backfill
3B:3	muck mixed w/bentonite around waste package : room backfilled with muck
3B:3A	muck mixed w/bentonite around waste package : room backfilled with muck & grouted
3B:3B	muck mixed w/bentonite around waste package : room backfilled with muck mixed w/bentonite
4:1	sand around waste package : no room backfill
4:3	sand around waste package : room backfilled with muck
4:4	sand around waste package : room backfilled with sand
4A:1	sand around waste package & grouted : no room backfill
4A:3	sand around waste package & grouted : room backfilled with muck
4A:3A	sand around waste package & grouted : room backfilled with muck & grouted
4A:4A	sand around waste package & grouted : room backfilled with sand & grouted
4B:1	sand mixed w/bentonite around waste package : no room backfill
4B:3	sand mixed w/bentonite around waste package : room backfilled with muck
4B:3A	sand mixed w/bentonite around waste package : room backfilled with muck & grouted
4B:3B	sand mixed w/bentonite around waste package : room backfilled with muck mixed w/bentonite
4B:4B	sand mixed w/bentonite around waste pacakge : room backfilled with sand mixed w/bentonite
5:1	bentonite around waste package : no room backfill
5:2	bentonite around waste package : room backfilled with concrete
5:2A	bentonite around waste package : room backfilled with concrete & grouted
5:3	bentonite around waste package : room backfilled with muck
5:3A	bentonite around waste package : room backfilled with muck & grouted

SUMMARY OF ALTERNATIVE BACKFILL SCHEMES

Table 6.4
3 of 3

CODE Waste Emplacement Hole Material/Additive Room Material/Additive	COMBINATION (see Table 6.3)
5:3B	bentonite around waste package : room backfilled with muck mixed w/bentonite
5:5	bentonite around waste package : room backfilled with bentonite
5:6	bentonite around waste package : room backfilled with illite
6:1	illite around waste package : no room backfill
6:2	illite around waste package : room backfilled with concrete
6:2A	illite around waste package : room backfilled with concrete & grouted
6:3	illite around waste package : room backfilled with muck
6:3A	illite around waste package : room backfilled with muck & grouted
6:3B	illite around waste package : room backfilled with muck mixed w/bentonite
6:5	illite around waste package : room backfilled with bentonite
6:6	illite around waste package : room backfilled with illite
7:1	clinoptilolite/zeolite around waste package : no room backfill
7:2	clinoptilolite/zeolite around waste package : room backfilled with concrete
7:2A	clinoptilolite/zeolite around waste package : room backfilled with concrete & grouted
7:3	clinoptilolite/zeolite around waste package : room backfilled with muck
7:3A	clinoptilolite/zeolite around waste package : room backfilled with muck & grouted
7:3B	clinoptilolite/zeolite around waste package : room backfilled with muck mixed w/ bentonite
7:5	clinoptilolite/zeolite around waste package : room backfilled with bentonite
7:6	clinoptilolite/zeolite around waste package : room backfilled with illite
7:7	clinoptilolite/zeolite around waste package : room backfilled with clinoptilolite/zeolite

APPARENT EFFECTIVENESS OF ALTERNATIVE BACKFILL SCHEMES

Table 6.5

ROOM BACKFILL MATERIAL/ADDITIVE (See Table 6.2)

WASTE EMPLACEMENT HOLE BACKFILL MATERIAL/ADDITIVE (See Table 6.2)

	1	2	2A	3	3A	3B	4	4A	4B	5	6	7
1	e			d								
2	d	d	c	d	c	c						
2A		d	c	d	c	c				c		
3	d			d								
3A	d			d	c							
3B	d			d	c	c						
4	d			d			d					
4A	d			d	c			c				
4B	d			d	c	c			c			
5	d	d	c	d	c	c				c	b	
6	d	c	b	c	c	b				b	b	
7	c	c	b	c	b	b				b	a	a

NOTE: The apparent effectiveness of each combination of waste emplacement hole and room backfill materials/additives is based on a preliminary evaluation (see Appendix E) using the subjective evaluation methodology developed in this study (Section 4), and should be considered only as an approximate indicator of the extent to which the generic backfill design basis used in this study (Section 3) might be achieved by that combination. The apparent effectiveness can range from 0. (no effectiveness at all) to 1. (total effectiveness or complete achievement of the backfill design basis). The key used to denote the apparent effectiveness is:

a	.6 ≤	Apparent	Effectiveness	
b	.5 ≤	"	"	<.6
c	.4 ≤	"	"	<.5
d	.3 ≤	"	"	<.4
e	.2 ≤	"	"	<.3

further study), it is felt that this approach is sufficient. In addition, due to the large number of detailed objectives used in the design basis, the results of the evaluation may be relatively insensitive to uncertainties (or even errors) in the assessment of specific objectives. Also, the approach has the distinct advantage of being explicit and exposed, so that areas of disagreement can be identified and hopefully resolved.

It is evident from the results of this preliminary evaluation (Table 6.5) that the radionuclide transport attenuation type backfills (i.e., illite, clinoptilolite or zeolite) might be most effective in achieving the generic backfill design basis used in this study, while no backfill might be least effective. Indeed, it is evident that for any type of room backfill, the radionuclide transport attenuation type backfills might be most effective around the waste package, with the water flow attenuation type backfills (i.e., bentonite, muck/sand mixed with bentonite, or concrete/muck/sand with sand-cement grout) being next most effective. Similarly, it is apparent that, for any type of backfill around the waste package, the radionuclide transport attenuation type backfills might also be most effective as room backfill, with the water flow attenuation type backfills again being next most effective. These evaluations, however, have been subjective and in any case relate to a generic design basis; both the design basis and the subsequent evaluations have been based on defined premises and perceptions, and not on quantitative performance modeling. Also, this is a comparative evaluation only, which can be used to suggest the best material/additive combination for the given generic design basis, but it does not address the acceptability of any (even the best) combination. Site-specific quantitative performance assessment, which is outside the scope of this study, would be necessary to address the acceptability of any scheme and, in addition, the results of such assessments might change the design basis and comparative evaluations.

Based on the results of the preliminary evaluation of alternative backfill schemes, the backfill materials/additives with the highest apparent effectiveness (i.e., zeolite/clinoptilolite, bentonite, and muck mixed with bentonite) have been selected for further study; muck with no additives has also been included for further study even though its apparent effectiveness with respect to achieving the generic design basis is not very high, because it has often been proposed by DOE especially in salt. These selected material/additives (see Table 6.6) are similar to some of the other backfill materials/additives not selected. For example, illite would be expected to utilize placement procedures similar to bentonite, sand would be expected to utilize placement procedures and exhibit performance similar to muck, and sand mixed with bentonite would be expected to utilize placement procedures and exhibit performance similar to muck mixed with bentonite. The alternative of no backfill has undertandably not been further considered in this study of appropriate construction procedures and testing methods.

APPARENT EFFECTIVENESS OF SELECTED ALTERNATIVE BACKFILL SCHEMES

Table 6.6

ROOM BACKFILL MATERIAL/ADDITIVE (See Table 6.2)

WASTE EMPLACEMENT HOLE BACKFILL MATERIAL/ADDITIVE (See Table 6.2)

	3. Muck	3B. Muck Mixed with Bentonite	5. Bentonite	7. Clinoptilolite/ Zeolite (synthetic)
3. Muck	d			
3B. Muck Mixed with Bentonite	d	c		
5. Bentonite	d	c	c	
7. Clinoptilolite/ Zeolite (synthetic)	c	b	b	a

NOTE: This summary of the apparent effectiveness of selected backfill schemes is based on a preliminary objective evaluation of how well the generic backfill design basis might be achieved by each (see Table 6.5). The apparent effectiveness, which is very approximate, can range from 0. (no effectiveness at all) to 1. (total effectiveness or complete achievement of the backfill design basis). The key used to denote the apparent effectiveness is:

a	.6	≤ Apparent Effectiveness	
b	.5	≤ " "	< .6
c	.4	≤ " "	< .5
d	.3	≤ " "	< .4

6.3 SUMMARY OF ALTERNATIVE CONSTRUCTION PROCEDURES FOR SELECTED BACKFILL MATERIALS/ADDITIVES

6.3.1 Introduction

Backfilling construction procedures associated with the various DOE-proposed or industry typical backfill schemes have been previously identified (Sections 5.2 and 5.3, respectively), and then summarized (Section 5.5). In this section, alternative procedures are identified and discussed for four selected backfill materials/additives, i.e., clinoptilolite/zeolite, bentonite, bentonite mixed with muck (excavated host rock) and muck with no additives. These procedures, chosen from those previously discussed (Section 5.5, Tables 5.8 and 5.9), include backfill placement and compaction, as well as preparation.

In this discussion of alternative procedures for selected backfill materials/additives, the following activities have been undertaken and are discussed in the following subsections:

- Identifying (in Section 6.3.2) a list of procedures (i.e., for placement and compaction) appropriate for waste emplacement hole and room backfill, from among all those procedures previously identified.
- Identifying (in Section 6.3.3) schemes (i.e., materials/additives and procedures) appropriate for waste emplacement hole and room backfill in various geologic media.
- Discussing (in Section 6.3.4) details (including possible equipment) of appropriate alternative backfill schemes, including preparation of selected backfill materials/additives (in Sections 6.3.4.2), placement/ compaction of selected types of room backfill (in Section 6.3.4.3), and placement/compaction of selected types of waste emplacement hole backfill (in Section 6.3.4.4).

6.3.2 Appropriate Alternative Procedures

The identification of appropriate alternative procedures for backfilling, from among those procedures previously identified (Section 5), has taken into consideration the following assumptions:

- It will be required to completely fill the room with backfill for structural, radionuclide transport attenuation, or water flow attenuation objectives (unless the swelling potential of the dry backfill upon wetting will cause filling of gaps).
- Expected environmental conditions (e.g., elevated temperatures, radiation) will be allowed for in equipment design and will not affect procedures or scheduling. Dewatering and ventilation activities will continue during backfilling operations.

- The emplacement holes will be backfilled prior to, during, or shortly after waste package placement and the rooms will be backfilled during or at the end of the retrievability period. Therefore, schedule of backfilling is not a consideration.

From among the previously identified available procedures, the following have been identified as being appropriate (taking into account the above assumptions):

- Waste Emplacement Hole Backfill Procedures
  - Mechanical placement (lowering into storage hole) of preformed backfill shapes with compaction performed only during manufacturing; placement equipment would include hoists, loaders, lifts, etc.
  - Mechanical placement (pouring) of dry/moist backfill below, around and on top of waste package with no compaction; placement equipment are unspecified.
  - Pneumatic placement of dry/moist backfill below, around, and on top of waste package with no compaction; placement equipment would include specialized pneumatic backfill systems.
- Room Backfill Procedures
  - Mechanical placement of loose, dry/moist backfill with no compaction; placement equipment would include some combination of trucks, dozers, loaders, and conveyor systems.
  - Mechanical placement of loose, dry/moist backfill with compaction in lifts (horizontal or inclined); placement/compaction equipment would include some combination of trucks, dozers, loaders, conveyor systems, traveling shield, rollers, special tamping and pressing equipment.
  - Mechanical placement of pre-formed backfill shapes with compaction performed only during manufacturing of shapes; placement equipment would include lifts and loaders.
  - Pneumatic placement of dry/moist backfill with no compaction; placement equipment would include specialized pneumatic backfill systems.

The other previously identified available procedures have not been considered to be appropriate for the following reasons:

- Waste Emplacement Hole Backfill Procedural Considerations
  - Compaction (tamping, pressing, or vibratory) would probably be of limited effectiveness and has been disregarded. Unless it is deduced from laboratory testing that the density of the backfill

  is critical to desired performance, it is perceived that compaction would be time-consuming and difficult. Special compaction equipment would need to be designed to fit around the waste package (e.g., annular tamping weights or vibrators). Also, compaction activities could be detrimental to package integrity.

  - The option of no backfill has been disregarded.

- Room Backfill Procedural Considerations

  - Hydraulic placement has been disregarded due to the undesirability of introducing large quantities of water into the repository.

  - The "Fill Pass" method has been disregarded due to the undesirability of creating additional openings within the repository that would eventually require sealing.

  - Compaction cannot be efficiently utilized with a centrifugal thrower or pneumatic placement.

  - Special tamping and pressing equipment would be necessary to compact backfill placed near and at the room ceiling, unless pneumatic backfilling can be effectively utilized (at the ceiling).

  - The centrifugal thrower has been disregarded, as it appears that it would be difficult to completely fill the room with backfill using this method.

  - The option of no backfill has been disregarded.

6.3.3 Appropriate Media Specific Alternative Backfill Schemes

Those backfill procedures which have been considered to be generally appropriate (Section 6.3.2) have been considered for construction of each selected combination of backfill materials/additives around the waste package and in the room in various geologic media. For this purpose, it has been perceived that basalt, tuff, and granite will be sufficiently similar with respect to backfilling objectives and conditions that they can be considered together as simply "hard rock." Appropriate backfill schemes (i.e., backfill materials/additives in the waste emplacement hole and in the room, and associated procedures) for hard rock and for salt have thus been identified, and summarized (see Tables 6.7 and 6.8). Other combinations of backfill materials/additives around the waste package or in the room and other procedures have not been considered to be appropriate for the following reasons:

- Water flow attenuation type backfills (i.e., bentonite or muck mixed with bentonite) will generally be inappropriate for backfilling of repositories in salt.

APPROPRIATE BACKFILL SCHEMES- HARD ROCK

Table 6.7

Waste Emplacement Hole Backfill Material/ Additive	Room Backfill Material/Additive			
	3. Muck	3B. Muck mixed with bentonite	5. Bentonite	7. Clinoptilolite/ Zeolite
3. Muck	●			
3B. Muck mixed with bentonite	●	●		
5. Bentonite	●	●	●	
7. Clinoptilolite/Zeolite	●	●	●	●

Combination of Backfill Materials/ Additives	Waste Emplacement Hole Backfill Material/Additive	3	3	3	3	3B	3B	3B	3B	5	5	5	5	7	7	7	7
	Room Backfill Material/Additive	3	3B	5	7	3	3B	5	7	3	3B	5	7	3	3B	5	7
Waste Emplacement Hole Backfill Procedures	Preformed Backfill Shapes					●	●			●	●	●					
	Mechanical Placement of Dry Backfill	●				●	●			●	●	●		●	●	●	●
	Pneumatic Placement of Dry Backfill	●												●	●	●	●
Room Backfill Procedures	Mechanical Placement of Loose Dry or Moist Backfill/No Compaction	●				●	●			●	●	●		●	●	●	●
	Mechanical Placement of Loose, Dry or Moist Backfill/Compaction in Lifts	●				●	●			●	●	●		●	●	●	●
	Mechanical Placement of Preformed Backfill Shapes/ No Compaction						●				●	●			●	●	
	Pneumatic Placement of Loose, Dry or Moist Backfill/No Compaction	●				●				●				●			●

● viable alternative combination of materials/additives and procedures for waste emplacement hole and room backfill

APPROPRIATE BACKFILL SCHEMES- SALT

Table 6.8

Waste Emplacement Hole Backfill Material/ Additive	Room Backfill Material/Additive			
	3. Muck	3B. Muck mixed with bentonite	5. Bentonite	7. Clinoptilolite/ Zeolite
3. Muck	●			
3B. Muck mixed with bentonite				
5. Bentonite				
7. Clinoptilolite/Zeolite	●			●

Combination of Backfill Materials/ Additives	Waste Emplacement Hole Backfill Material/Additive	3	3	3	3	3B	3B	3B	3B	5	5	5	5	7	7	7	7
	Room Backfill Material/Additive	3	3B	5	7	3	3B	5	7	3	3B	5	7	3	3B	5	7
Waste Emplacement Hole Backfill Procedures	Preformed Backfill Shapes																
	Mechanical Placement of Dry Backfill	●												●			●
	Pneumatic Placement of Dry Backfill	●												●			●
Room Backfill Procedures	Mechanical Placement of Loose Dry or Moist Backfill/No Compaction	●												●			●
	Mechanical Placement of Loose, Dry or Moist Backfill/Compaction in Lifts	●												●			●
	Mechanical Placement of Preformed Backfill Shapes/ No Compaction																
	Pneumatic Placement of Loose, Dry or Moist Backfill/No Compaction	●												●			●

- ● viable alternative combinations of materials/additives and procedures for waste emplacement hole and room backfill

- Pneumatic placement of bentonite or muck mixed with bentonite has been considered to be inappropriate due to potential dust creation and/or low backfill densities. Water added to circumvent the dust problem might make the material too cohesive to transport by pneumatic procedures. It would be difficult to monitor pneumatic placement sufficiently to ensure that the design has been achieved.

- Clinoptilolite/zeolite and muck would not be manufactured into pre-formed shapes.

The resulting matrices (Tables 6.7 and 6.8) contain ten appropriate combinations of waste emplacement hole and room backfill materials/additives in hard rock and three in salt. Six generally appropriate combinations of placement/compaction procedures for backfilling waste emplacement holes and rooms have been identified for each appropriate backfill material/additive combination. Thus, a total of 60 alternative backfill schemes, which have been considered as generally appropriate for backfilling repositories in hard rock, and a total of 18 in salt have been identified.

This identification of appropriate alternative backfill schemes has been based on the pre-selection of certain backfill materials/additives and certain procedures, as well as on additional considerations which have precluded some combinations of these for certain media. Backfill design, i.e., selection of materials/additives and appropriate procedures, will require further definition of design objectives and, hence, desired in-place backfill characteristics (under repository conditions), as well as further evaluation of materials/additives and procedures with respect to achieving these objectives.

6.3.4 Details of Appropriate Construction Procedures and Equipment

6.3.4.1 Introduction

Representative preparation procedures, selected placement/compaction procedures and related equipment for the construction of room and waste emplacement hole backfill have been identified and summarized with respect to each material/additive. It should be recognized that the final selection of backfilling procedures, comprised of preparation, placement and compaction activities, should optimize each activity with respect to providing a system that is compatible in time, common equipment use and capacity, as well as performance.

6.3.4.2 Preparation of Backfill

Preparation of backfill will be comprised of the following sequential activities:

- Receipt at the surface of the repository site (including excavation and transportation of muck to the surface, if necessary)

- Initial sizing and mixing

- Transportation from the surface to the repository level

- Underground preparation, including mixing and addition of water and/or components (if necessary)

- Loading and transportation to area to be backfilled.

The type of backfill will determine to some degree what steps will be required and where the preparation will be performed. In terms of preparation, the four selected backfill materials/additives have been categorized into three groups:

(1) Loose muck (with or without bentonite) or zeolite/clinoptilolite
(2) Loose bentonite (pellets and/or powder)
(3) Pre-formed backfill shapes of bentonite (with or without muck).

Preparation of each of the above three groups of backfill materials/additives will be different, as discussed separately for each below. In general, the procedures for each type of backfill material/additive will be relatively unaffected by whether the backfill is for the waste emplacement hole or the room.

Preparation procedures for (1) <u>loose muck (with or without bentonite) or zeolite/clinoptilolite</u> will be <u>the most flexible</u>:

- <u>Receipt at the surface of the repository site (including excavation and transportation of muck to the surface)</u>-
  After underground excavation, muck to be used for backfill can either be stored underground or transported to the surface, depending on schedule, the next preparation step, and additives, if any. If there will be no immediate need for the muck, it would be stored at the surface; muck should only be retained underground if underground preparation of the backfill is possible and/or imminent after excavation. Receipt of materials such as zeolite obviously occurs at the surface facilities.

- <u>Initial sizing and mixing</u>-
  This step will include crushing and grading of muck to the specified size or the grading of zeolite/clinoptilolite. Various feeder/breakers and/or mills might be used for crushing. Mixing of muck and bentonite could be accomplished on the surface, provided the material is transported carefully to the repository horizon using hoists and skips or remixed at the repository level. The mixing may be performed using belt mixers prior to transport to the repository.

- <u>Storage</u>-
  If storage at the surface will be necessary, it will be desirable for storage to precede mixing and sizing, and that the backfill be protected from excessive moisture. Underground storage may be

useful for operations and may complement or replace surface storage depending upon the relative timing of surface preparation to backfill placement, and the availability of underground space.

- Transportation from the surface to the repository level-
  The transport of mixed backfill should be carefully performed using hoists and skips. The friction hoist system, using two skips on one hoist, can often be automated and might be particularly useful. However, the hoist and skip system in general would be more expensive than the alternative means of dumping backfill down pipes, boreholes or chutes in or around the shaft, a component referred to as a "slick" pipe. Transportation by a "slick" pipe will probably lead to segregation of materials, particularly if a wide range of particle sizes will be utilized, and thus remixing would be necessary.

- Underground preparation, including mixing and addition of water and/or other backfill components-
  Underground mixing (often remixing) of backfill would be desirable from the standpoint that the backfill gradation can be better controlled just prior to placement. Resizing (i.e., grading/no crushing) of a singular component of the backfill might be required if significant segregation has occurred during transport, so that the proper gradation can be achieved. Given the partial duplication of mixing, it may be desirable for some backfills to be mixed together underground solely. Mixing equipment may be of the belt type, particularly if components are fed onto the belt. Drum-type mixers may also be utilized. It will be desirable to add water to the backfill underground in order to facilitate transport and maintain the water content during placement. High water contents are not envisioned with these materials, but given the quantities of material to be placed, a significant amount of water may be required.

- Loading and transportation to area to be backfilled-
  Loading into haul/dump vehicles may be accomplished in a number of ways, but will be somewhat dependent on the vehicle. In the case of belly/side/end-dump trucks or rail cars, a system of surge/storage bins can be used to load the backfill. Some systems of transport, such as conveyors, could load directly after the mixing belt. A system of low-profile articulated front-end loaders appears to be highly practical for mechanical placement. These loaders could be loaded from a bin, but could also load themselves from a drawpoint, which is an opening excavated above the room in which the vehicles will be loaded. The backfill material would be stored in the above opening and would fall to the room below via the drawpoint as material is self-loaded into the front-end loaders from a small storage pile of backfill.

  More realistically, the entire load-haul-dump scheme may be a combination of the above, e.g., utilizing conveyors to a surge bin (or draw point), trucks or rail cars to the room being backfilled, and front-end loaders to the working face of backfill.

Preparation of (2) bentonite (pellets and/or powder) will have relatively few options:

- Receipt at the surface of the repository site-
  The bentonite may be received raw (i.e., requiring further refining) or directly in the form of pellets or powder. Pressing of pellets at the site may be a viable option, given the large amounts of backfill necessary.

- Initial sizing and mixing-
  It is not anticipated that crushing or sizing will be necessary, except that related to refining. Mixing will be necessary if both pellets and powder are used. Mixing of powder will create significant dust.

- Storage-
  Storage of backfill at the surface should be carefully controlled to minimize adsorption of moisture from humid air or surface water..

- Transportation from the surface to the repository level-
  Transport of the bentonite to the repository will most likely be via skips and hoists in view of the dust which would be created by free-falling backfill.

- Underground preparation, including mixing and addition of water-
  Some remixing of the backfill may be required if both pellets and powder are used. Water may be added to the backfill to help control dust and/or facilitate compaction. It should be noted that bentonite (particularly powder) is very sensitive to moisture and often becomes difficult to handle or compact with the addition of excessive moisture. Handling and compaction of material should be dependent on exact moisture content and may require prototype test methods.

- Loading and transportation to area to be backfilled-
  Loading will most likely be from storage/surge bins or conveyors, as the storage of bentonite backfill needs to be more controlled than would be possible from draw-point sources. Transport could be by any combination of conveyors, rail cars, trucks or front-end loaders.

Preparation of (3) pre-formed backfill shapes of bentonite (with or without muck) would be relatively inflexible:

- Receipt at the surface of the repository site-
  Bentonite, raw or refined, will be received/refined (as for pellets and/or powder); muck (if used) will be excavated, transported to the surface, and processed (as for loose muck mixed with bentonite).

- Initial sizing and mixing-
  The bentonite and muck (if used) will be sized, mixed and then pressed into appropriate shapes. These activities will utilize techniques similar to those for the pressing of pellets and would

require a manufacturing plant. Development of special pressing procedures may be required for large shapes or due to the possible addition of muck.

- Storage-
  Storage of pressed blocks at the surface should be controlled to prevent degradation of the backfill shapes from excess moisture, handling, etc.

- Transportation from the surface to the repository level-
  Transport of pressed blocks should be via hoist and skip systems.

- Underground preparation-
  No underground mixing or addition of water/components will be necessary, but some storage may be needed. As at the surface, storage should not allow degradation of the backfill shapes.

- Loading and transportation to area to be backfilled-
  Loading and transport of backfill shapes could utilize fork-lifts, front-end loaders, or winch systems for loading and a combination of conveyors, rail cars, trucks, or front-end loaders for transport to the backfill area.

6.3.4.3 Placement/Compaction of Room Backfill

Appropriate procedures for placing room backfill can be divided into mechanical and pneumatic placement, and will be specific for the various backfill materials/additives. Equipment and procedures considered appropriate for placement of backfill in the room and associated compaction(if required) for selected backfill materials/additives have been identified, and their relative advantages and disadvantages summarized (see Table 6.9):

- Muck-

  It is perceived that the most feasible means to place muck in the room would be via mechanical or pneumatic placement. The backfill, if placed mechanically, may or may not require compaction (depending on desired properties). If placed pneumatically, compaction would not be feasible, but various degrees of density could be attained by varying material characteristics and placement techniques.

  Mechanical placement would include either:
  - dumping/placing by load/haul vehicles and spreading by dozers
  - dumping by conveyor belt systems and spreading by dozers.

  Dozers would most likely be low profile front-end loaders with a dozer attachment. The conveyor belt systems could be on the floor or ceiling, but would have to be portable if the backfill is dumped in the room and near the working face.

Table 6.9
1 of 2

RELATIVE ADVANTAGES AND DISADVANTAGES OF ROOM BACKFILLING PROCEDURES (PLACEMENT AND COMPACTION)

METHOD	ADVANTAGES	DISADVANTAGES
Mechanical placement of loose, dry or moist backfill	• Standard underground equipment can be used (trucks, loaders, dozers, conveyors, etc.) • Wide range of particle sizes could be used • Load-haul-dump-place would be a relatively efficient procedure; however, equipment (with exception of conveyors, if used) must avoid completed emplacement holes • Relatively small amounts of water would be required to facilitate compaction and dust control.	• Operators must be protected from environment • Traveling equipment may interfere with other repository operations in corridors, depending on method of transport and timing between backfilling and other operations • It would be difficult to completely fill the room • Conveyor systems are relatively inflexible
- no compaction	• Procedure would have little constraint, e.g., steeper backfill face to roof could be maintained by dozer since no compaction specified.	• Without compaction, a suitably uniform, dense backfill may not be constructed.
- with compaction	• Uniform, dense backfill can be achieved.	• Provisions must be made for complete coverage of lift by construction traffic or compactors • Special procedures would be required to compact the uppermost layer of backfill, and even then the interface between the backfill and the crown will probably not be tight unless swelling materials or grouts are used • Compaction would be time-consuming.

RELATIVE ADVANTAGES AND DISADVANTAGES OF ROOM BACKFILLING PROCEDURES (PLACEMENT AND COMPACTION)

Table 6.9
2 of 2

METHOD	ADVANTAGES	DISADVANTAGES
Mechanical placement of pre-formed shapes	• With various sizes of backfill shapes, placement can be made next to roof using a stacking operation • Dust might be insignificant.	• Operators must be protected from environment • Operation may be less efficient and slower than others due to required transporting and stacking of specific shapes • Room would not be entirely filled, limiting this method to swelling backfills.
Pneumatic placement of loose dry or moist backfill	• Backfilling would be continuous • Wide range of particle sizes could be used • Uniform, dense backfill can be achieved • The room can be completely filled.	• Depending on percentage of fine-grained material and type of material, placement may be sensitive to moisture content • Method may be expensive, in terms of energy and wear of equipment • Success of method depends on type of material and operator technique and experience • Dust may be a problem • **Interface between crown and backfill will probably not be tight, unless swelling materials or grouts are used** • **QA/QC will be difficult to monitor.**

The muck backfill material would be loose, probably well-graded (a wide-selection of particle sizes from cobble to sand size) and dry. A small percentage of moisture may be added to control dust and facilitate compaction.

Mechanical compaction of muck backfill would include:

- load/haul/dump vehicle traffic and dozer traffic
- low-profile compactors (rollers of various types, sheepsfoot, smooth drum or rubber-tired)
- boom-type plate compactors (static and/or vibratory)
- special traveling shield.

Compaction via traffic would only be adequate assuming proper coverage of the backfill lift. The same concern would exist for compactors; however, the compactors would be self-propelled or towed explicitly for compaction and would attempt to cover the room width and not rely on haul routes. A major concern for both procedures would be that no compaction would be achieved for the uppermost lifts against the ceiling. A boom-type plate compactor would be able to compact the forward face utilizing static force and/or vibration. A traveling shield might be applicable as well. This piece of equipment, which would need to be specially developed, would feed material through the movable shield via an auger or belt, and then compress the material against a fill fence or previously-placed backfill. The traveling shield would probably only be used for the uppermost layer. The exact height of this remaining (i.e., uncompacted) layer will be dependent upon the specific low profile equipment utilized, but considering practically sized equipment (e.g., front-end loaders ranging in bucket size from 1 to 17 cubic yards) the remaining layer could be as great as 7 to 8 feet. In any case, adequate compaction against the crown of an underground opening will be difficult to ensure. Typically, even with careful procedures, the interface between the crown and backfill will not be tight.

Pneumatic placement of muck backfill would utilize specialized pneumatic backfill equipment. The equipment would require a feeder, stower, blower, drive unit and associated pipe and nozzle. The equipment is commercially available.

It appears that the success of pneumatic placement would be dependent upon system design (i.e., power, exit velocity, etc.), type of material and technique. Thus, prototype testing may be a suitable option, especially to evaluate the density near the crown and the interface between the crown and backfill. In any case, it will be difficult to ensure that pneumatically placed backfill has been constructed, and thus will perform, according to design.

The material for this placement would usually be dry (with only enough moisture to control dust), generally less than 3 inches in particle size, and with a minimum of fine-grained particles.

A combination of mechanical and pneumatic placement might also be used. A hybrid scheme of mechanical and pneumatic placement might be desirable from the standpoint of high quality fill with efficient, existing techniques. Such a scheme, similar to ones currently used in some mines, would specify mechanical placement and compaction of the backfill to a point where low-profile compaction equipment or construction equipment could no longer travel on top of the placement lift due to the lack of headroom. The remainder of the opening would then be backfilled using pneumatic placement. Drawbacks to this scheme include mixing two techniques, perhaps causing some interference in operation. Also, the length of opening for pneumatic placement (along the room axis) must be small so that backfill would not have to be projected over long distances, as density achieved in pneumatic backfill is related somewhat to impact velocity of the particles. Again, the interface between the crown and backfill will probably not be tight, nor will it be easy to ensure that pneumatically-placed backfill has been constructed according to design.

- Muck mixed with bentonite-

  It is perceived that the characteristics of a mixture of muck and bentonite, pertinent to placement and compaction, will be a function of the relative percentages of each. That is, for a large percentage of bentonite, the mixture would have many of the same characteristics as bentonite alone, and thus the placement and compaction procedures would be essentially identical to those feasible for bentonite alone. Conversely, for a large percentage of muck, the mixture would have many of the characteristics of muck alone, and thus the placement and compaction procedures would be essentially identical to those feasible for muck alone. For example, for a large percentage of muck in the mixture:

  - Pre-formed shapes would not be easily manufactured and would not be expected to retain shape during storage.

  - The mixture would show little dependence on water content, but would require optimization of other parameters during placement/compaction.

  - Some dust control would be required, due to the bentonite.

  - A tight interface between the crown and backfill could be achieved, due to the swelling characteristics of the bentonite.

- Bentonite-

  It is perceived that bentonite backfill for the room would be in one of the following forms:

  - pellets, with or without powder
  - pre-formed shapes.

Bentonite backfill of pellets and powder would be most likely placed by mechanical means, including a system of load/haul/dump vehicles in combination with dozers, roller compactors, boom-type compactors or a traveling shield. The procedure would be similar to that of mechanical placement of muck, with the exception that if compaction is necessary, it would require strict addition and control of moisture content. The moisture content, added during the preparation stage at the repository level, would need to match the optimum moisture content for the desired properties and yet provide a workable surface for construction. It should be noted that vibratory compaction is unlikely to be effective for this material and that certain types of rollers (e.g., sheepsfoot) may be more effective than other rollers (e.g., smooth-drum). A tight interface between the crown and backfill could be achieved, due to the swelling characteristics of the bentonite.

Pre-formed backfill shapes would arrive at the backfill area in load/haul/dump vehicles and would likely be placed by fork-lift type vehicles, front-end loader type vehicles (with optional grabbing boom) or specially developed equipment. The pre-formed shapes would be stacked to fill the room as completely as possible (which may require various-sized shapes). Gaps between blocks might be filled with loose bentonite powder. No compaction, other than contained swelling of bentonite upon wetting, would be required.

- Clinoptilolite/Zeolite (synthetic)-

  At the time of this report, the exact gradation and consistency of zeolite (synthetic) or clinoptilolite is uncertain; however, it has been assumed that the material would be granular. Thus, the procedures for placing and compacting clinoptilolite/zeolite would be identical to those for muck.

6.3.4.4 Placement/Compaction of Waste Emplacement Hole Backfill

Appropriate procedures for placing backfill in the vertical waste emplacement hole are limited to:

(1) Mechanical placement of pre-formed backfill shapes
(2) Mechanical placement of dry backfill
(3) Pneumatic placement of dry backfill.

Compaction of loose, dry backfill after placement (excluding pre-formed shapes) has not been considered, as no existing procedure is readily adaptable to such compaction nor has density of the backfill in the waste emplacement hole been shown to be important. Some consideration has been given to special equipment, such as an annular ring through which the backfill would be placed and also through which a vibratory and/or static force could be applied. Such a device would complicate completion of emplacement, perhaps unnecessarily. For these reasons, compaction of backfill in the emplacement hole has not been considered to be appropriate, and it has been assumed that other techniques can suitably fill the hole with backfill in the space provided.

Equipment and procedures considered appropriate for placement of backfill in the waste emplacement hole have been identified, and their relative advantages and disadvantages summarized (see Table 6.10):

- Muck-

  Placement of muck would utilize mechanical or pneumatic placement of dry backfill.

  Mechanical placement would utilize either:

  - Waste package transporter modified to pour the backfill material around the waste package after the package has been positioned. The transporter could have a portable storage bin and placement guide that would fit into the emplacement hole, center the waste package and guide the falling backfill around the waste package. Some placement of backfill may be required prior to waste package emplacement to level the hole bottom.

  - Small front-end loaders to pour the backfill in conjunction with a placement guide (similar to above).

  Pneumatic placement would utilize equipment identical to that described for pneumatic backfilling of rooms. Differences might exist in the size of equipment (large capacity and force would not be necessary) and in maximum size of particles used. Initial pouring of backfill into the hole bottom might be necessary to provide a level surface for the package. A centering guide would be necessary to position the waste package during pneumatic placement.

- Muck mixed with bentonite-

  As in room backfilling, it is perceived that a mixture of muck and bentonite would be placed depending on the relative percentages of each material. A high percentage of muck would suggest using those procedures applicable to muck by itself, and would also require dust control and probably preclude the successful manufacture and storage of pre-formed shapes. Conversely, a high percentage of bentonite would suggest using those procedures applicable to bentonite by itself.

- Bentonite-

  Placement of bentonite would likely include mechanical placement of dry bentonite (in pellets or powder) or mechanical placement of pre-formed backfill shapes. Pneumatic backfilling has been excluded due to excessive dust creation and the inability to achieve a more compact placement of the bentonite.

Table 6.10

RELATIVE ADVANTAGES AND DISADVANTAGES OF WASTE EMPLACEMENT HOLE BACKFILLING PROCEDURES (PLACEMENT AND COMPACTION)

METHOD	ADVANTAGES	DISADVANTAGES
Mechanical placement of pre-formed shapes	- Placed shapes can provide support for waste package - Desired backfill would completely surround waste package - Emplacement holes can be prepared in advance of waste package (provided water is not present) and completed quickly - Operators may not be exposed to adverse conditions during backfilling, due to pre-placement - Density of backfill can be controlled by manufacturing.	- Loose backfill may be required underneath and around pre-formed shapes, requiring another placement procedure - Operation may be slow due to required transporting and stacking of specific shapes.
Mechanical placement of dry backfill	- By using a backfill guide, the waste package in the hole can be centered and backfill poured through the guide can be accurately placed - Equipment to place (pour) backfill may be included on the transporter, thus simplifying construction.	- Operator may be exposed to elevated temperatures, radiation - Backfill is not likely to be dense (as placed).
Pneumatic placement of dry backfill	- By using a backfill guide, the waste package in the hole can be centered and backfill blown through the guide can be accurately placed - Equipment to place backfill may be included on the transporter, thus simplifying construction - Depending upon materials, backfill may be dense (as placed).	- Operator may be exposed to elevated temperatures, radiation - Dust may be created (depending on materials).

Mechanical placement of loose dry bentonite (pellets or powder) would be similar to the procedure for mechanical placement of dry muck, i.e., various means of pouring the backfill into the hole.

Mechanical placement of pre-formed shapes would require the use of a modified fork-lift, front-end loader or modified waste package transporter with which to lower the shapes into the hole. Some means (as described in mechanical placement of loose, dry backfill in the hole) may be required to place miscellaneous backfill to level the bottom of the hole and/or fill around the shapes. The pre-formed shapes would be placed in position prior to waste package emplacement.

- Clinoptilolite/Zeolite (synthetic)-

  As in room backfilling, it is perceived that placement of zeolite or clinoptilolite would utilize procedures essentially identical to those for muck.

6.4 VERIFICATION OF BACKFILL DESIGN

6.4.1 Introduction

Verification will be required that the backfill design has been properly implemented, i.e., that it has been constructed and will thus perform as expected and achieve the intended backfill design objectives. This verification can be provided by:

- Monitoring backfill construction (i.e., preparation, placement, and compaction, if any)
- Determining the in-place characteristics of backfill (as constructed), for use in predictive numerical performance models
- Measuring and extrapolating the results of backfill simulation tests
- Monitoring actual backfill performance.

Although all of these approaches may be necessary to adequately verify the implementation of a specific backfill scheme, the primary emphasis must be on the verification of in-place backfill characteristics, as monitoring of either simulated or actual backfill performance will not be timely.

6.4.2 Significant Backfill Characteristics

Those in-place characteristics of backfill (as constructed) which are significant, and thus must be assessed to verify design, will be a function of the backfill design objectives which the specific backfill scheme attempts to achieve. Based on the generic backfill design basis used in this study (Section 3), those backfill performance characteristics which are perceived to be most important have been identified, and include:

- Mechanical characteristics (i.e., strength, deformation, creep, consolidation/swelling), especially with respect to structural support (room scale) and transfer of stresses from the rock mass to the waste package

- Thermal characteristics (i.e., thermal conductivity, heat capacity, thermal expansion), especially with respect to thermal insulation/heat transfer between the waste package and host rock

- Hydrologic characteristics (i.e., hydraulic conductivity, effective porosity, specific storage), especially with respect to water flow attenuation

- Geochemical characteristics (i.e., radionuclide dispersivity/retardation/adsorption, alteration/solubility potential), especially with respect to radionuclide transport attenuation and mitigation of corrosive groundwater.

The significance of each of the above characteristics will depend on the specific backfill design; it is not likely that each of the above characteristics will be significant for every backfill scheme. More realistically, the degree to which the expected value of the characteristic is to be optimized may determine if verification will be necessary; verification will be irrelevant if no attempt to achieve certain specific values of a characteristic will be made. However, most (if not all) of these performance characteristics will need to be assessed in any case for repository system performance assessment (Section 2.3).

Backfill performance characteristics will be primarily a function of the physical characteristics of the in-place backfill, i.e., material type(s), gradation, particle shape, density, moisture content, etc. Hence, the correlaton between the performance and physical characteristics will need to be established, so that the performance characteristics can be verified by controlling and assessing the pertinent in-place physical characteristics. Homogeneity/variability of the in-place backfill will thus also be a significant consideration, as will be the natural variability of the site.

6.4.3 Verification of Backfill Characteristics

Four stages of testing/monitoring will most likely be necessary for adequate verification of backfill performance characteristics, i.e.:

- Laboratory testing
- Construction monitoring

- In situ testing
- In situ performance monitoring.

Laboratory testing will be required to establish correlations between the backfill performance characteristics under a specific set of conditions and the backfill physical characteristics. These laboratory tests may be a part of a research program to assess backfill performance characteristics under expected repository conditions, as required for design purposes; however, the tests must relate to values of physical characteristics which can be rapidly and easily monitored during construction of the backfill. It may be necessary to also assess the change in backfill properties from the time of construction to those at future conditions.

Construction monitoring (i.e., inspection of preparation, placement, and compaction) will be required to assess the quality of construction as backfilling progresses. Tests should be a minimum in type, be rapidly and easily performed, and yield sufficient information to assess the in-place physical characteristics (and thereby performance) of the backfill, as constructed. The properties measured and their critical values will be defined during laboratory testing.

In situ testing will be required to further assess the quality of construction and compare measured values of backfill characteristics (in-place) to those measured in laboratory tests and those used in predictive repository modeling. In addition, laboratory tests will generally be limited in scale, as well as regarding physical characteristics; thus, in situ testing will generally be needed to provide properties for more representative conditions. While construction monitoring will be essentially continuous, relatively few in situ tests will be performed, primarily to directly verify that the desired backfill performance characteristics have been achieved.

In situ performance monitoring will be required to assess and verify backfill performance with actual longer-term conditions, assuming that in situ tests will be completed in a relatively short time period. The period of monitoring will be dependent on the time available between backfilling and decommissioning.

General testing/monitoring methods which are available for assessing the significant backfill characteristics have been identified (see Table 6.11). However, it should be recognized that not all of the identified testing or monitoring methods will be necessary for a specific backfill scheme. In fact, the selection of tests and monitoring to be performed should be made on an individual basis. Tests and monitoring should not be performed unless the results will be compared to expected performance characteristics, specified physical characteristics, or modeled behavior. Hence, only those characteristics which are significant to the given design should be focused on. The extent and schedule of testing/monitoring, e.g., prior or subsequent to LA, will depend on the level of confidence in satisfactory repository system performance required for licensing purposes (especially at LA) and on the reliance

APPROPRIATE TESTING/MONITORING METHODS FOR ASSESSING SIGNIFICANT BACKFILL CHARACTERISTICS

Table 6.11

SIGNIFICANT BACKFILL CHARACTERISTICS	LABORATORY TESTS	CONSTRUCTION MONITORING		IN SITU TESTS		IN SITU PERFORMANCE MONITORING	
		Waste Emplacement Hole	Room	Waste Emplacement Hole	Room	Waste Emplacement Hole	Room
PERFORMANCE:							
(MECHANICAL)							
Strength	●				●		
Deformation	●				●		
Creep	●				○		
Consolidation/ Swelling	●				○		○
(THERMAL)							
Thermal Conductivity	●				●	○	○
Heat Capacity	●				●		
Thermal Expansion	●				●		
(HYDROLOGIC)							
Hydraulic Conductivity	●				●		
Effective Porosity	●				●		
Specific Storage	●				○		
(GEOCHEMICAL)							
Radionuclide Retardation/Adsorption	●				●	○	○
Alteration/Solubility Potential	●				○		
PHYSICAL:							
Homogeneity		○	●		○		
Material Type	●	●	●		○		
Gradation	●	●	●		○		
Particle Shape	●	●	●		○		
Moisture Content	●	●	●		○		
Density /Porosity	●	○	●		●		

● primary testing/monitoring method
○ possible secondary testing/monitoring method

NOTE: Performance characteristics are primarily a function of specific physical characteristics. Appropriate testing/monitoring methods will depend on the significance of each characteristic, which in turn will depend on backfill design. It is unlikely that all of these identified methods will be necessary for any given backfill scheme. The extent and schedule of testing/monitoring, e.g., prior or subsequent to LA, will depend on the level of confidence in satisfactory repository system performance required for licensing purposes (especially at LA) and on the reliance placed on backfill in achieving this performance, neither of which have yet been clearly established.

placed on backfill in achieving this performance, neither of which have yet been clearly established.

Specific testing and monitoring have been identified in the following section. Standard test methods for specified tests have been mentioned, where possible. The methodology and some of the test procedures are similar to those described in the Task 2 report, "In Situ Test Programs Related to Design and Construction of High-Level Nuclear Waste (HLW) Deep Geologic Repositories" (Golder Associates, 1982c).

6.4.4 Identification of Specific Testing and Monitoring Methods

6.4.4.1 Laboratory Testing

Laboratory tests for defining measurable physical characteristics assume that the environmental conditions will be known and can be adequately represented in laboratory tests. Further, it is often assumed for simplicity in construction monitoring that the desired performance properties can be adequately correlated with the following measurable physical characteristics:

- Mineralogy/additive content
- Backfill gradation and particle shape
- As-placed dry density
- As-placed moisture content.

Specific laboratory tests which can be utilized in the assessment of significant backfill characteristics include:

- Mechanical Characteristics
  - Strength/Deformation Tests - establish relationship of deformation properties (e.g., modulus of deformation) and shear strength with type and gradation of backfill, density/porosity, moisture content/degree of saturation, temperature, confining stress, time, drainage conditions, etc.

    The exact test details depend greatly on the backfill material chosen and conditions required for the tests. A vast number of laboratory tests for backfill materials are available and vary greatly in complexity. Typical tests include unconfined compression, triaxial compression, direct shear, simple shear, torsional shear, and true triaxial (cubical) tests.

    Recognized methods exist for these tests but vary somewhat depending on conditions and available laboratory equipment. Standardized test methods include:

    . Unconfined Compressive Strength of Cohesive Soil,
      ASTM D2166-66 (1979)
    . Triaxial Test, ASTM D2850-70 (undrained only)
    . Direct Shear, ASTM D3080-72 (1979).

- Volume Change Tests - establish relationship between settlement/shrinkage/swelling of backfill with type and gradation of backfill, initial and changing degrees of saturation/moisture content, temperature, time, density/porosity, loading, etc.

  No standard tests exist, but one-dimensional consolidation tests (ASTM D2435-70) could be modified for fine-grained backfills.

- Thermal Characteristics

  - Thermal Conductivity Tests - establish relationship between thermal conductivity (and/or other necessary thermal properties) with type and gradation of backfill, density/porosity, moisture content / degree of saturation, temperature, temperature gradient, confining stress, time, groundwater chemistry and flow, etc.

- Hydrologic Characteristics

  - Hydraulic Conductivity Tests - establish relationship between hydraulic conductivity and type and gradation of backfill, including adsorbed cations in backfill (if applicable), density/porosity, moisture content, temperature, confining stress, groundwater chemistry, hydraulic gradient, flow direction (if applicable).

    A standardized hydraulic conductivity test, ASTM D2434-6E (1974), exists for granular soils only. Procedures for testing fine-grained soils are numerous and not standardized, and depend greatly on conditions under which the test is to be performed.

- Geochemical Characteristics

  - Column/Tracer Tests - establish relationship between adsorption and temperature, gradation and type of backfill, density/porosity of backfill, moisture content, groundwater chemistry, time, radionuclide type, etc.

  - Column/Water Chemistry Tests - establish relationship between Eh, pH, and parameters that would indicate adverse corrosive conditions for the waste package metals, as well as temperature, density/porosity of backfill, moisture content, time, and gradation and type of backfill.

- Physical Characteristics

  - Moisture-Density Tests (for soils containing significant percentage [12% or more] of fine-grained backfill [less than #200 sieve size]), e.g.,
    - . ASTM D698-78
    - . ASTM D1557-78

- Relative Density Tests (for soils relatively free [less than 12%] of fine-grained backfill [less than #200 sieve]), e.g., ASTM D2049-69

- Classification and Index Testing (as necessary), e.g.,
  - . Particle Size Analysis of Backfill
  - . Chemical Analysis of Pore Water.

It should be noted that conflicting optimums will often exist between the sets of properties, that is, dual desirable characteristics (such as modulus of deformation and hydraulic conductivity) may require optimization of a property (such as moisture content) at different values. In these cases, a single characteristic must be optimized or compromises must be selected for design. In addition, coupled behavior between backfill characteristics occurs. Laboratory tests should be able to assess the backfill performance characteristics for specific sets of physical characteristics given the range of expected or existing environmental conditions.

6.4.4.2 Construction Monitoring

It is assumed that the significant backfill performance characteristics are primarily a function of backfill gradation and additive content, and in-place dry density and moisture content. Hence, assessment and control of these physical characteristics, as well as homogeneity/variability, must be emphasized during construction monitoring. Inherent in this assumption is that methods will be available to perform tests at the backfill site and that a small laboratory will be available at the repository level. Special tests may need to be derived depending on selected backfill, procedures or conditions. Tests that could be utilized include:

- Classification of Emplaced Backfill, e.g.,
  - ASTM D2488-69 (1975) (Visual Method)
  - ASTM D422-63 (1972)
  - ASTM D1140-54 (1971)
  - ASTM D2487-69 (1975)
  - Special procedures for rock fill

- Determination of Moisture Content, e.g.,
  - ASTM D2216-80

- Determination of Dry Density, e.g.,
  - ASTM D1556-64 (1974)
  - ASTM D2167-66 (1977)
  - ASTM D2937-71 (1976)
  - ASTM D2922-78
  - Special procedures for rock fill

- Other tests as required to verify specifications for backfills or measure other correlative properties.

6.4.4.3 In Situ Testing

The in situ tests required for this stage are not necessarily standard or currently utilized. These tests represent existing concepts or methods that may be readily modified for application to backfill in a repository. In situ testing for site characterization was the topic of Task 2 of this project (Golder, 1982c); this Task 2 study has been used extensively in the identification of appropriate in situ tests for verifying backfill design.

It has been assumed that in situ tests will be performed shortly after placement/compaction during the retrievability period. In addition to the specific test methods identified, large scale samples of constructed (in-place) backfill can be obtained and tested in the laboratory. Other suggested test concepts or methods that could be suitably modified for repository backfill applications include:

- Mechanical Characteristics

    - Deformation testing of room backfill on exposed surfaces, in boreholes or small test openings. Existing test procedures that may be applicable include:

        . Various jacking tests
        . Plate load tests (similar to jacking tests)
        . Borehole jack test
        . Pressuremeter tests.

        Other, less advantageous tests include:

        . Seismic velocity testing, where values of modulus calculated are representative only at very low values of strain

        . Cone penetration testing, where correlations of cone capacity with modulus of deformation are required, as modulus of deformation is not directly measured.

        Special test procedures may be necessary to account for deformation of the nearby host rock during any test and also for coupled behavior.

    - Strength testing of room backfill on exposed surfaces or in boreholes. Existing test procedures that may be applicable include:

        . Plate load tests
        . In situ direct shear tests
        . Pressuremeter tests.

        Other less advantageous tests include:

  - . Cone penetration testing, where correlations of cone capacity with shear strength are required as strength is not directly measured

  - . Borehole shear tests, where the test measures only a small volume of soil

  - . Screw plate test, where correlations are required to determine shear strength.

  Special test procedures may be necessary to account for the presence of the host rock and for coupled behavior.

- Thermal Characteristics

  - Heater tests in blocks or boreholes in room backfill to verify thermal conductivity and/or other thermal properties. Special procedures may be necessary to account for boundary conditions (e.g., contact of host rock and geometry of test instrumentation) and coupled behavior.

- Hydrologic Characteristics

  - Borehole permeability tests in room backfill to verify hydraulic conductivity and/or other hydrologic properties. Special procedures may be necessary to include problems associated with backfill configuration/contact with host rock, saturation of backfill and swelling of bentonite (if used), vertical and horizontal components of permeability and coupled behavior.

- Geochemical Characteristics

  - Radionuclide/tracer tests to verify adsorption of specific radionuclides by backfill materials for actual repository geometry/conditions. Special test procedures need to be developed.

Backfill objectives/designs that require a tight interface between the backfill and the roof of the opening present special problems in testing. A test location near the roof may require that the orientation of the test be changed (e.g., from vertical to horizontal). Such a modification may cause significant changes in boundary conditions and may require different analysis techniques or modifications to test equipment/procedures. Placement and compaction of backfill against the roof is more difficult than elsewhere, and hence testing at the roof should be emphasized.

It may be desirable to delay testing until environmental conditions equilibrate or reach a peak (e.g., temperatures in the rock are expected to reach their peak between about 5 and 50 years, depending on location, media, thermal loading, etc.); this may not be logistically possible, however.

6.4.4.4 In Situ Performance Monitoring

Performance monitoring will begin shortly after backfill placement and is intended to provide data on backfill performance where in situ tests are inadequate or easily augmented. As in testing, monitoring should only be performed for that behavior determined to be significant by the design objectives. In addition, long-term design objectives have not been included in the monitoring (e.g., the time to resaturation, assuming that such an event occurs after decommissioning).

Suggestions for in situ performance monitoring, in excess of monitoring required to detect hazardous conditions during normal repository operations, include:

- Mechanical Characteristics/Performance-

  Instrumentation should be placed in the room backfill to detect volume changes between the roof and sides of the room and the backfill. Gaps could be created as a result of backfill shrinkage or backfill settlement (due to self-weight or upon wetting). Swelling of backfill may occur if bentonite is utilized. Such volume change would likely occur in the short-term and may affect the ability of the backfill to satisfy its design objectives.

  In conjunction with this instrumentation, it may also be desirable to measure strains in the room backfill due to closure of the opening and to measure stresses or strains in the waste emplacement hole backfill to determine the stresses acting on the waste package.

- Thermal Characteristics-

  The difficulty of measuring thermal properties of emplacement hole backfill suggests the use of an actual waste package in prototype testing. Instrumentation placed in a few emplacement holes to monitor temperature at the waste package and at the outer surface of the backfill could provide such data. The duration of the testing would be dependent upon the build-up of temperatures through the waste package. It may also be desireable to monitor temperatures in the room backfill to assess thermal response.

- Hydrologic and Geochemical Characteristics-

  Instrumentation should be placed above storage holes and in several locations in the room to detect moisture content/pore pressures and the transport of radionuclides.

6.5 DESIGN CONSIDERATIONS FOR HORIZONTAL WASTE EMPLACEMENT

The backfill schemes presented in this report have been based on repository design concepts in which waste packages are placed in vertical emplacement holes (Section 2). Recently, consideration has been given to the use of horizontal waste emplacement (particularly in basalt, Section 2). Horizontal emplacement holes would span between rooms, with multiple packages placed in each hole. Backfill to be placed (pneumatically) in the holes might consist of 75% muck and 25% bentonite, and be deferred in time of placement. Also, the size of the room would change from 20 feet high by 15 feet wide to 10 feet high by 20 feet wide.

This different design concept has several implications with respect to structural behavior, engineered barrier performance and construction activities:

- Structural Behavior-

  In general, the stability of the room would be improved by this change of shape where horizontal stresses are high, as stress conditions would tend to be more uniform around the opening with a reduction of tensile stress expected near the springline and minimization of compressive stress effects expected at the crown and floor. However, the larger roof span and curvature would create greater opportunities for slab, block, or wedge failure, due to a more exposed geologic structure.

  A larger width-to-height aspect of the room would lessen the support efficiency of the backfill; however, backfill would be most efficient in preventing total opening collapse or in the reduction of stress, and would not generally provide rigid support.

  The stress condition in the pillars would generally be expected to be more desirable due to the possible reduced volume of excavation.

  The stability of the horizontal waste emplacement hole would be of greater concern, especially due to gravity rock failures controlled by the geologic structure. Such failures would depend on ground conditions and opening dimensions/orientation, and might impact retrievability.

- Engineered Barrier Performance

  Potential flow paths to or within engineered barriers might be longer with horizontal waste emplacement, depending on the site conditions and specific repository design. In fact, the role of room backfill in the integrated system of repository components would be revised, especially for predominantly vertical hydraulic gradients; in such a case, flow paths from the waste package would most likely bypass the room.

  Heat loading and therefore differential thermal effects on rock/backfill interaction would tend to be more uniform with horizontal waste emplacement and might create less severe heat-related stress problems.

However, the conditions acting on individual waste packages might be more severe with horizontal emplacement. For example, due to the close proximity of adjacent waste packages, the waste package temperatures might be increased. This, in conjunction with possible stress concentrations in the waste package caused by the support rack, might result in an increased degradation rate of the waste package.

- Construction Activities-

  A lower roof height may present more restrictions on the use of equipment for backfill placement and removal (if necessary). Otherwise, however, there would be little, if any, impact on room backfilling procedures.

  It would be difficult to complete and fully compact backfilling around the waste package. In fact, pneumatic backfill appears to be the sole backfilling option and might require more than one backfill pipe to fill the annular space. Even with such an arrangement, the backfill would likely be of low density, especially at the top of the hole; the interface between the crown and backfill would probably not be tight unless swelling materials (e.g., bentonite) or grouts were used. It also appears that the backfill pipe must be withdrawn as the fill progresses. It will be difficult to ensure that the fill has been placed as intended, due to remoteness. If compaction is attempted, which is not likely, it will be similarly difficult to ensure that this is adequately and uniformly accomplished.

  For pneumatic placement, the maximum size of backfill aggregate would be restricted to a fraction of the backfilling pipe diameter. In addition, a large amount of dust might be created. Control of dust could be accommodated at the open end of the waste emplacement hole, as the other end of the hole would have to act as a fill fence.

  The openings (room and waste emplacement hole) would be amenable to mechanized excavation, thereby minimizing rock damage.

  Drainage of the waste emplacement hole (prior to backfilling) could be more effectively carried out and with less direct impact on the containment aspects of the rock mass.

  The completed horizontal waste emplacement hole would probably cause less interference with construction and backfilling equipment than one in the floor.

  Retrieval of the waste package (if required) could theoretically be performed utilizing a push or pull motion from either end. However, retrieval may be rendered very difficult under any of the following conditions:

- If the hole has been backfilled
- If loose rock should fall from the roof of the hole to partially block the passage
- If the in-hole waste package transport mechanism should malfunction.

These difficulties in retrieval would be compounded due to the potential distance from the room into the rock at which the problems might occur.

7. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

7.1 SUMMARY

This report presents the results of Task 5, regarding the construction and testing aspects of backfill, both around waste packages and within rooms. These results include:

- Establishment of study premises; i.e., repository design concepts, performance assessment methodology, and media/site specific conditons for basalt at Hanford, tuff at NTS, domal salt on the Gulf Coast, and generic bedded salt and granite. The subsequent results and conclusions of the Task 5 study may require revision should any of these premises, as given in Section 2, change.
- Identification of backfill design objectives, which have been derived from, and thus can be explicitly related to, the repository system performance objectives of safety in short-term construction/operation and long-term waste containment/isolation. These backfill design objectives, as given in Table 3.1, have been categorized in terms of the subject of concern (schedule, procedures, mechanical characteristics, thermal characteristics, hydrologic characteristics, or geochemical characteristics), the scale of concern (room scale, waste package scale, or both), and the period of concern (during retrieval period, post-decommissioning to resaturation, or post-resaturation). These backfill design objectives could form the basis for either backfill design optimization (which has not been intended here) or comparative evaluations of alternative backfill schemes.
- Assessment of the relative significance, or weights, of each identified backfill design objective with respect to its potential contribution to achieving the repository system performance objectives. Essentially, these weights, as given in Table 3.2, represent the perceived sensitivity of the repository system performance objectives to the backfill design objectives for generic site conditions. These weights have been subjectively assessed, and thus have significant inherent uncertainty. Hence, these weights should be considered only as rough indicators of relative significance, which is sufficient for the purposes of this study. These weighted backfill design objectives could be used as preliminary guidelines for backfill design optimization (which has not been intended here) or as a generic basis for comparative evaluations of alternative backfill schemes.
- Development of an explicit evaluation methodology by which alternative backfill schemes can be subjectively evaluated and then compared. This evaluation methodology, as given in Section 4, essentially results in the assessment of the extent to which the generic backfill design basis, and thereby the repository system performance objectives, would be achieved by any backfill scheme's

expected performance. This methodology consists of subjectively evaluating the percentage of each significant backfill design objective which is achieved by a backfill scheme's expected performance, and then multiplying that percentage by that objective's previously assessed relative weight. A numerical score can then be obtained for each alternative backfill scheme by summing the products for all the significant backfill design objectives. The higher the score, the more likely it is that the generic backfill design basis, and thereby the repository system performance objectives, will be achieved. On this basis, the best schemes, i.e., those with the highest scores, can be identified and selected. Although sufficient for the purposes of this study, significant uncertainty persists due to the subjective nature of the assessments.

- Identification of a representative set of alternative backfill schemes, which consist of combinations of materials/additives and associated construction procedures (i.e., preparation, placement, and compaction, if any) for backfilling around the waste package and within rooms. These alternative backfill schemes, as summarized in Tables 5.8 and 5.9, have been identified from schemes:

  - previously proposed by the Department of Energy for repositories
  - typically used in mining and surface civil engineering
  - previously identified under the "Engineered Barriers" contract.

  Alternative backfill materials/additives have been found to be primarily a function of the primary objectives for backfill, i.e., providing structural support, water flow attenuation, radionuclide transport attenuation. These materials/additives include:

  - none
  - concrete, alone or with sand-cement grout
  - muck, alone or with sand-cement grout or mixed with bentonite
  - sand, alone or with sand-cement grout or mixed with bentonite
  - bentonite
  - illite
  - clinoptilolite
  - zeolite (synthetic).

  Alternative placement procedures will essentially be related to the types of materials/additives used, as well as the primary backfill objectives, and include:

  - mechanical placement procedures
  - pneumatic placement procedures
  - hydraulic placement procedures.

  Alternative compaction procedures will essentially be related to the types of materials/additives and placement procedures used, as well as the primary backfill objectives, and include:

- none
- static mechanical compaction
- dynamic mechanical compaction
- vibratory compaction
- electro-osmosis
- drainage or consolidation.

- Evaluation of alternative backfill schemes, with respect to achieving the generic backfill design basis. Each of the viable combinations of waste emplacement hole and room backfill materials/additives has been preliminarily evaluated, as summarized in Table 6.5, using the subjective but explicit evaluation methodology. Based on this preliminary evaluation, the four materials/additives selected for further study include:

  - muck
  - muck mixed with bentonite
  - bentonite
  - clinoptilolite/zeolite (synthetic).

  Appropriate alternative combinations of procedures have been discussed and identified, as summarized in Tables 6.7 and 6.8, for the use of the selected materials/additives in hard rock or salt. The procedures and equipment include only those combinations deemed to be feasible and practical for achieving the generic backfill design basis.

  Verification of expected backfill behavior is anticipated to occur in four stages:

  - laboratory testing
  - construction monitoring
  - in situ testing
  - in situ performance monitoring.

  Appropriate testing/monitoring methods for each stage have been discussed and identified, as summarized in Table 6.11.

  Additional design/construction considerations for horizontal waste emplacement have also been discussed, as given in Section 6.5.

7.2 CONCLUSIONS AND RECOMMENDATIONS

Golder Associates believes that a logical and explicit approach has been utilized in this Task 5 study to:

- Develop a generic design basis for backfill sufficient for the purposes of this study
- Identify and discuss alternative backfill schemes
- Comparatively evaluate the identified feasible alternative backfill schemes with respect to the design basis.

Indeed, it is felt that the identification of a comprehensive set of backfill design objectives, which are explicitly derived from and thus related to the repository system performance objectives, is an important development in the definition of the role of backfill as an integral component of the repository system. The subsequent weighting of these backfill design objectives gives additional focus as to their perceived relative significance within the repository system. The development of an explicit evaluation methodology using these weighted backfill design objectives provides a useful tool in the comparative evaluation of alternative backfill schemes. However, it must be emphasized that quantitative performance assessment of the repository system, including backfill as an integral component, on a site-specific basis will be necessary for a rigorous evaluation of any backfill design. Indeed, such performance assessments, in the form of sensitivity studies and including consideration of the natural variability of site conditions, would refine the weighting estimates and thus guide backfill design.

It is Golder Associates' opinion that the NRC should utilize the Task 5 results in their review of backfill aspects contained within an SCR or LA, as follows:

- Backfill design basis - Are the applicant's design objectives consistent with the generic backfill design basis, especially the most significant backfill design objectives, developed here; i.e., does the applicant correctly perceive backfill's role in the repository system? If the applicant's design basis is significantly different, to what extent will that affect the probability of satisfactory repository system performance? This impact can be roughly assessed through the hierarchy of performance objectives developed here. Does the applicant's design basis take into proper account the natural variability in site conditions?

- Backfill materials/additives - Are the applicant's proposed backfill materials/additives consistent with his and the generic Task 5 design basis; i.e., can the materials/additives reasonably achieve the design basis? This can be assessed by consulting the discussions presented here on alternative backfill materials/additives, their range in properties, and the evaluation of each with respect to achieving the generic Task 5 design basis.

- Procedures - Are the applicant's proposed backfill procedures feasible and appropriate for the proposed materials/additives in achieving the design basis? This can be answered by consulting the discussions presented here on the feasibility of alternative backfill procedures (including equipment) for each material/additive in hard rock or salt. Also, is the applicant's QA/QC program regarding procedures sufficient to adequately ensure proper implementation of design?

- Testing - Is the applicant's test program sufficient to verify that the backfill design has been correctly implemented? This can be partially determined by consulting the discussions presented here on the tests which are available for assessing the various significant in-place characteristics of backfill and thus verifying design. However, sufficiency regarding the extent and schedule of testing will depend on presently undefined licensing requirements and the site-specific role of backfill.

7.3 RECOMMENDATIONS FOR FURTHER WORK

The results of Task 5 suggest that additional work, which is presently outside the scope of this study, would be very effective in both focusing on the important aspects of repository development and in developing useful evaluation tools. Golder Associates thus recommends that the following items be considered for further work:

- The hierarchy of repository performance subobjectives should be further developed, culminating in a comprehensive set of objectives for site screening/selection and repository design/construction/operation, and not just backfill design objectives. These repository variable objectives would thus be derived from and explicitly related to the summary repository performance objectives. Hence, the manner in which each component of the repository system contributes to system performance would be clearly established and, very importantly, easily demonstrated. Also, the purpose of various criteria could be demonstrated and justified, and guidelines for achieving these criteria established using this framework.

- Once the hierarchy of repository performance subobjectives has been fully developed, and thus the complete set of repository variable objectives identified, the relative significance (or weights) of these repository variable objectives with respect to achieving the summary repository performance objectives should be assessed, as for the set of backfill design objectives. Hence, the extent to which each component of the repository system potentially contributes to system performance would be approximately determined using "significant element" sensitivity analyses rather than typically intractable overall system analyses. This would allow for focusing on those repository variables which have the largest potential impact on achieving the summary repository performance objectives. Defensible decisions regarding these significant repository variables, including consideration of all the potential ramifications, could thus be made.

- Due to the potentially significant uncertainty inherent in the subjective assessment of weights, uncertainties in these weights should be assessed. This would help to clarify the relative significance of each repository variable objective. If the hierarchy of repository performance subobjectives was not further developed and the complete set of repository variable objectives identified, then uncertainties should at least be incorporated in the weight assessment of backfill design objectives.

- Similarly, due to the potentially significant uncertainty inherent in the subjective assessment of how well a backfill scheme achieves each backfill design objective, uncertainties in this percentage should also be assessed and incorporated in the comparative evaluation of each backfill scheme.

- Costs, although typically outside of NRC's jurisdiction, should be estimated for alternative backfill schemes and subsequently incorporated in the evaluation procedure, as previously discussed herein.

- The generic backfill design basis used in this study, and the subsequent comparative evaluations of alternative backfill schemes with respect to achieving this design basis, should be refined for site-specific conditions and designs. Similarly, the complete set of weighted objectives for repository design/construction/operation, if developed, should be refined on a site-specific basis for optimization of design. In either case, the natural variability of the site must be considered and ameliorating design contingencies incorporated.

- At some point, performance of the repository system, possibly including a chosen backfill scheme as an integral component, must be predicted for a given site and evaluated with respect to established system performance criteria. The pertinent aspects of backfill in this site-specific quantitative performance assessment should be identified, and the uncertainties assessed, in order to facilitate the review of this performance prediction. Such quantitative performance assessments could also be used to sufficiently refine the backfill design basis for given site conditions in order to use it to guide backfill design at any site.

- Additional research should be conducted regarding the in-place properties of backfill under repository conditions, e.g., retardation of specific radionuclides.

REFERENCES

American Society for Testing and Materials, 1982 Annual Book of ASTM Standards, Part 19, Natural Building Stones; Soil and Rock, ASTM, 1982. Available in public technical libraries.

Basalt Waste Isolation Project Staff, "Nuclear Waste Repository in Basalt, Project B-301, Preconceptual Design Report," RHO-BWI-CD-35, Rockwell Hanford Operations, Richland, WA, February 1980. Available from RHO.

Bechtel National, Inc., "National Waste Terminal Storage (NWTS), Conceptual Reference Repository Description (CRRD) (Draft)," Vols. I, II, III, IV, ONWI/Sub-79/E512-01600.16, September 1979. Available from ONWI.

Department of Energy, "Proceedings of Peer Review on Nevada Nuclear Waste Storage Investigations," August 1981. Available from DOE.

Golder Associates, "Identification of Characteristics which Influence Repository Design: Domal Salt, Final Report, Task 1," prepared for U.S. Nuclear Regulatory Commission, NUREG/CR-2613, March 1982a. Available in NRC PDR for inspection and copying for a fee.

Golder Associates, "Identification of Characteristics which Influence Repository Design: Tuff, Final Report, Task 1," prepared for U.S. Nuclear Regulatory Commission, NUREG/CR-2614, March 1982b. Available in NRC PDR for inspection and copying for a fee.

Golder Associates, "In Situ Test Programs Related to Design and Construction of High Level Nuclear Waste (HLW) Deep Geologic Repositories, Final Report, Task 2," Vols. I and II, prepared for U.S. Nuclear Regulatory Commission, NUREG/CR-3065, November 1982c. Available in NRC PDR for inspection and copying for a fee.

Golder Associates, "Evaluation of Alternative Shaft Skinking Techniques for High Level Nuclear Waste (HLW) Deep Geologic Repositories, Final Report, Task 3," prepared for U.S. Nuclear Regulatory Commission, NUREG/CR-2854, July 1982d. Available in NRC PDR for inspection and copying for a fee.

Golder Associates, "Relationship of an In Situ Test Facility to a Deep Geologic Repository for High Level Nuclear Waste, Final Report, Task 4," prepared for U.S. Nuclear Regulatory Commission, NUREG/CR-2959, October 1982e. Available in NRC PDR for inspection and copying for a fee.

Kaiser Engineers, "Conceptual Design Description Report for a National Waste Terminal Storage Repository in a Bedded Salt Formation for Spent Unreprocessed Fuel," 78-58-R, KE, Oakland, CA, December 1978a. Available from ONWI.

Kaiser Engineers, "Conceptual Design Report for a National Waste Terminal Storage Repository in a Bedded Salt Formation for Spent Unreprocessed Fuel," Vol. 1, 78-57-RE, KE, Oakland, CA, December 1978b. Available from ONWI.

Kaiser Engineers/Parsons, Brinckerhoff, Quade and Douglas, Inc., "Nuclear Waste Repository in Basalt, Project B-301, Functional Design Criteria," RHO-BWI-CD-38 Rev. 3, Rockwell Hanford Operations, Richland, WA, November 1980. Available from RHO.

Kaiser Engineers/Parsons, Brinckerhoff, Quade and Douglas, Inc., "Nuclear Waste Repository in Basalt, Project B-301, Conceptual System Design Description," Draft, Vol. 1, RHO-BWI-C-116, Rockwell Hanford Operations, Richland, WA, March 1982. Available from RHO.

Kerr, R.W., "Fill System for 108 Blasthole Stope at Inco's Birchtree Mine," p. 16 in Mining with Backfill: 12th Canadian Rock Mechanics Symposium, Canadian Institute of Mines and Metallurgy, Ontario, 1978. Available in public technical libraries.

Langkopf, B.S., "Thermal Analysis of Nuclear Waste Emplacement in Welded Tuff," SAND80-2639, Sandia National Laboratories, Albuquerque, NM, 1981. Available for purchase from NTIS.

Parsons, Brinckerhoff, Quade and Douglas, Inc., "Technical Support for GEIS: Radioactive Waste Isolation in Geologic Formations, V. 8--Repository Preconceptual Design Studies: Salt," Y/OWI/TM-36/8, Office of Waste Isolation, Oak Ridge, TN, April 1978a. Available for purchase from NTIS.

Parsons, Brinckerhoff, Quade and Douglas, Inc., "Technical Support for GEIS: Radioactive Waste Isolation in Geologic Formations, V. 10--Repository Preconceptual Design Studies: Granite," Y/OWI/TM-36/10, Office of Nuclear Waste Isolation, Oak Ridge, TN, April 1978b. Available for purchase from NTIS.

Parsons, Brinckerhoff, Quade and Douglas, Inc., "Technical Support for GEIS: Radioactive Waste Isolation in Geologic Formations, V. 14--Repository Preconceptual Design Studies: Basalt," Y/OWI/TM-36/14, Office of Nuclear Waste Isolation, Oak Ridge, TN, April 1978c. Available for purchase from NTIS.

Science Applications, Inc., "Tabulation of Waste Isolation Computer Models," Vols. I and II, ONWI-78, SAI/OR-749-2, December 1979. Available from ONWI.

Science Applications, Inc., "Performance of Engineered Barriers in a Geologic Repository, Task 2 Progress Report," draft report for Golder Associates, SAI, La Jolla, CA, December 1981. Available in NRC PDR for inspection and copying for a fee.

Soderberg, R.L. and D.R. Corson, "Support Capabilities of Pneumatically Stowed Materials," U.S. Bureau of Mines Report of Investigation 8202, 1976. Available in public technical libraries.

Stearns-Roger Engineering Co., "National Waste Terminal Storage Repository No. 1, Special Study No. 2: Waste Retrieval from Backfilled Regions," S-R, Denver, CO, 1978. Available from ONWI.

Stearns-Roger Engineering Co., "National Waste Terminal Storage Repository No. 1, Vol. 1, Conceptual Design Report," ONWI-0127, U.S. Department of Energy, Oak Ridge, TN, January 1979a. Available from ONWI.

Stearns-Roger Engineering Co., "National Waste Terminal Storage Repository No. 1, Conceptual Design Descriptions," ONWI-0129, U.S. Department of Energy, Oak Ridge, TN, January 1979b. Available from ONWI.

Westinghouse Electric Corporation, Advanced Energy Systems Division, "Engineered Waste Package Conceptual Design Defense High Level Waste (Form 1), Commercial High Level Waste (Form 1), and Spent Fuel (Form 2), Disposal in Basalt," AESD-TME-3113, September 1981a. Available from ONWI.

Westinghouse Electric Corporation, Advanced Energy Systems Division, "Engineered Waste Package Conceptual Design Defense High-Level Waste (Form 1), Commercial High-Level Waste (Form 1), and Spent Fuel (Form 2), Disposal in Salt," AESD-TME-3131, November 1981b. Available from ONWI.

Woodward-Clyde Consultants, "NWTS Repository No. 1, Supporting Studies for Conceptual Design of Underground Facilities," Vols. 1 and 4, March 1978. Available from ONWI.

GLOSSARY

Backfill - an integral engineered component of the repository system, specifically one part of the engineered barrier system. As used in this study, backfill includes material placed around the waste package, in the mined openings and in tunnels, but not including bulkheads, grouting, or material placed in shafts or boreholes.

Backfill Design Basis - a comprehensive set of weighted backfill design objectives. By optimizing backfill schemes with respect to this design basis, optimization with respect to the repository system performance objectives is achieved. Hence, the backfill design basis could be used to guide backfill design or to comparatively evaluate alternative backfill schemes.

Backfill Design Objectives - objectives for backfill performance which have been explicitly derived from, and thus are directly related to, the repository system performance objectives. By optimizing backfill schemes with respect to these backfill design objectives (i.e., the design basis), optimization with respect to the repository system performance objectives is achieved. Hence, these backfill design objectives should form the basis for backfill design/implementation/verification, as well as for comparative evaluations of alternatives.

Backfill Procedures - procedures for constructing backfill, i.e., implementing backfill design. These procedures include preparation, placement, and compaction, if any, of backfill.

Backfill Scheme - an appropriate combination of materials/additives, procedures, and schedule.

Primary Backfill Objectives -

- Structural: to limit displacements of the waste emplacement hole or room or to control failure of the opening, i.e., prevent the development of unstable collapse mechanisms.
- Water flow attenuation: to retard the seepage of water through the waste emplacement hole or room.
- Radionuclide transport attenuation: to suppress the transport of radionuclides wholly or partly by adsorption of radionuclides.

Repository Performance Subobjectives - objectives for repository system performance which are subordinate to the two summary repository system performance objectives. These repository performance subobjectives have been explicitly derived from, and thus are directly related to, the two summary repository system performance objectives.

Repository System - the integration of all geologic/hydrologic and engineered components which contribute to achieving the repository system performance objectives.

Repository System Performance Objectives - the objectives related to public safety which must be achieved by the performance of deep geologic repositories for permanent disposal of high level nuclear waste (HLW). These performance objectives can be summarized as:

- Short-term construction and operation objective (through decommissioning, about 100 years) of minimizing hazards jeopardizing the safety of the public and personnel during repository construction and operation (including possibly retrieval and decommissioning activities).

- Long-term waste containment and isolation objective (post-decommissioning, from about 100 to 10,000's years) of minimizing radionuclide flux (rate/unit area) to the accessible environment and thus minimizing hazards jeopardizing public safety after decommissioning. This objective dictates maintaining a waste retrieval capability for a specified period after waste emplacement and prior to decommissioning, thereby providing the opportunity for verifying a sufficiently high probability of satisfactory long-term performance and also providing a contingency plan for demonstrated non-verification.

Other performance objectives can be considered as subordinate to these two summary performance objectives.

Repository Variables - those aspects of the repository system related to either site screening/selection or repository design/construction/operation, by which the repository system performance objectives are achieved.

Repository Variable Objectives - objectives for repository variables which have been derived from, and thus are directly related to, the repository system performance objectives. By optimizing repository variables with respect to these repository variable objectives, optimization with respect to the repository system performance objectives is achieved. Hence, these repository variable objectives should form the basis for site screening/selection and repository design/construction/operation, as well as for comparative evaluations of alternatives.

Sovereign (Sub)Objective - a (sub)objective whose achievement is contributed to by some other (sub)objective, which is termed the subordinate (sub)objective.

Subordinate (Sub)Objective - a (sub)objective which contributes to achieving some other (sub)objective, which is termed the sovereign (sub)objective.

Weight - the significance of an (sub)objective, relative to the other (sub)objectives in a comprehensive set, with respect to its potential contribution to achieving a sovereign (sub)objective. This weight represents the sensitivity of the sovereign (sub)objective to the subordinate (sub)objective and the potential range in that subordinate (sub)objective.

APPENDIX A
DEVELOPMENT OF BACKFILL DESIGN OBJECTIVES

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APPENDIX A - DEVELOPMENT OF BACKFILL DESIGN OBJECTIVES

In the absence of accepted backfill designs, or even objectives, it has been necessary to generate a reasonable comprehensive backfill design basis for the purpose of this study. However, backfill (if used) will be an integral component of a very complex repository system. Due to this complexity, a systematic and trackable approach has been adopted to generate this backfill design basis. This approach (see Section 3 - Main Text) consists of identifying a hierarchy of comprehensive sets of performance subobjectives which contribute to achieving the repository system performance objectives related to short-term construction/operation and long-term waste containment/isolation. This hierarchy can be developed by subdividing the two summary performance objectives into a comprehensive but tractable set of performance subobjectives and then in turn further reducing these subobjectives as appropriate, and so on. This process can be taken down through many levels, until an objective related solely to the aspects of either site screening/selection or repository design/construction/operation (i.e., repository variables) has been explicitly related to the two summary performance objectives. This hierarchy of repository performance subobjectives, and the resulting comprehensive set of repository variable objectives, would be based on preconceived repository design concepts and performance assessment methodology (see Section 2.0 - Main Text).

For example (see Figure A.1):

> The parameter used as a measure of one of the repository system performance objectives might be "x". From the repository design concepts and performance assessment methodology, it might be determined that generally:
>
> $$x = f(a, b, c, d)$$
>
> where, e.g.:
> x = the radionuclide flux to the accessible environment
> a = radionuclide release rate from the waste packages
> b = radionuclide transport time from waste packages to accessible environment
> c = adsorption of radionuclides prior to reaching accessible environment
> d = distance to accessible environment.
>
> If the objective were to minimize "x" as much as is reasonably possible, the form of the function "f" might, for example, dictate a comprehensive set of subobjectives consisting of decreasing "a" and increasing each of "b", "c", and "d". (The relationship of "x" to "a", "b", "c", and "d", in conjunction with the cost and limitations in achieving each subobjective, will dictate how the objective should be achieved by optimizing among the competing subobjectives. This is discussed in Appendix B.)

In turn, it might be determined that generally:

$$a = g(l, m, n)$$

where, e.g.:
l = total initial radionculide content
m = opportunity to detect and mitigate waste packages which will not perform satisfactorily
n = corrosion/leaching of waste packages.

If, as discussed above, the objective were to now minimize "a" as much as is reasonably possible (in order to minimize "x"), the form of the function "g" might, for example, dictate a comprehensive set of subobjectives consisting of decreasing each of "l" and "n" and increasing "m". These three subobjectives could thus replace the objective of decreasing "a", so that in order to minimize "x" as much as is reasonably possible, "l" and "n" would be decreased and "b", "c", "d", and "m" would be increased; i.e.:

$$x = f(g(l, m, n), b, c, d)$$

Similarly, functions for "b", "c", and "d" might be determined. Then in turn, functions for "l", "m", and "n", as well as for "b", "c", and "d", might be determined, and subobjectives dictated by their form, and so on. In this way, the manner in which each of the repository variables contributes to achieving the repository system performance objectives can be established.

Using the above approach, a hierarchy of performance subobjectives has been developed through several levels of detail (see Figure A.2), based on assumed repository design concepts and performance assessment methodology (see Section 2 - Main Text); should these premises change, this hierarchy may change, especially at the more detailed level.

The performance subobjectives at the most detailed level in the identified hierarchy (Figure A.2) can be further broken down eventually to objectives related solely to either site screening/selection or repository design/construction/operation. As the complete development of this hierarchy of performance subobjectives is outside the scope of this study, only those performance subobjectives which are perceived to be significantly related to backfill have been further investigated.

In this Appendix A, the following performance subobjectives (Figure A.2) have thus been further broken down:

1.3.2 (see Figure A.3)
1.3.3 (see Figure A.4)
1.3.4 (see Figure A.5)
1.4.1 (see Figure A.6)
1.4.2 (see Figure A.7)
1.4.3 (see Figure A.8)

1.4.4 (see Figure A.9)
2.1.2 (see Figure A.10)
2.1.3 (see Figure A.11)
2.2.1 (see Figure A.12)
2.2.2 (see Figure A.13)
2.3.1 (see Figure A.14)
2.3.2 (see Figure A.15).

In the breakdown of these performance subobjectives, a subordinate performance subobjective may be reached which is common to many. Rather than repeating the further breakdown of these common performance subobjectives, the breakdown has been referenced and illustrated once (see Figures A.16 to A.70). Hence, in each case, the performance subobjectives have been broken down to common performance subobjectives (which are referenced and further broken down elsewhere) or subobjectives unrelated to backfill (which are not further investigated) or backfill design objectives (which are culmination points). If all performance subobjectives had been broken down completely, then comprehensive sets of objectives related solely to either site screening/selection or repository design/ construction/operation (i.e., the repository variables) would have been identified; backfill design objectives simply constitute a subset of the repository design/construction/operation objectives. A code has been used to identify each common performance subobjective, which indicates the scale of concern (room scale or waste package scale) and the time period of concern (during the retrieval period, post decommissioning to resaturation, or post resaturation). A similar code has been used to identify each backfill design objective. This code indicates the subject of concern (schedule, procedures, mechanical characteristics, thermal characteristics, hydrologic characteristics, or geochemical characteristics), the scale of concern (room scale, waste package scale, or both), and the period of concern (during retrieval period, post decommissioning to resaturation, or post resaturation).

An annotated hierarchy of repository performance subobjectives and backfill design objectives to the two summary repository system summary performance objectives has been developed (see Table A.1). Hence, each occurrence of a backfill design objective has been explicitly derived from, and thus can be related to, the two summary repository system performance objectives. However, the breakdown of the referenced common performance subobjective down to backfill design objectives has simply been summarized, as this breakdown sometimes proceeds through numerous levels and in some cases loops.

The backfill design objectives have subsequently been summarized with respect to the three areas of concern (i.e., subject, scale, and period), and the specific sovereign performance subobjective(s) (Figures A.3 to A.70) for each has been indicated (see Table A.2) for reference purposes.

It should be noted that the complete hierarchy of performance subobjectives, culminating in backfill design objectives, is relatively complex (Figures A.2 to A.70). In fact, not only are specific common performance subobjectives referenced at various levels in this hierarchy, but in some cases a loop is formed, e.g., x is subordinate to y which may eventually be subordinate to x again. Also, it is apparent that specific backfill design objectives are subordinate to different performance subobjectives, i.e., for different reasons (Tables A.1 and A.2). It is also apparent that some backfill design objectives are contradictory, i.e., maximize increase (or minimize decrease) for one reason and maximize decrease (or minimize increase) for another reason. As suggested, some backfill design objectives might be considered as active (e.g., maximizing generally connotes active involvement), whereas others might be considered as passive (e.g., minimizing generally connotes passive involvement).

It must be emphasized that the hierarchy of performance subobjectives, culminating in backfill design objectives, has been developed based on assumed repository design concepts and performance assessment methodology (see Section 2.0 - Main Text). Should these assumptions change, this hierarchy may change, especially at the more detailed level. Hence, the identified backfill design objectives should be considered valid only for the given repository design concepts and performance assessment methodology. Areas of technical disagreement regarding backfill design objectives can be identified using this framework and resolved, e.g., by adding, deleting, or modifying specific performance subobjectives.

Hence, a comprehensive set of backfill design objectives has been identified (Table A.2). The relationship of each backfill design objective to the two summary repository system performance objectives has been clearly established within the context of backfill as an integral component of the repository system (Table A.1). These backfill design objectives will form the basis for backfill design, and for the evaluation of the implementation and verification of that design, as will be used in this study. The significance of each backfill design objective, with respect to achieving the repository system performance objectives, is discussed in Appendix B.

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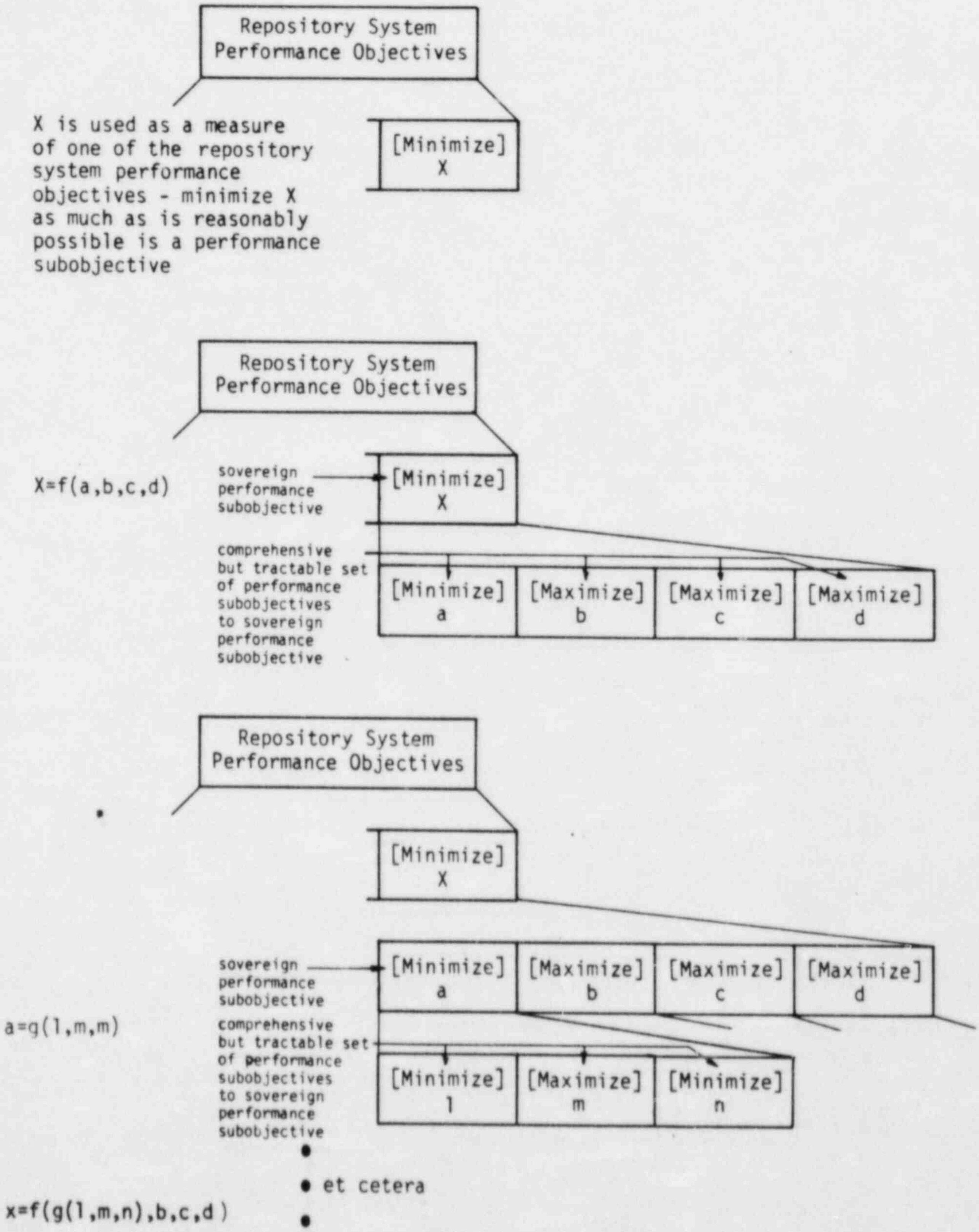
DEVELOPMENT OF A HIERARCHY OF PERFORMANCE SUBOBJECTIVES (EXAMPLE)

Figure A.1

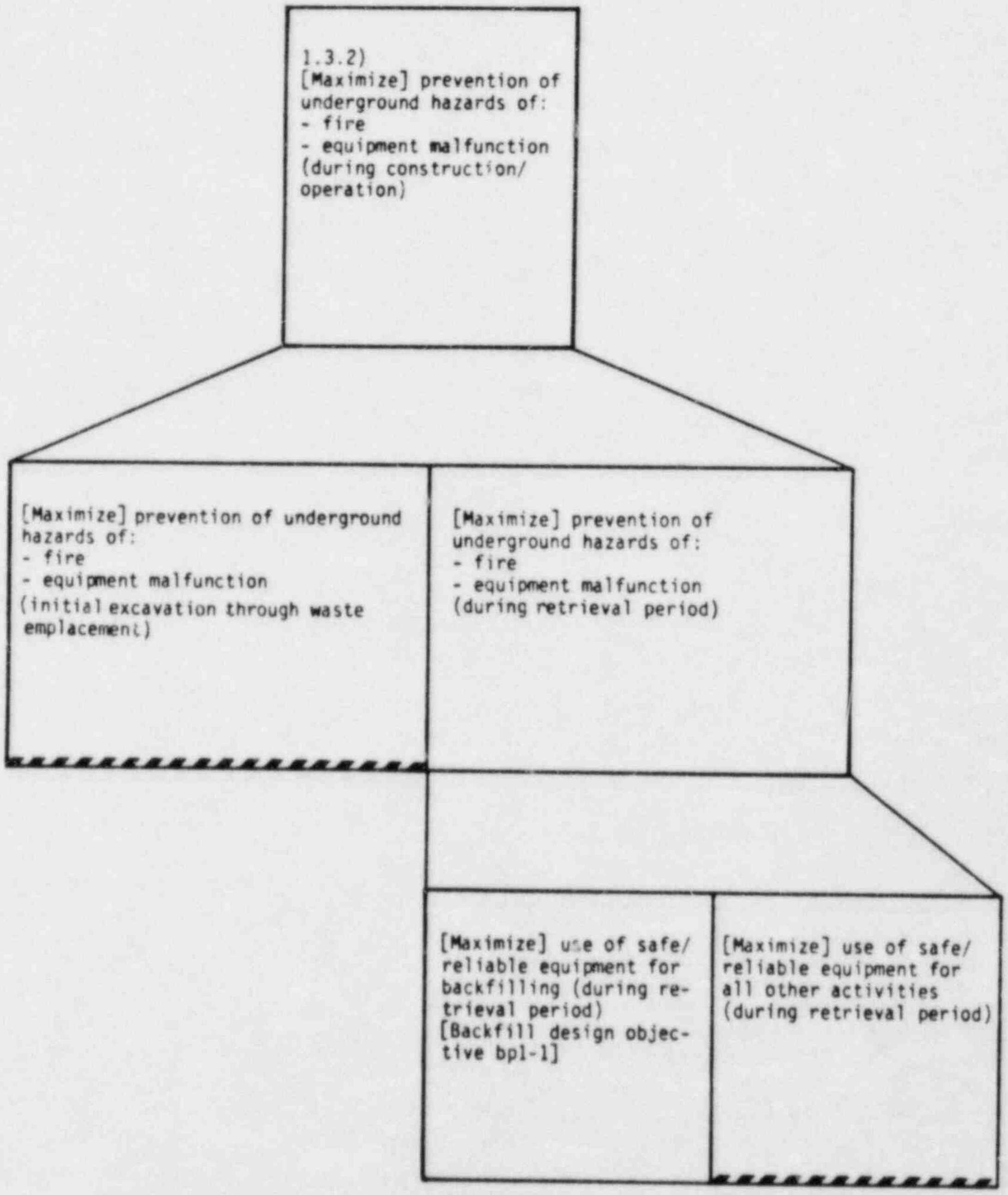


X is used as a measure of one of the repository system performance objectives - minimize X as much as is reasonably possible is a performance subobjective

DEVELOPMENT OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES TO PERFORMANCE SUBOBJECTIVE 1.3.2

Figure A.3

(Refer to Figure A.2)



1.3.2)
[Maximize] prevention of underground hazards of:
- fire
- equipment malfunction

(during construction/operation)

[Maximize] prevention of underground hazards of:
- fire
- equipment malfunction

(initial excavation through waste emplacement)

[Maximize] prevention of underground hazards of:
- fire
- equipment malfunction

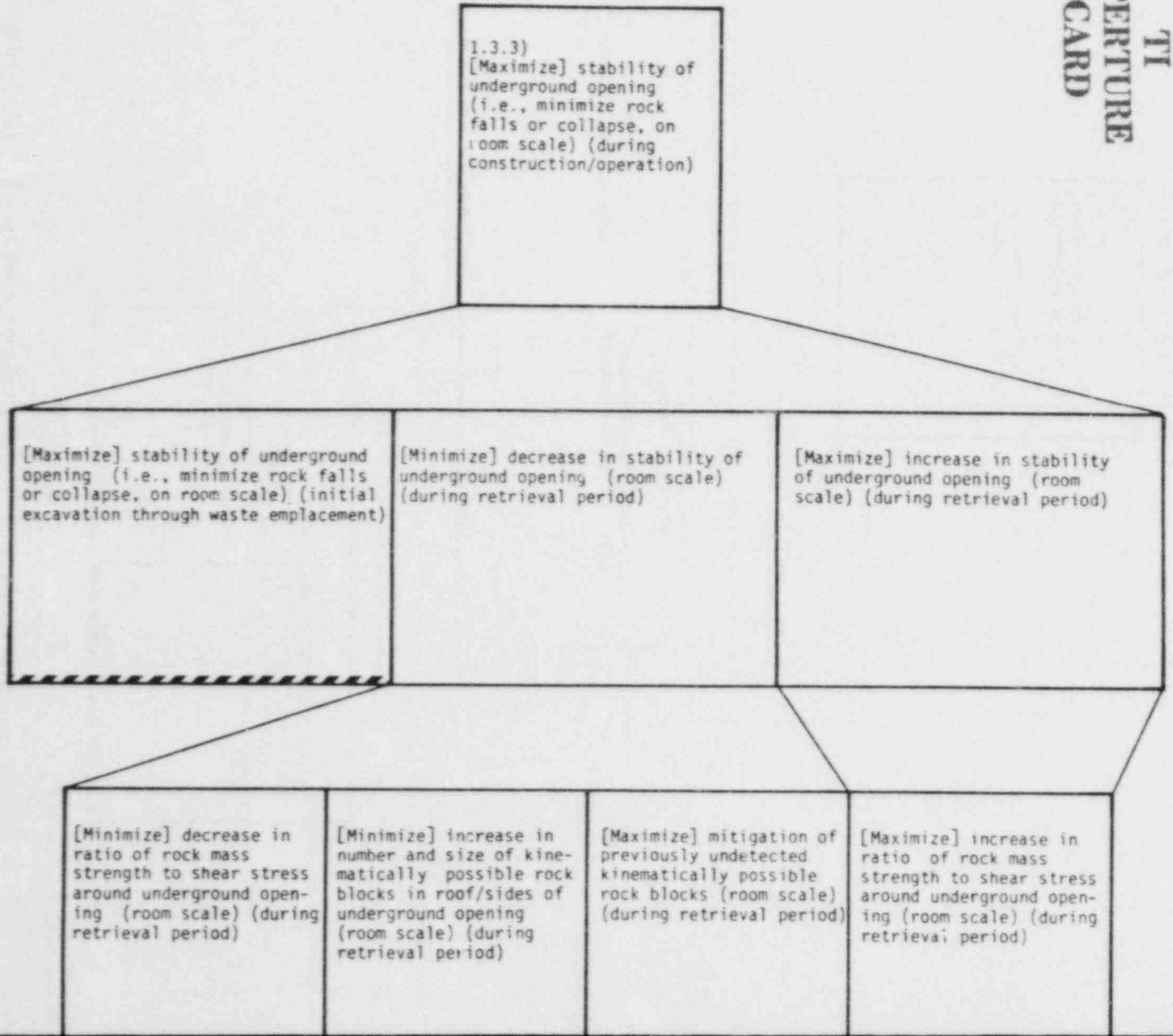
(during retrieval period)

[Maximize] use of safe/reliable equipment for backfilling (during retrieval period)
[Backfill design objective bpl-1]

[Maximize] use of safe/reliable equipment for all other activities (during retrieval period)

Note: Refer to Figure A.2 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and futher broken down elsewhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▨▨▨▨.

(Refer to Figure A.2)



1.3.3) [Maximize] stability of underground opening (i.e., minimize rock falls or collapse, on room scale) (during construction/operation)

[Maximize] stability of underground opening (i.e., minimize rock falls or collapse, on room scale) (initial excavation through waste emplacement)

[Minimize] decrease in stability of underground opening (room scale) (during retrieval period)

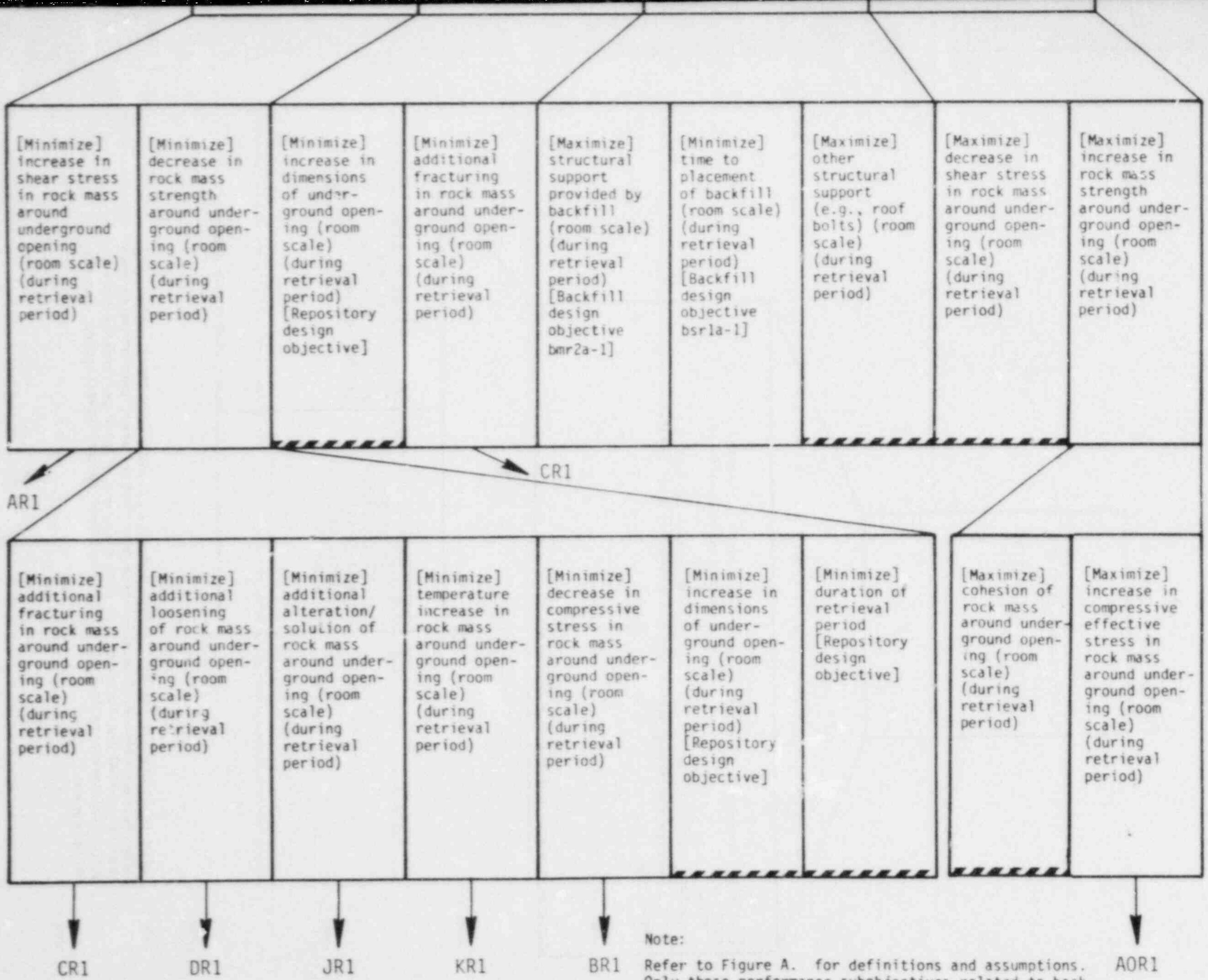
[Maximize] increase in stability of underground opening (room scale) (during retrieval period)

[Minimize] decrease in ratio of rock mass strength to shear stress around underground opening (room scale) (during retrieval period)

[Minimize] increase in number and size of kinematically possible rock blocks in roof/sides of underground opening (room scale) (during retrieval period)

[Maximize] mitigation of previously undetected kinematically possible rock blocks (room scale) (during retrieval period)

[Maximize] increase in ratio of rock mass strength to shear stress around underground opening (room scale) (during retrieval period)

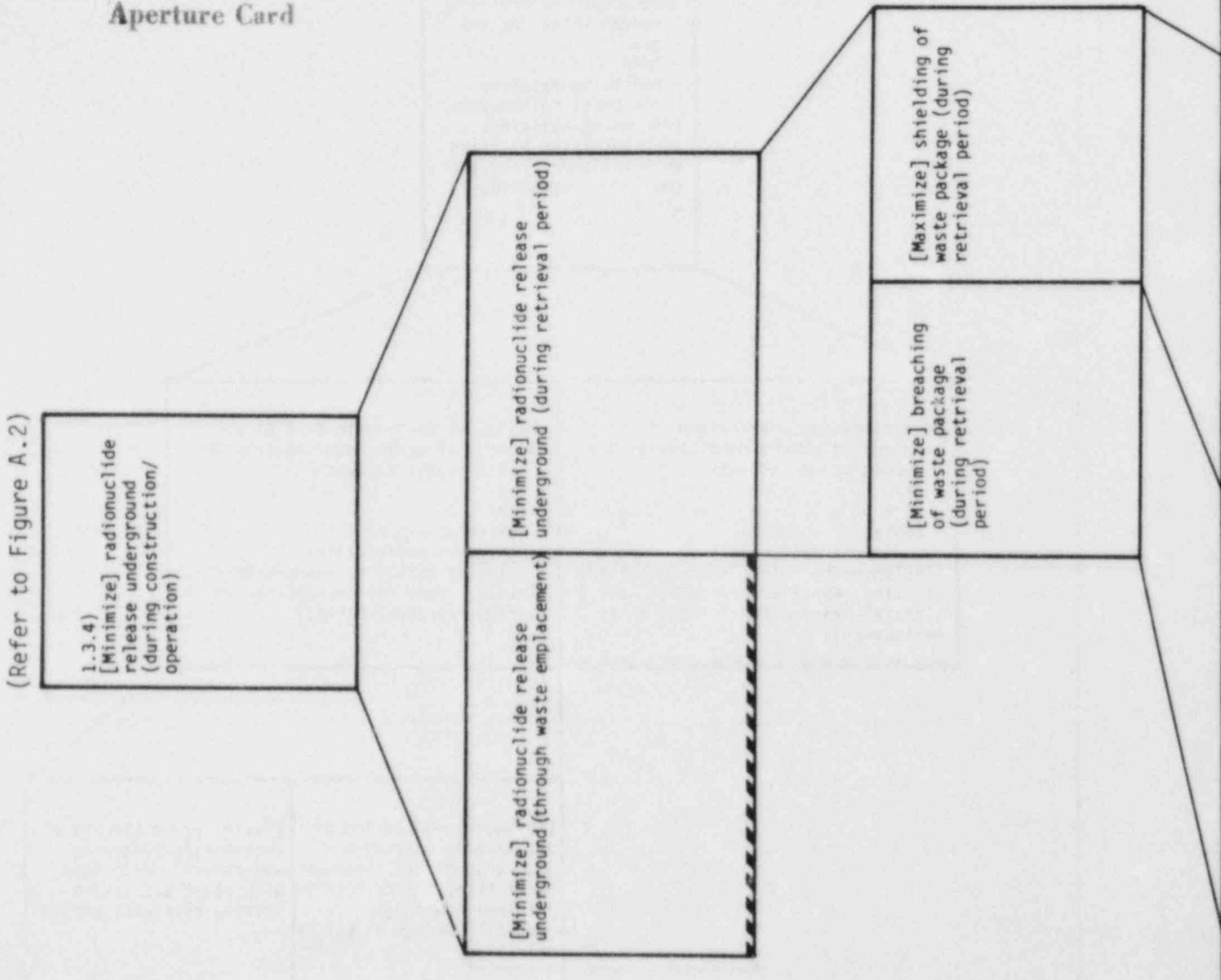


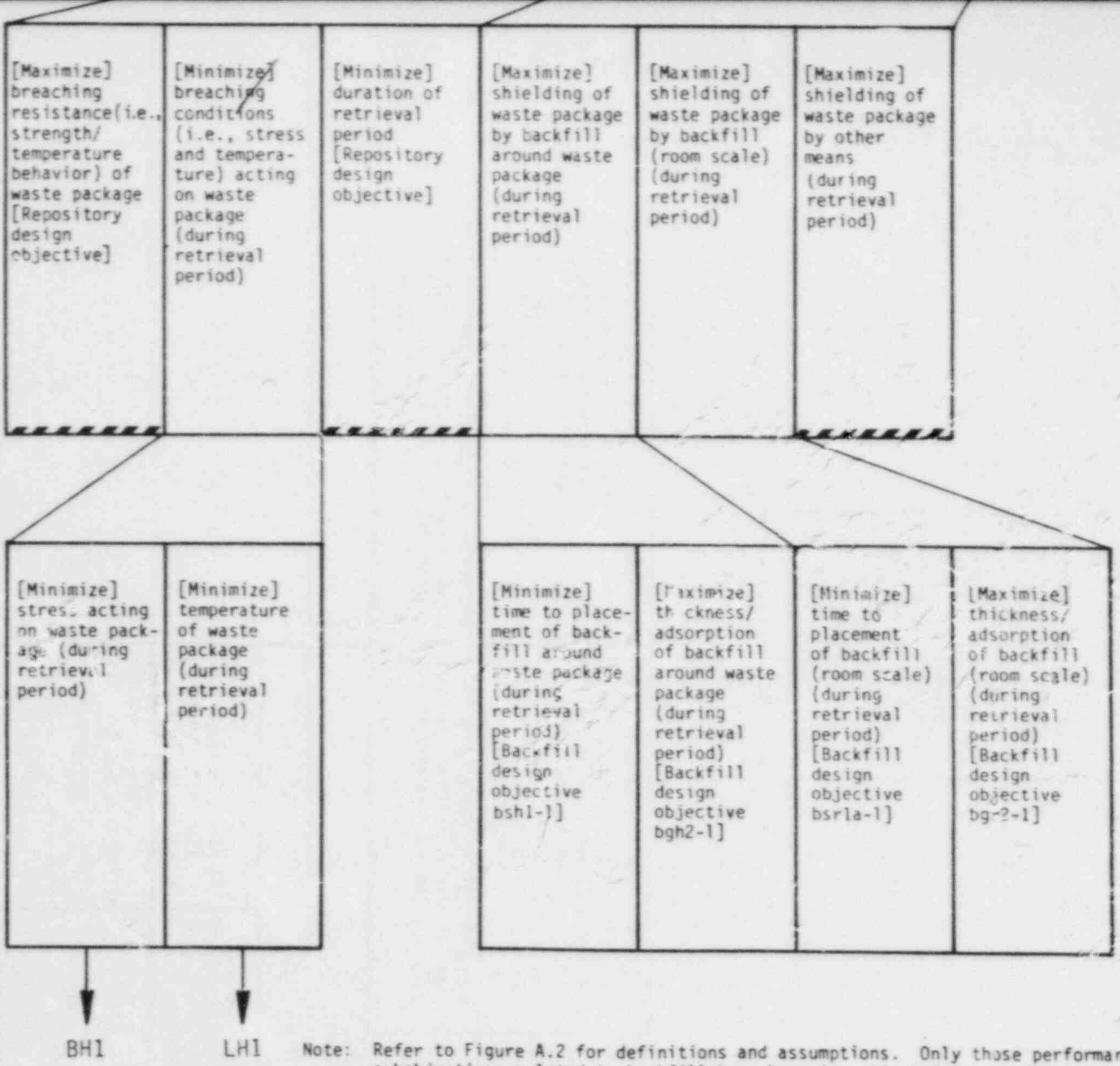
Note:

Refer to Figure A. for definitions and assumptions. Only those performance subobjectives related to back fill have been investigated, some of which have been referenced and further broken down elsewhere. Those performance Subobjectives unrelated to backfill have not been further investigated, and are marked ▨.

Figure A.4

DEVELOPMENT OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES TO PERFORMANCE SUBOBJECTIVE 1.3.3


(Refer to Figure A.2)
1.3.4)
[Minimize] radionuclide release underground (during construction/ operation)
[Minimize] radionuclide release underground (during retrieval period)
[Minimize] radionuclide release underground (through waste emplacement)
[Maximize] shielding of waste package (during retrieval period)
[Minimize] breaching of waste package (during retrieval period)



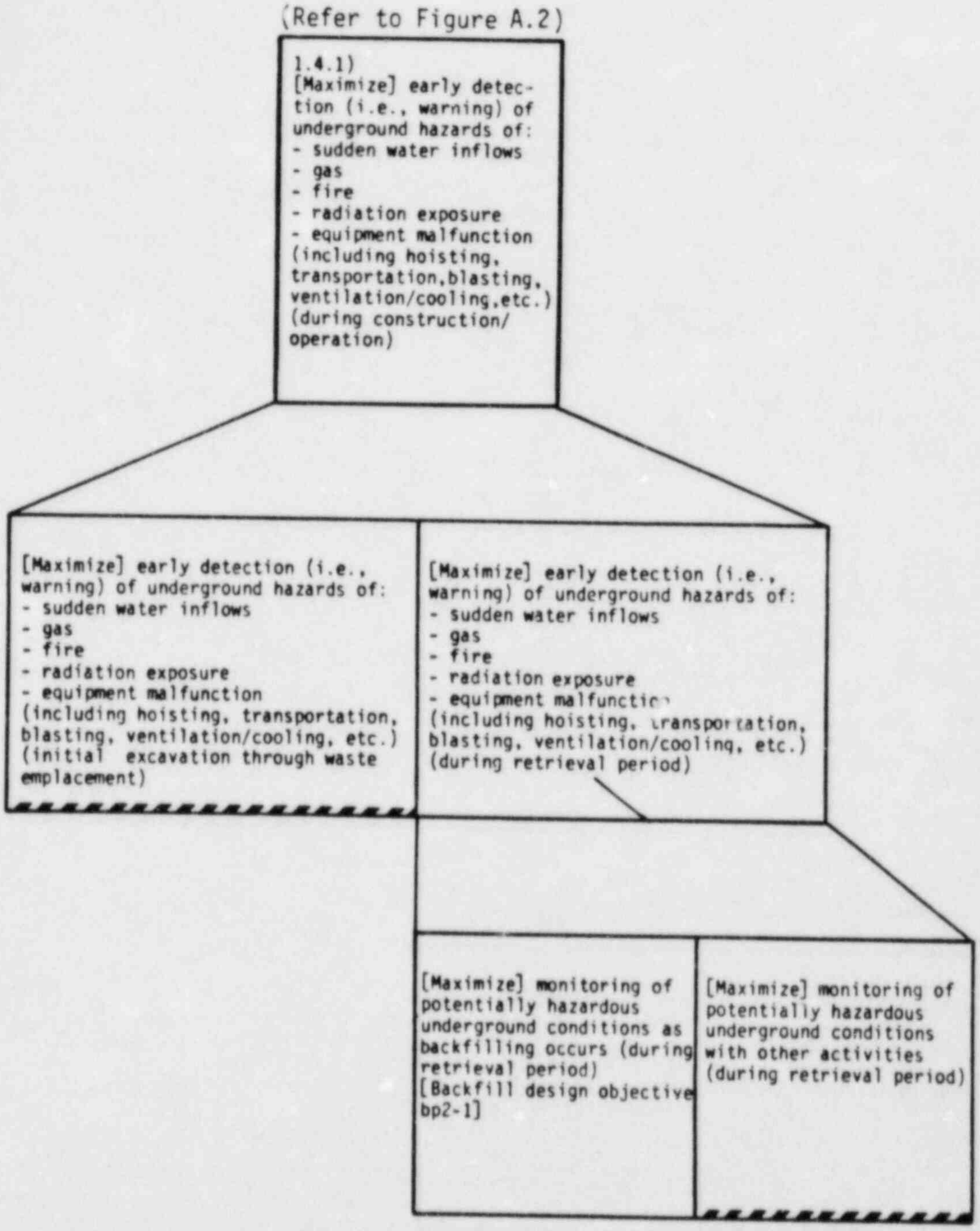
Note: Refer to Figure A.2 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down elsewhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▨▨▨▨.

Figure A.5

DEVELOPMENT OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES TO PERFORMANCE SUBOBJECTIVE 1.3.4

DEVELOPMENT OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES TO PERFORMANCE SUBOBJECTIVE 1.4.1

Figure A. 6



Note: Refer to Figure A.2 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down elsewhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▰▰▰▰.

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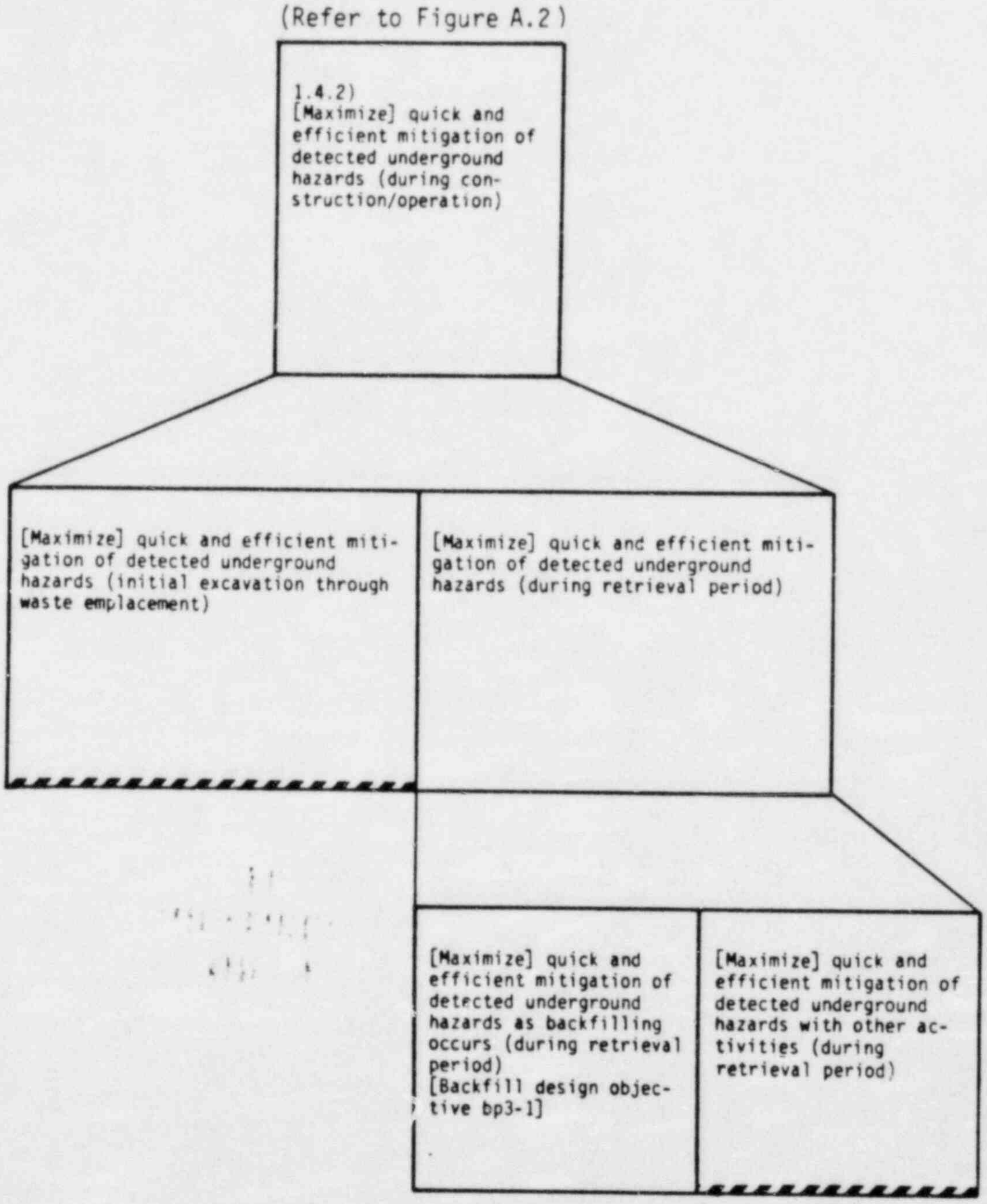
DEVELOPMENT OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES TO PERFORMANCE SUBOBJECTIVE 1.4.2

Figure A.7



Note: Refer to Figure A.2 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down elsewhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▨▨▨.

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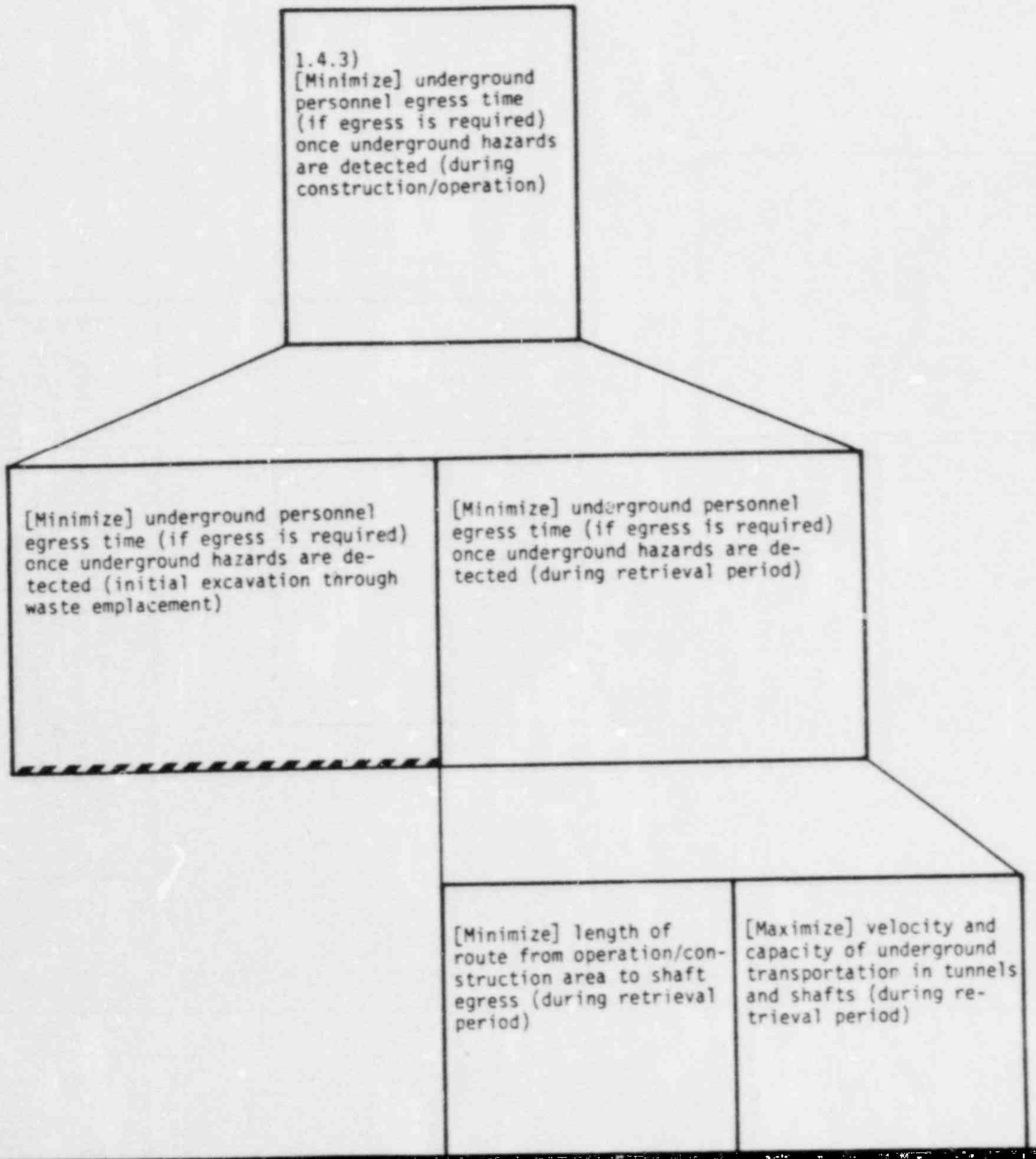
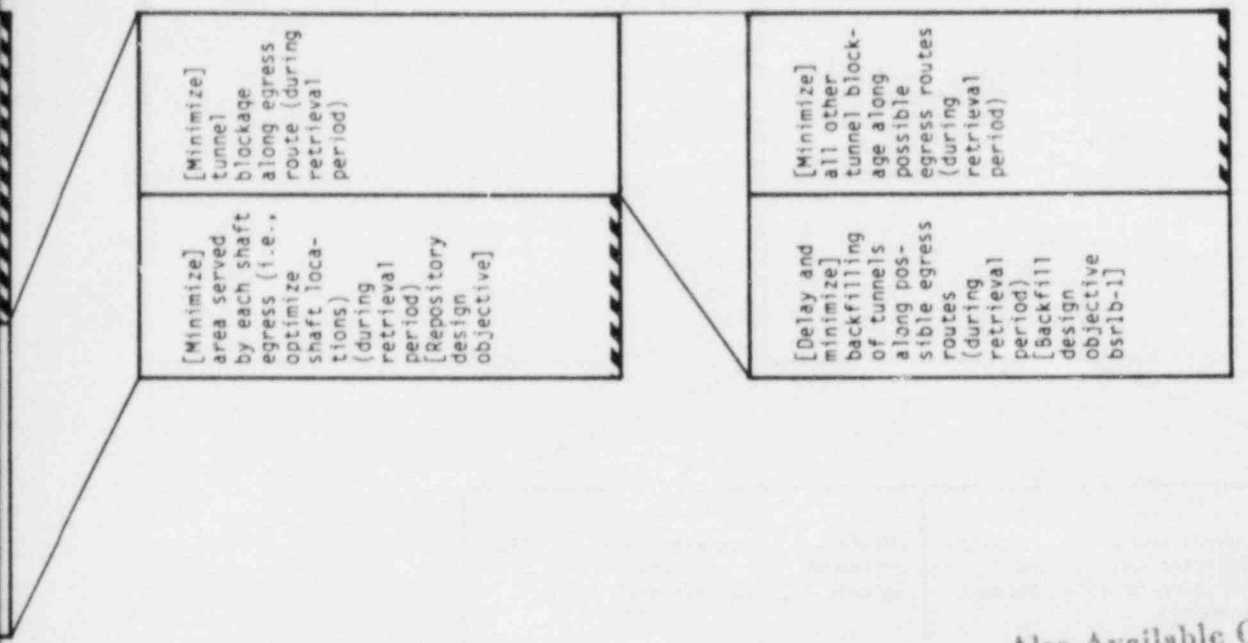
(Refer to Figure A.2)



DEVELOPMENT OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES TO PERFORMANCE SUBOBJECTIVE 1.4.3

Figure A.8



Note: Refer to Figure A.2 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down elsewhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▰▰▰▰.

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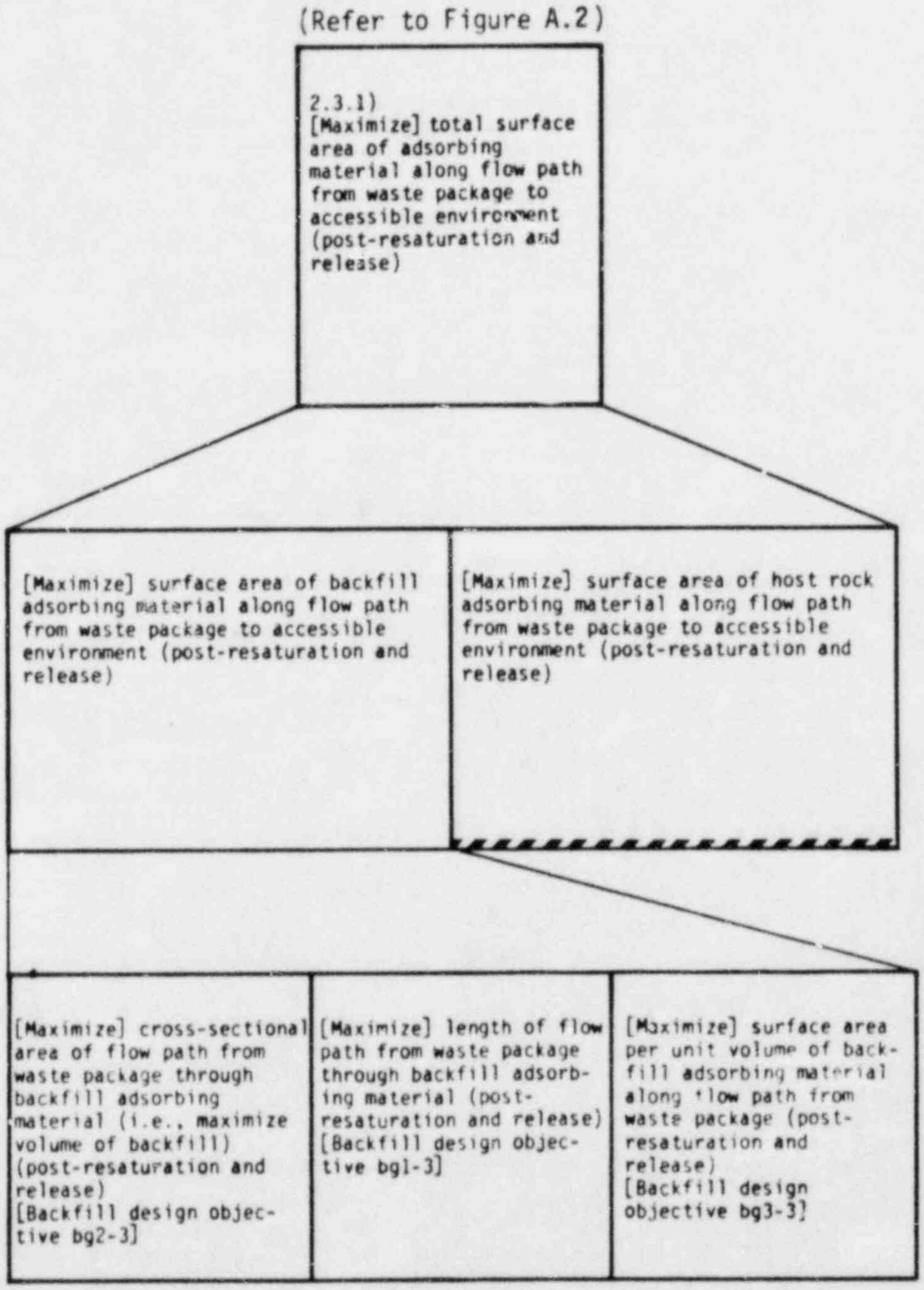
DEVELOPMENT OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES TO PERFORMANCE SUBOBJECTIVE 2.3.1

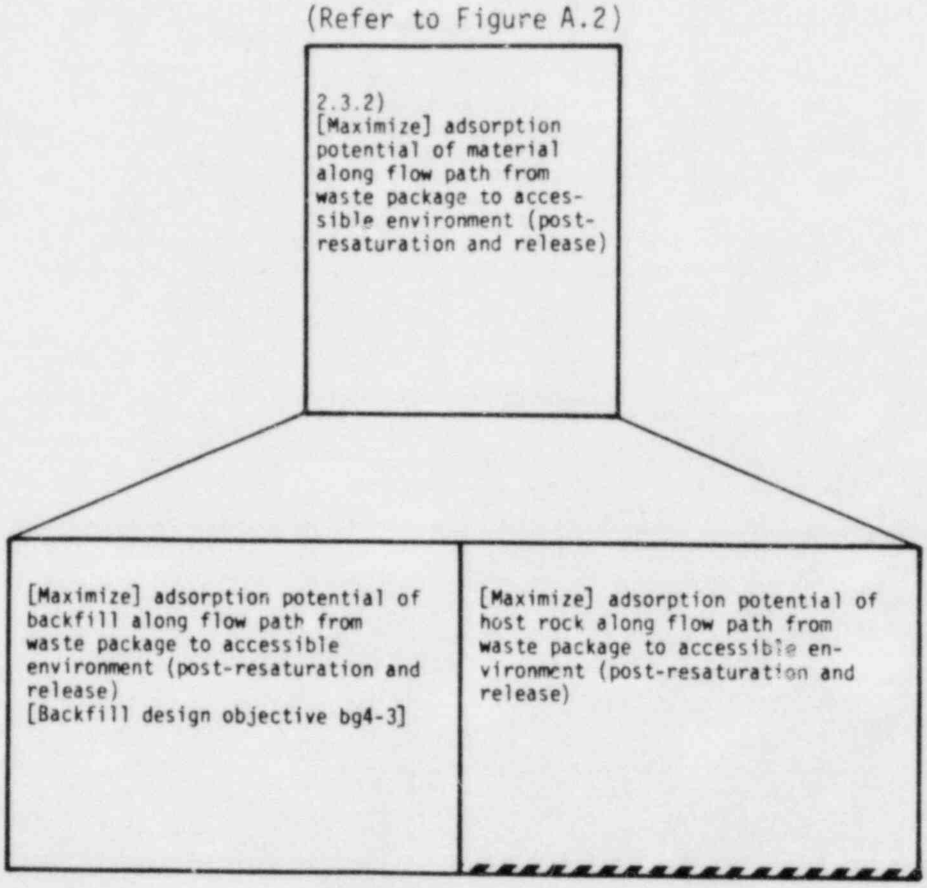
Figure A.14



Note: Refer to Figure A.2 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down elsewhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▰▰▰.

DEVELOPMENT OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES TO PERFORMANCE SUBOBJECTIVE 2.3.2

Figure A.15



(Refer to Figure A.2)

2.3.2)
[Maximize] adsorption potential of material along flow path from waste package to accessible environment (post-resaturation and release)

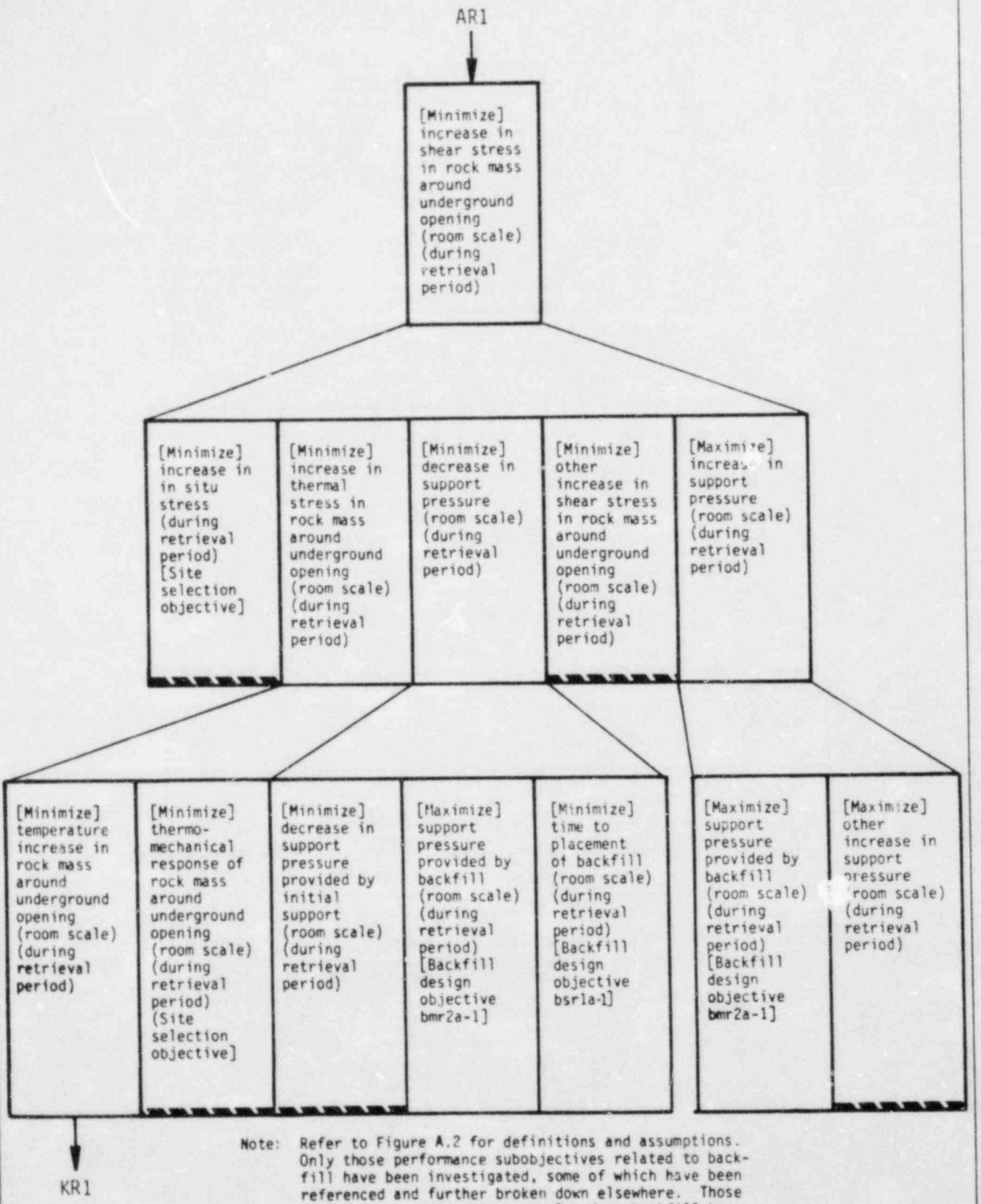
[Maximize] adsorption potential of backfill along flow path from waste package to accessible environment (post-resaturation and release)
[Backfill design objective bg4-3]

[Maximize] adsorption potential of host rock along flow path from waste package to accessible environment (post-resaturation and release)

Note: Refer to Figure A.2 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down elsewhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▨.

DEVELOPMENT OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES TO REFERENCED COMMON PERFORMANCE SUBOBJECTIVE AR1

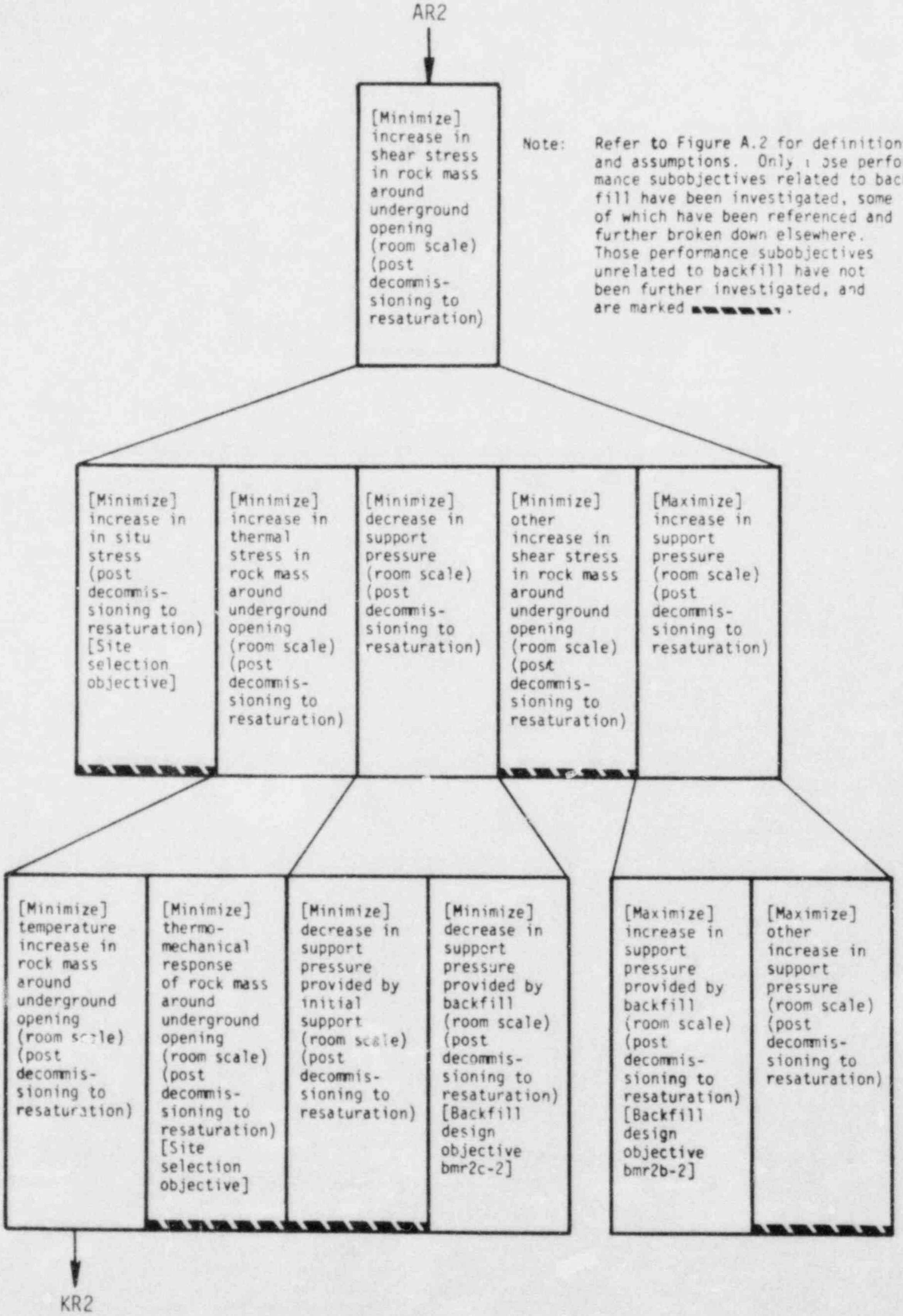
Figure A.16



Note: Refer to Figure A.2 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down elsewhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▬▬▬

DEVELOPMENT OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES TO REFERENCED COMMON PERFORMANCE SUBOBJECTIVE AR2

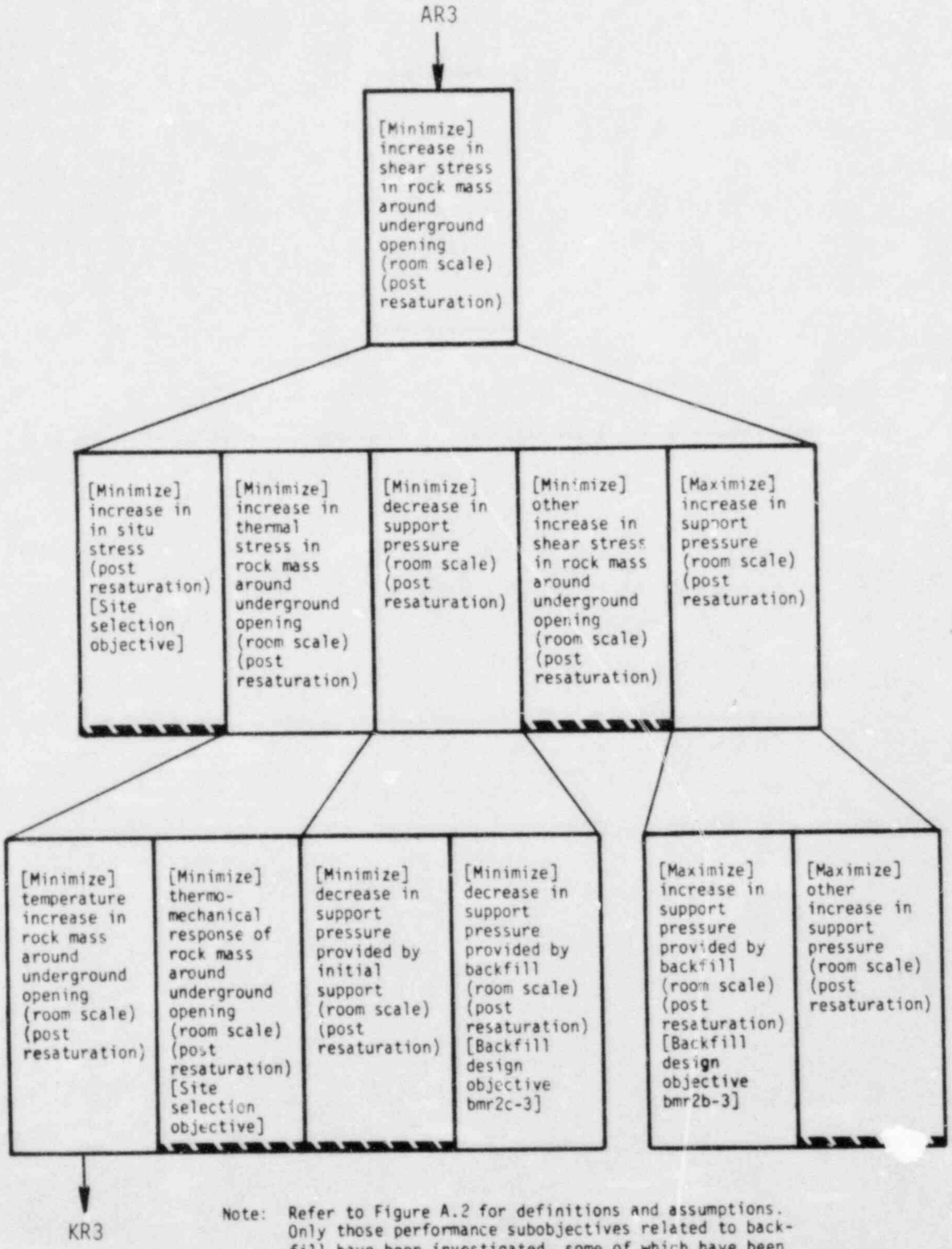
Figure A.17



Note: Refer to Figure A.2 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down elsewhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▨▨▨▨.

Figure A.18

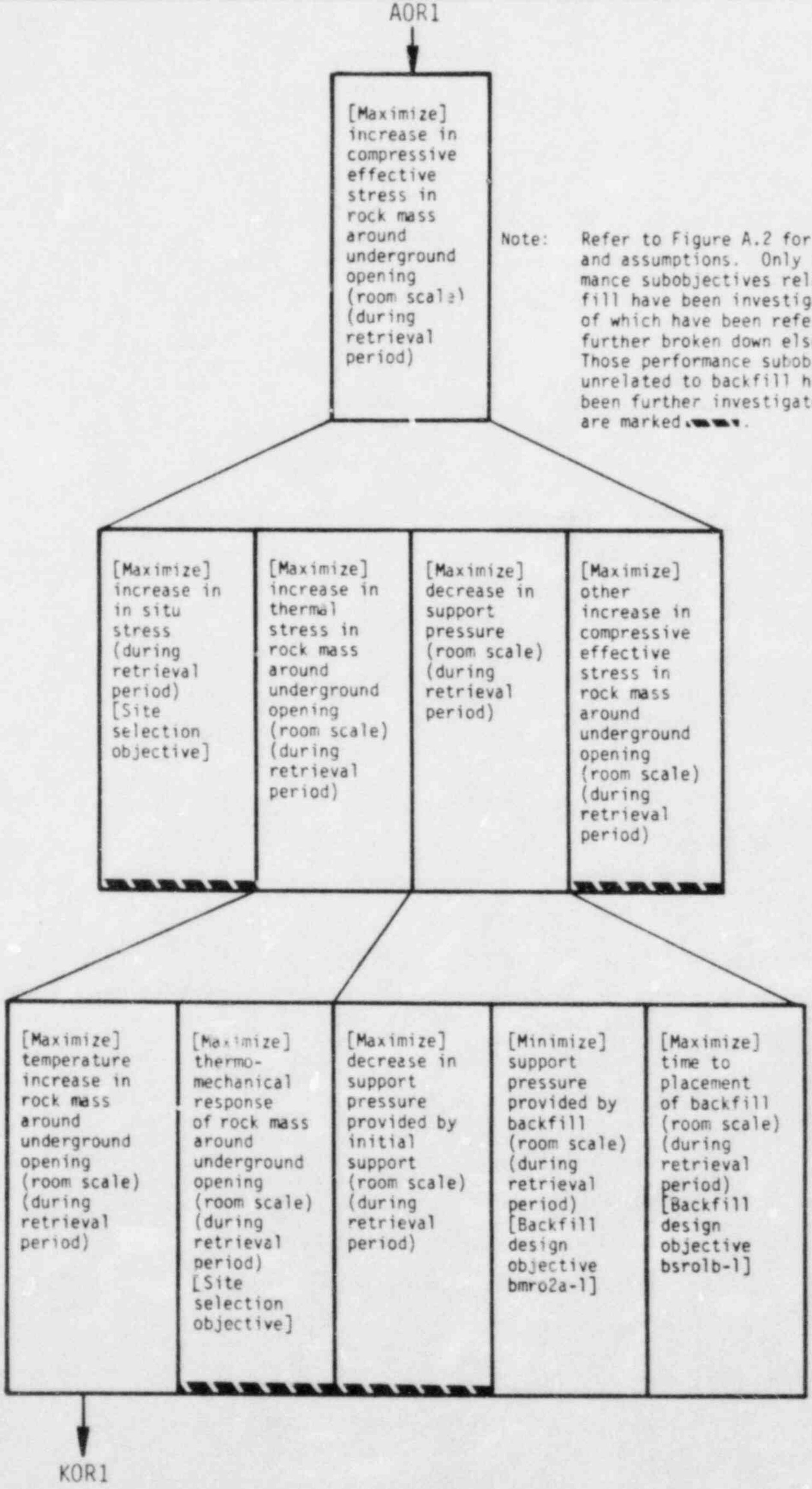
DEVELOPMENT OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES TO REFERENCED COMMON PERFORMANCE SUBOBJECTIVE AR3



Note: Refer to Figure A.2 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down elsewhere. Those performance subobjectives unrelated to backfill have not been futher investigated, and are marked ▨.

DEVELOPMENT OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES TO REFERENCED COMMON PERFORMANCE SUBOBJECTIVE AOR1

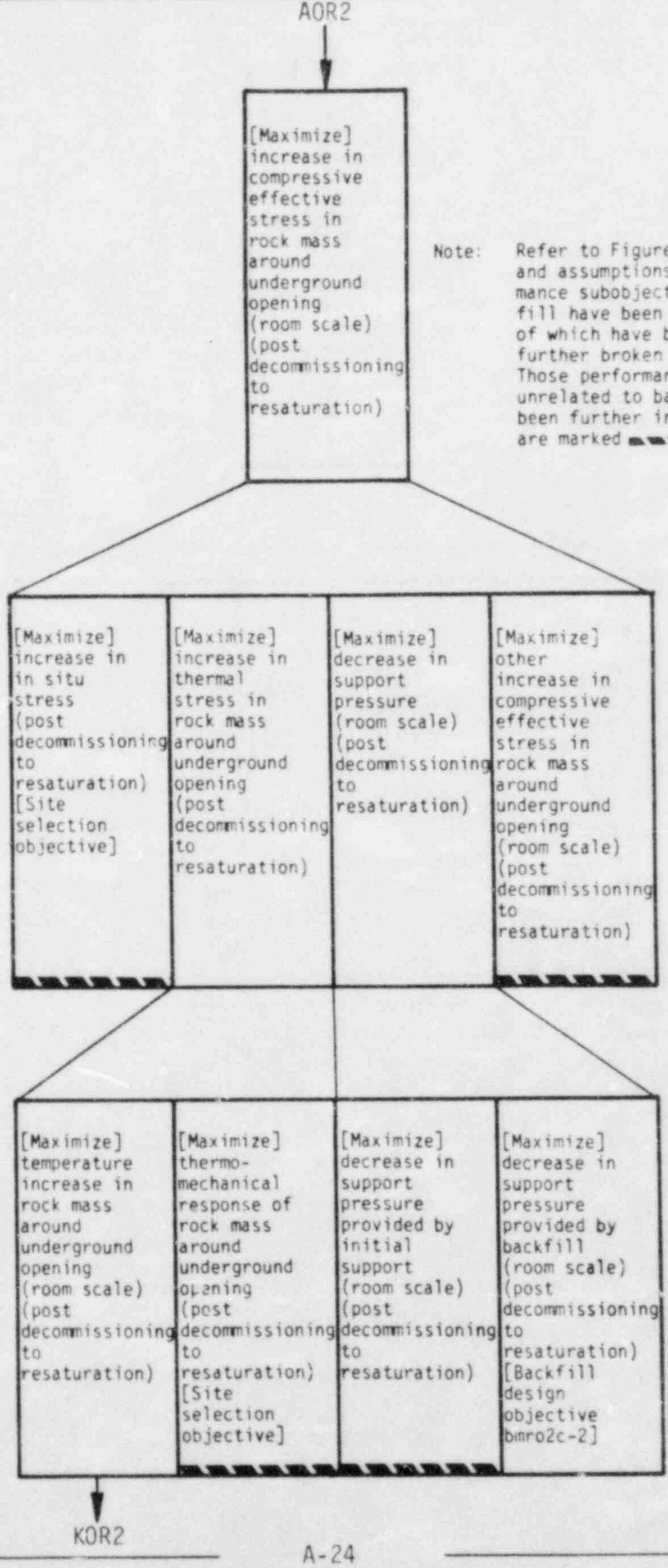
Figure A.19



Note: Refer to Figure A.2 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down elsewhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▨.

DEVELOPMENT OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES TO REFERENCED COMMON PERFORMANCE SUBOBJECTIVE AOR2

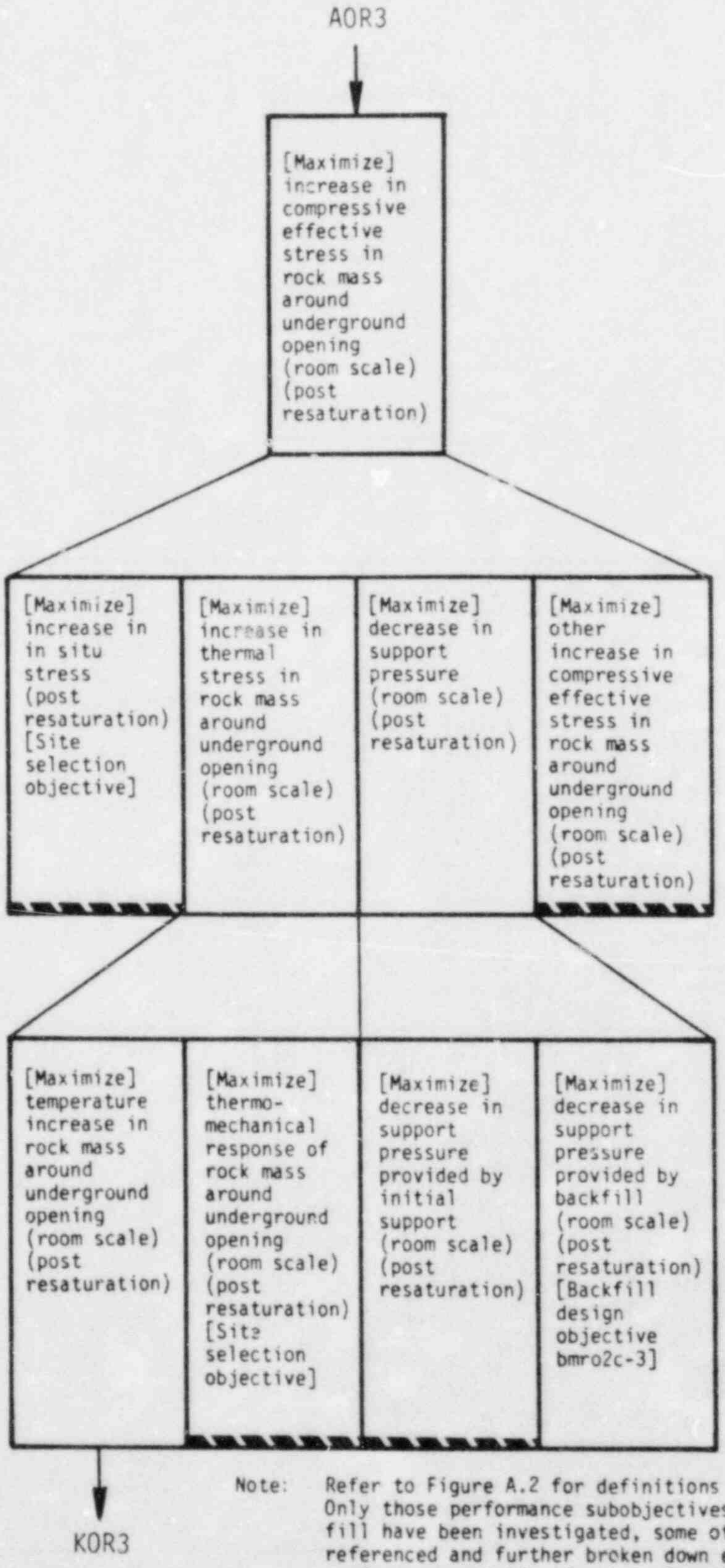
Figure A.20



Note: Refer to Figure A.2 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down elsewhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▬▬▬.

DEVELOPMENT OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES TO REFERENCED COMMON PERFORMANCE SUBOBJECTIVE AOR3

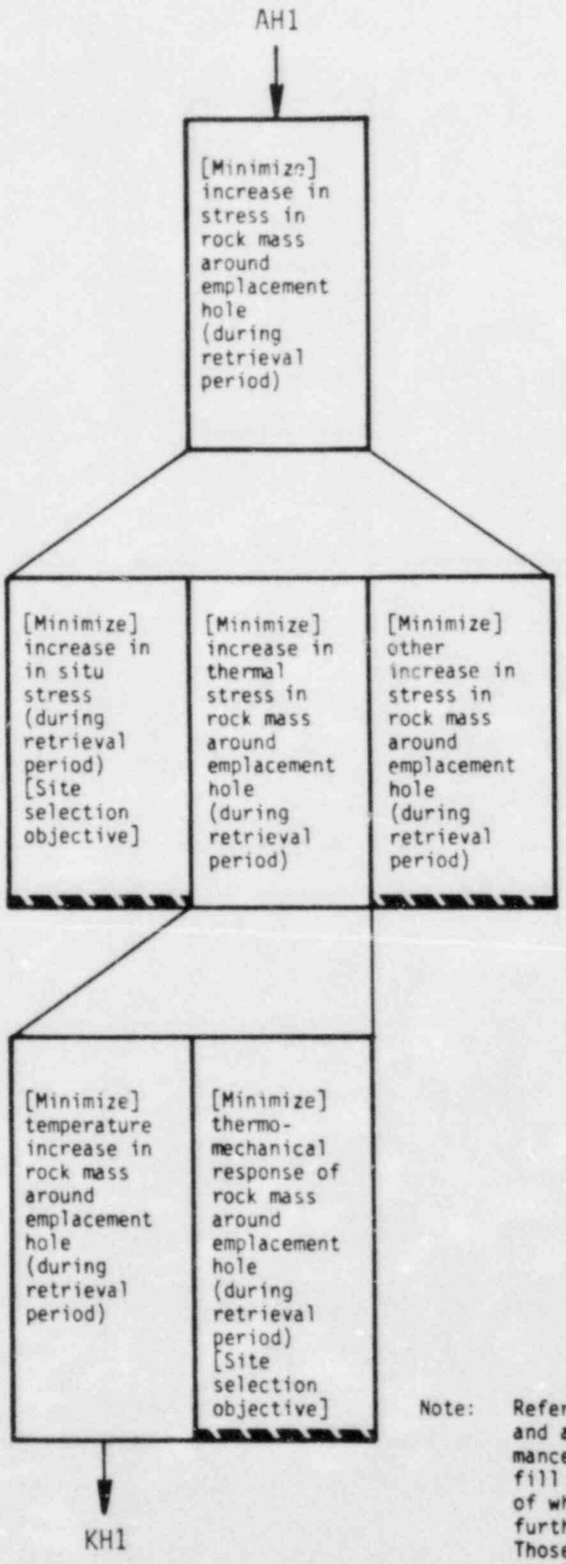
Figure A.21



Note: Refer to Figure A.2 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down elsewhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▬▬▬.

DEVELOPMENT OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES TO REFERENCED COMMON PERFORMANCE SUBOBJECTIVE AH1

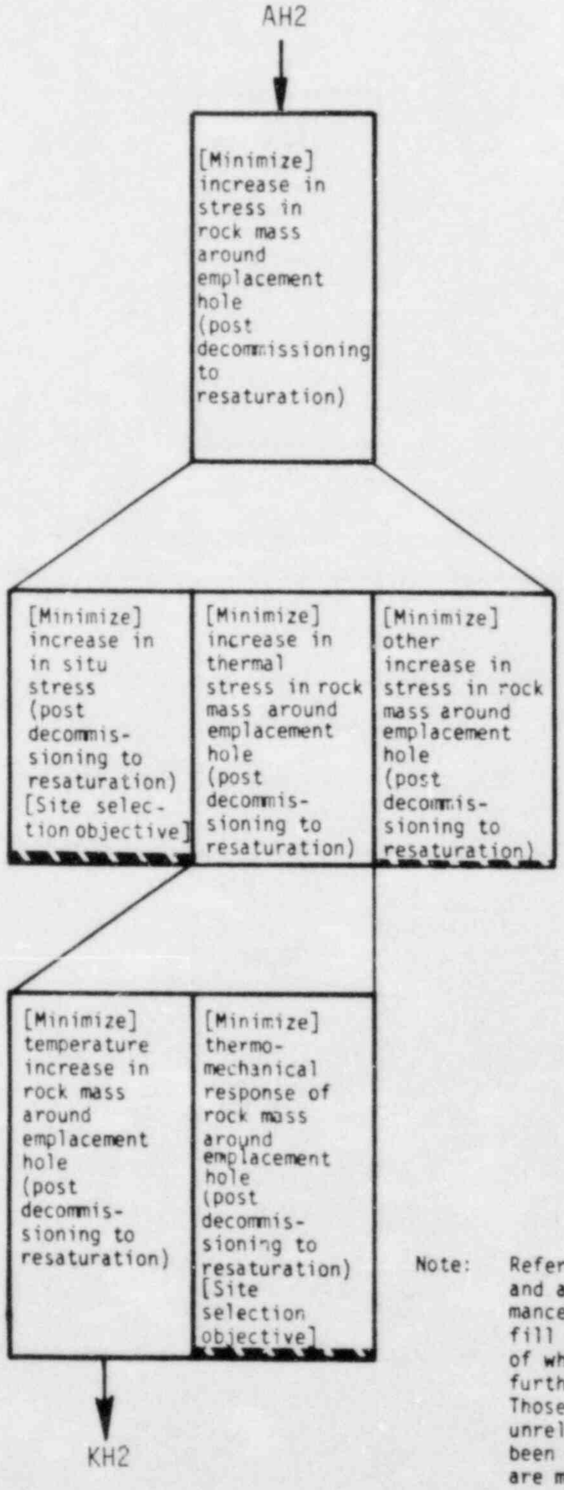
Figure A.22



Note: Refer to Figure A.2 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down elsewhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▬▬▬.

DEVELOPMENT OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES TO REFERENCED COMMON PERFORMANCE SUBOBJECTIVE AH2

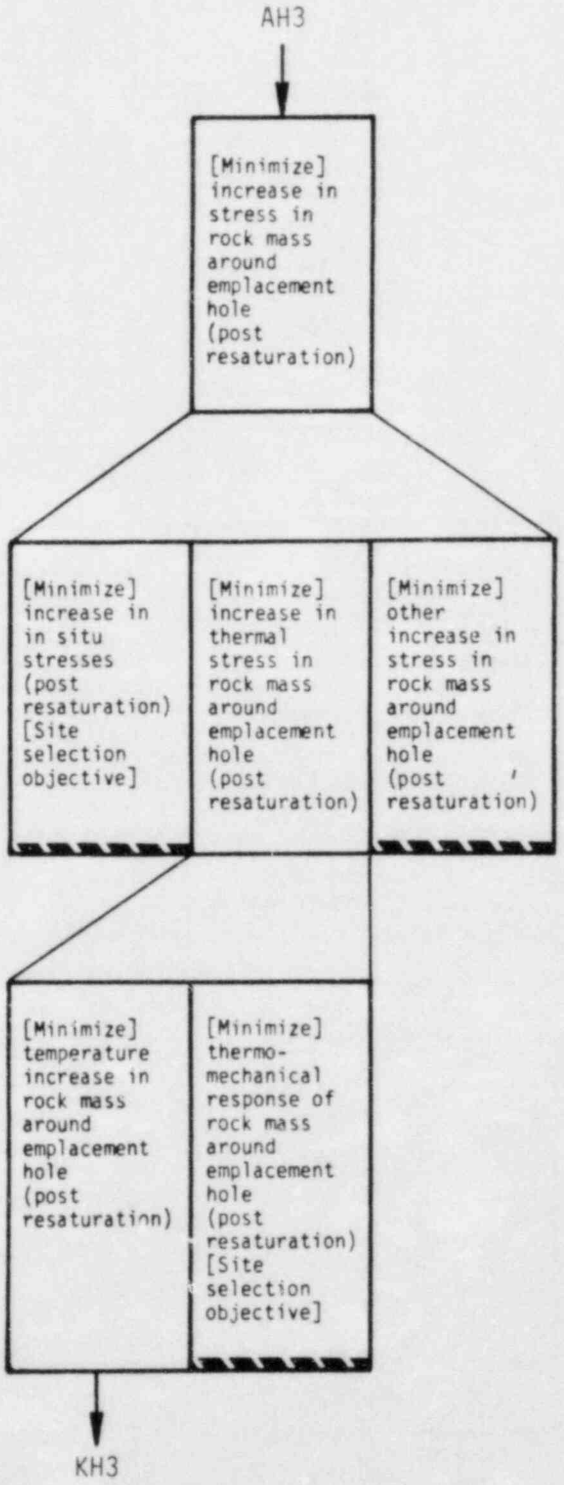
Figure A.23



Note: Refer to Figure A.2 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down elsewhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▬▬▬.

DEVELOPMENT OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES TO REFERENCED COMMON PERFORMANCE SUBOBJECTIVE AH3

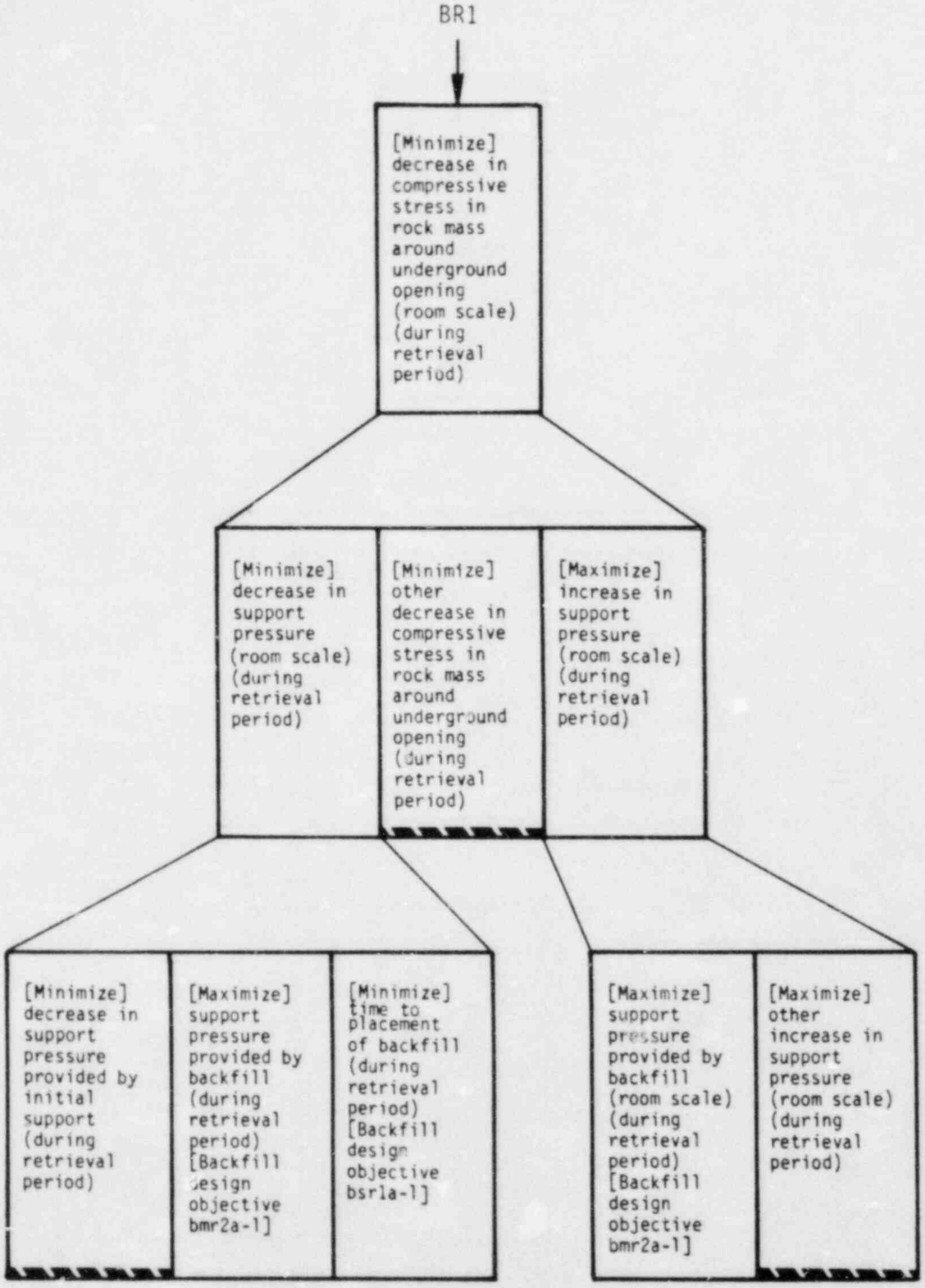
Figure A.24



Note: Refer to Figure A.2 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down elsewhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▀▀▀

DEVELOPMENT OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES TO REFERENCED COMMON PERFORMANCE SUBOBJECTIVE BR1

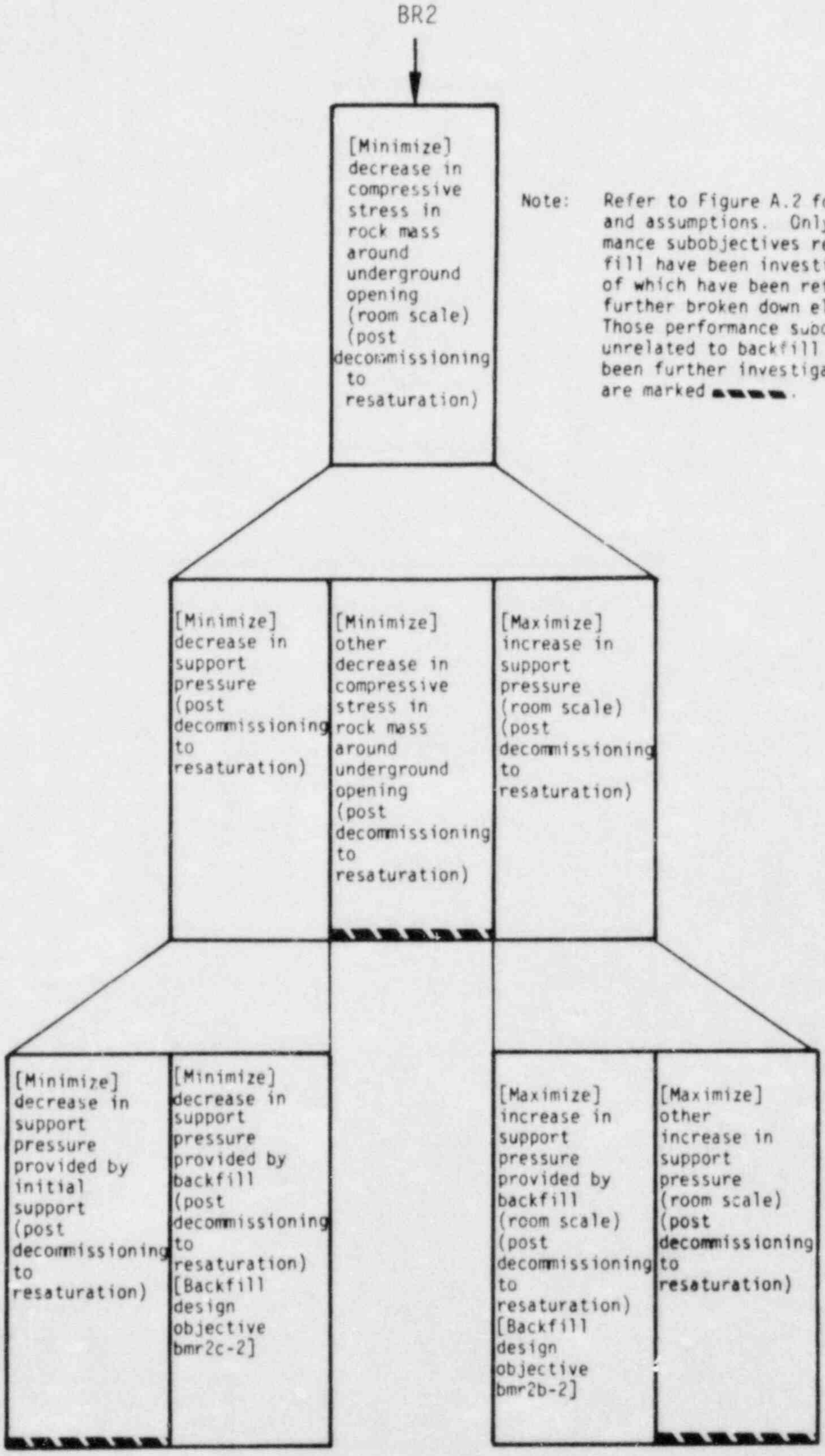
Figure A.25



Note: Refer to Figure A.2 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down elsewhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▀▀▀▀.

DEVELOPMENT OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES TO REFERENCED COMMON PERFORMANCE SUBOBJECTIVE BR2

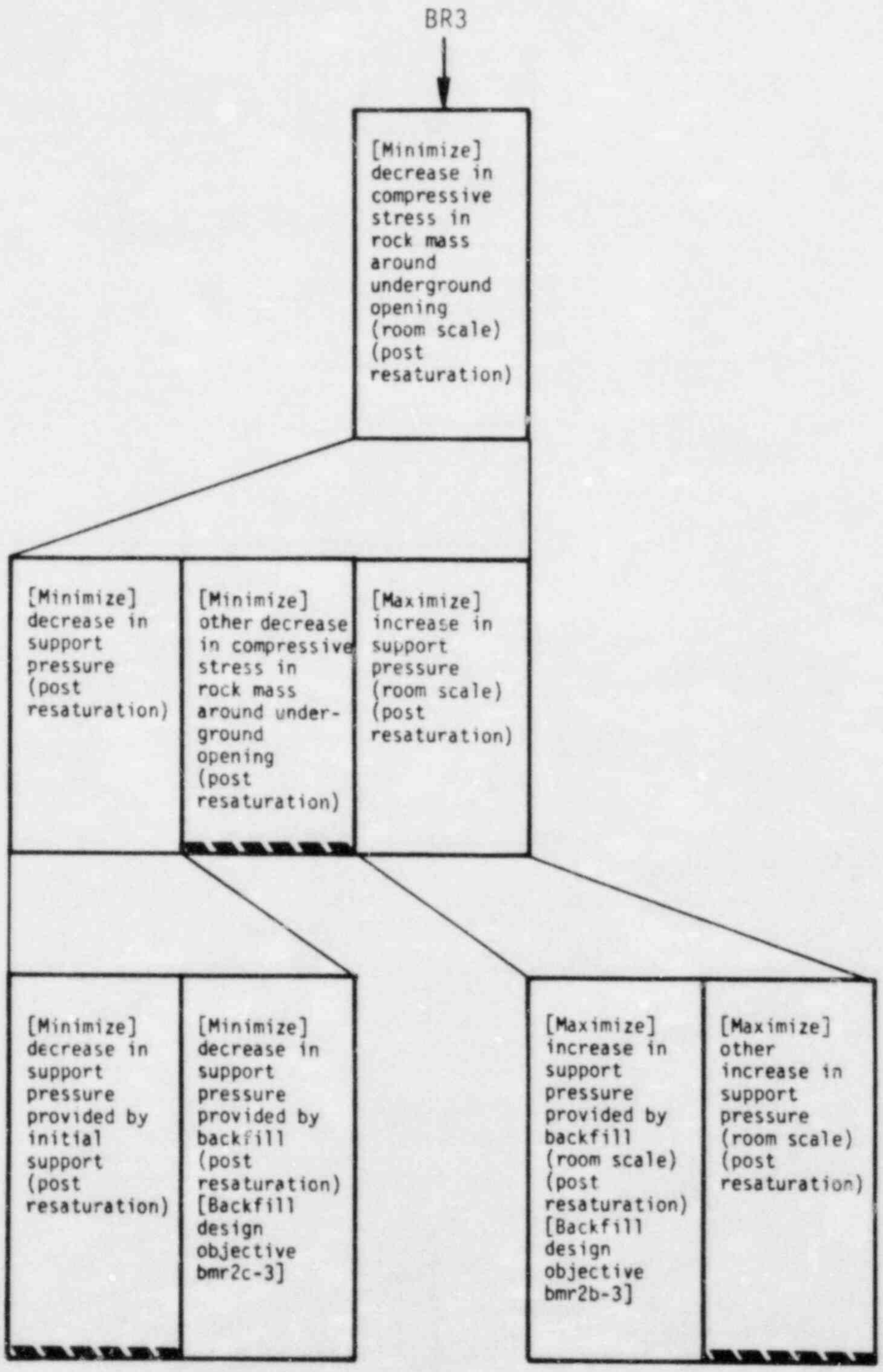
Figure A.26



Note: Refer to Figure A.2 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down elsewhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▬▬▬.

DEVELOPMENT OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES TO REFERENCED COMMON PERFORMANCE SUBOBJECTIVE BR3

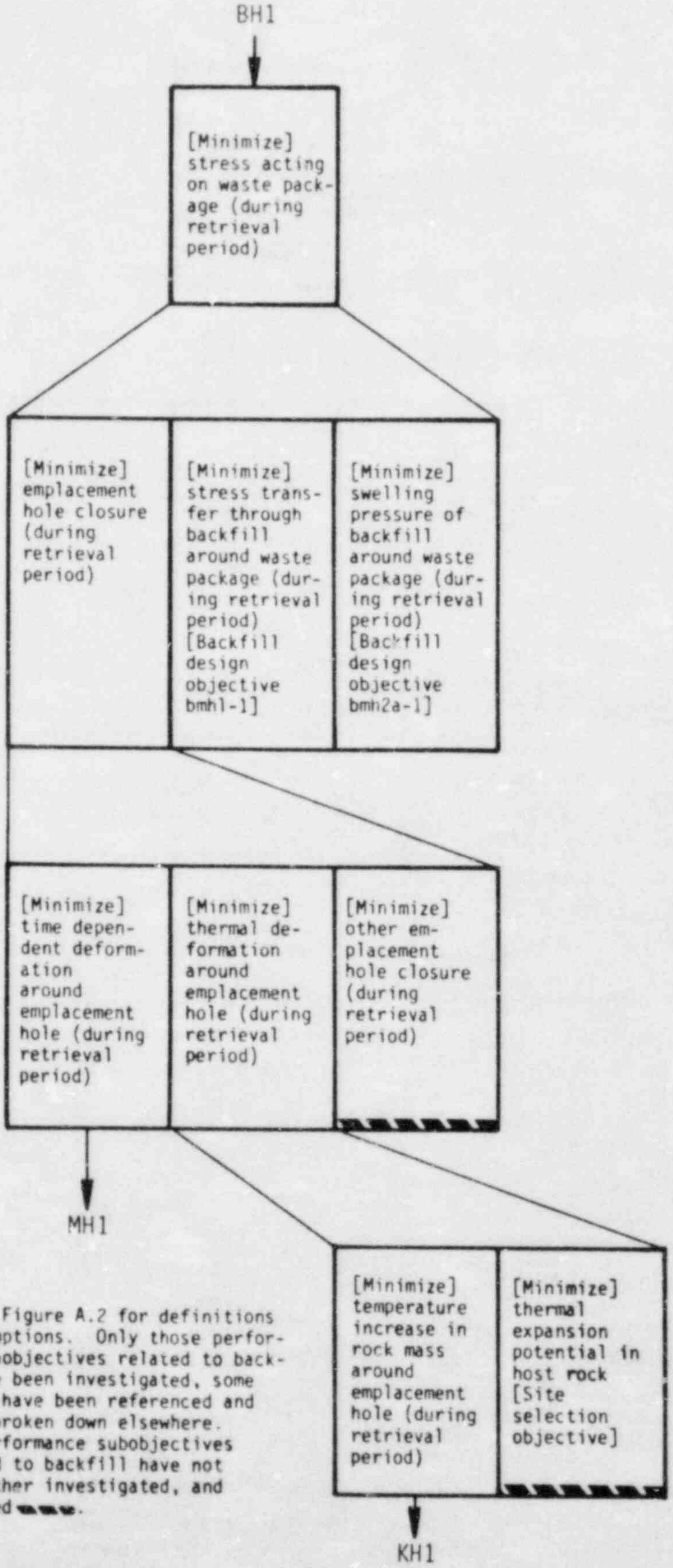
Figure A.27



Note: Refer to Figure A.2 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down elsewhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▬▬.

DEVELOPMENT OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES TO REFERENCED COMMON PERFORMANCE SUBOBJECTIVE BH1

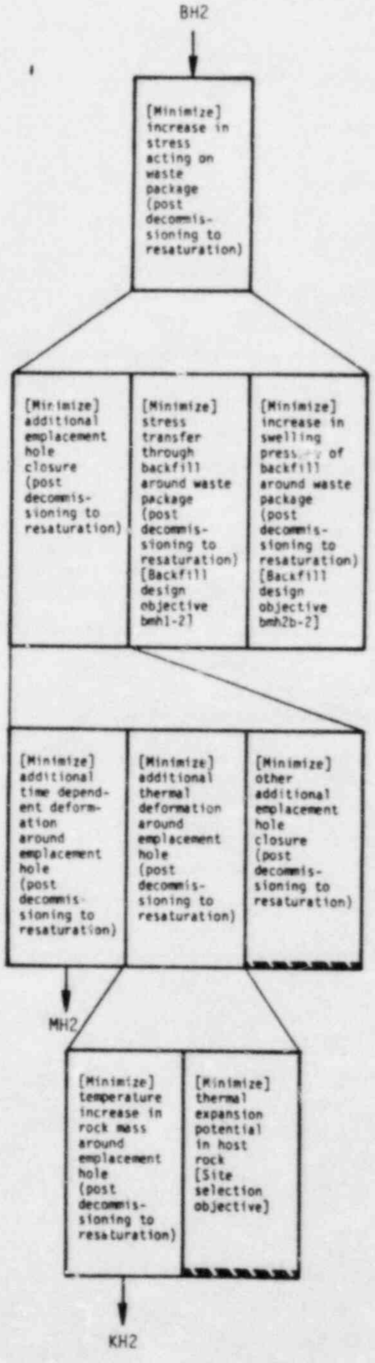
Figure A.28



Note: Refer to Figure A.2 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down elsewhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▨.

DEVELOPMENT OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES TO REFERENCED COMMON PERFORMANCE SUBOBJECTIVE BH2

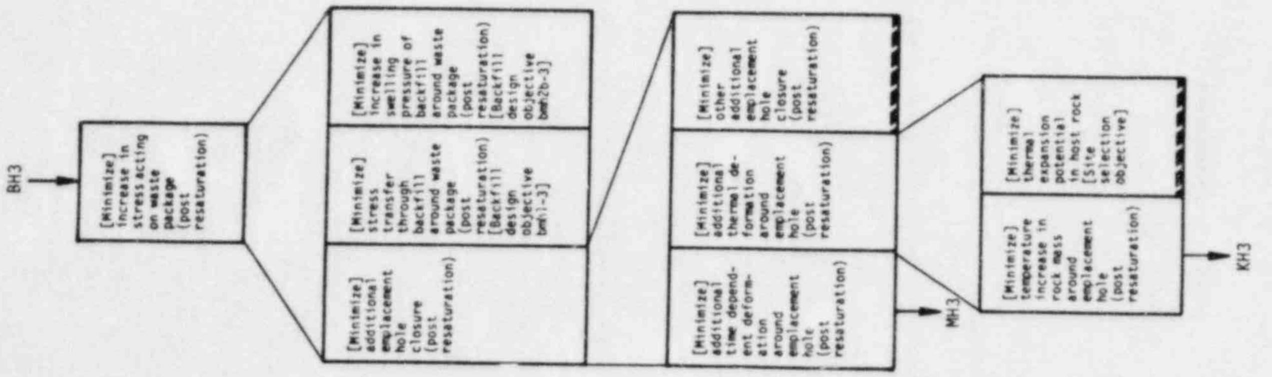
Figure A.29



Note: Refer to Figure A.2 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down elsewhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▨

DEVELOPMENT OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES TO REFERENCED COMMON PERFORMANCE SUBOBJECTIVE BH3

Figure A.30



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Note: Refer to Figure A.2 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down elsewhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▨▨▨.

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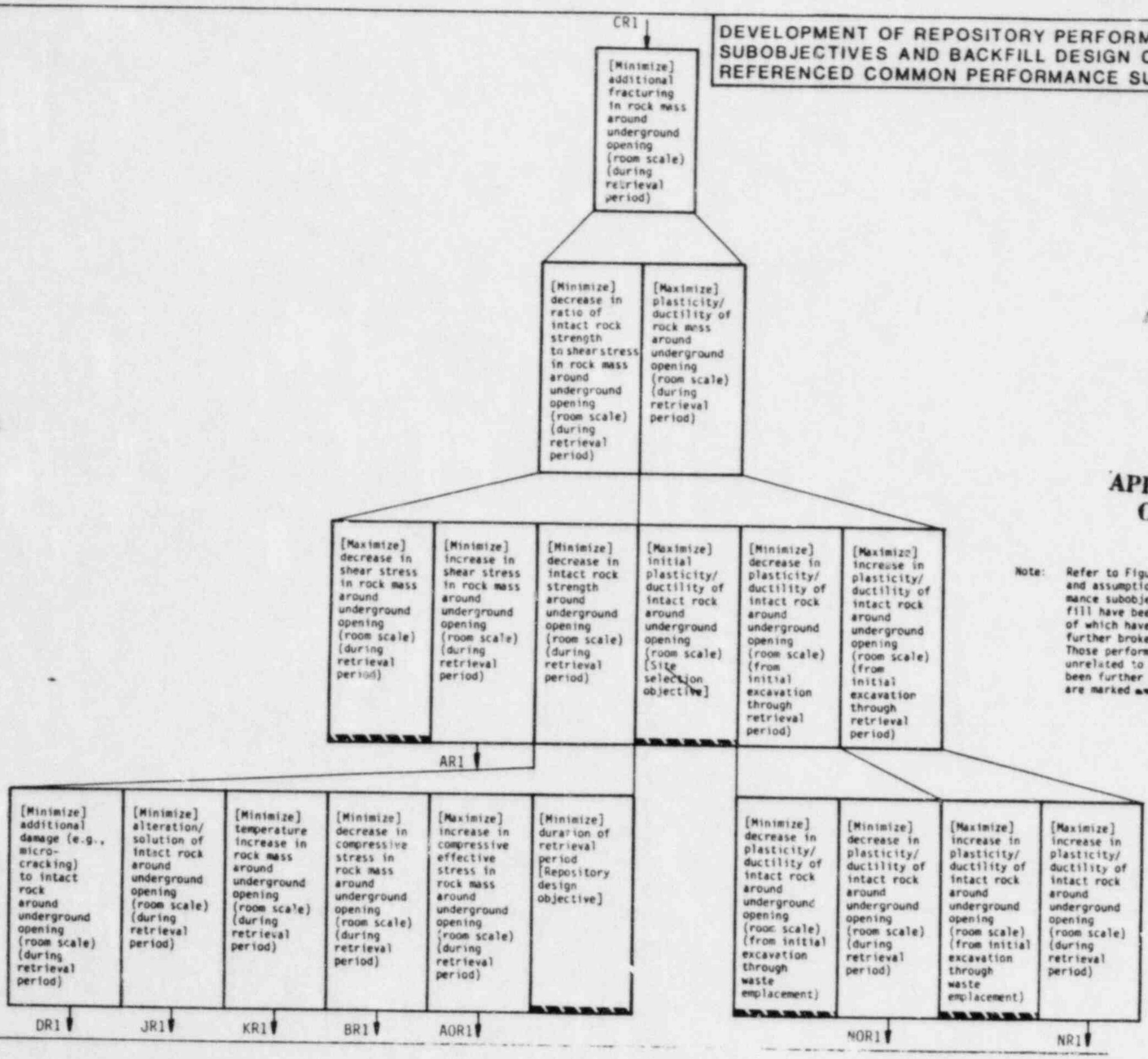
DEVELOPMENT OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES TO REFERENCED COMMON PERFORMANCE SUBOBJECTIVE CR1

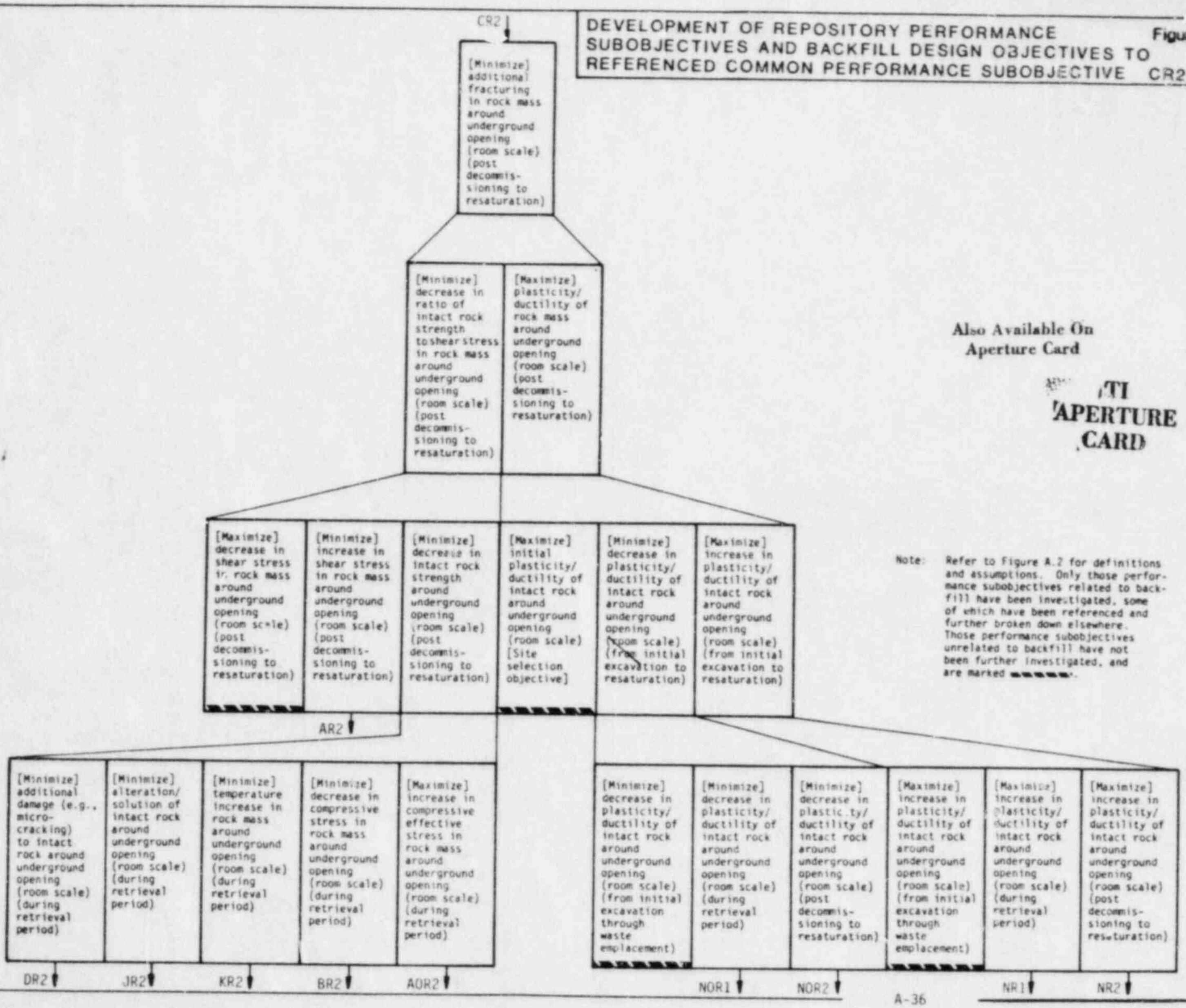
Figure A.31



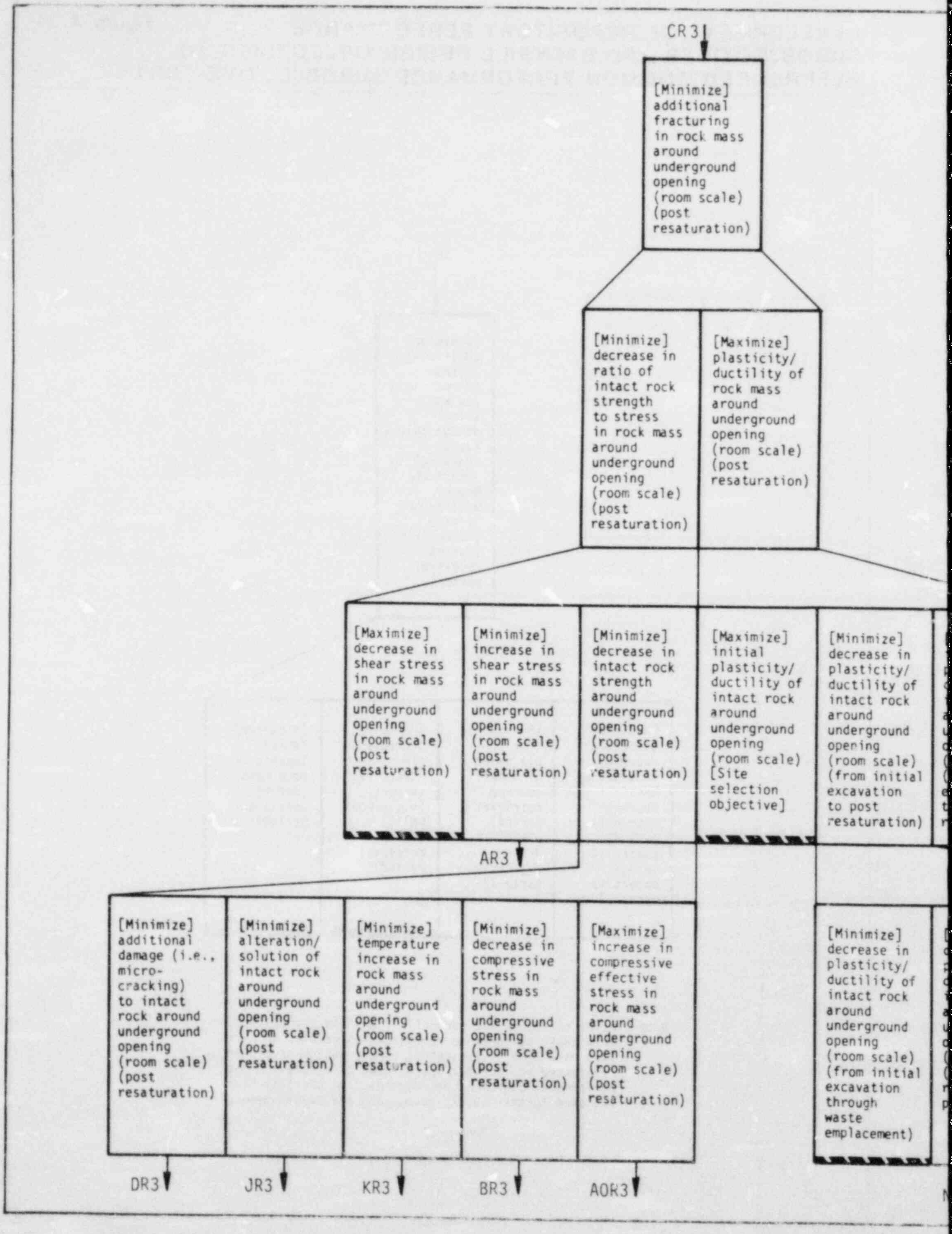
Note: Refer to Figure A.2 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down elsewhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▨▨▨.

DEVELOPMENT OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES TO REFERENCED COMMON PERFORMANCE SUBOBJECTIVE CR2

Figure A.32

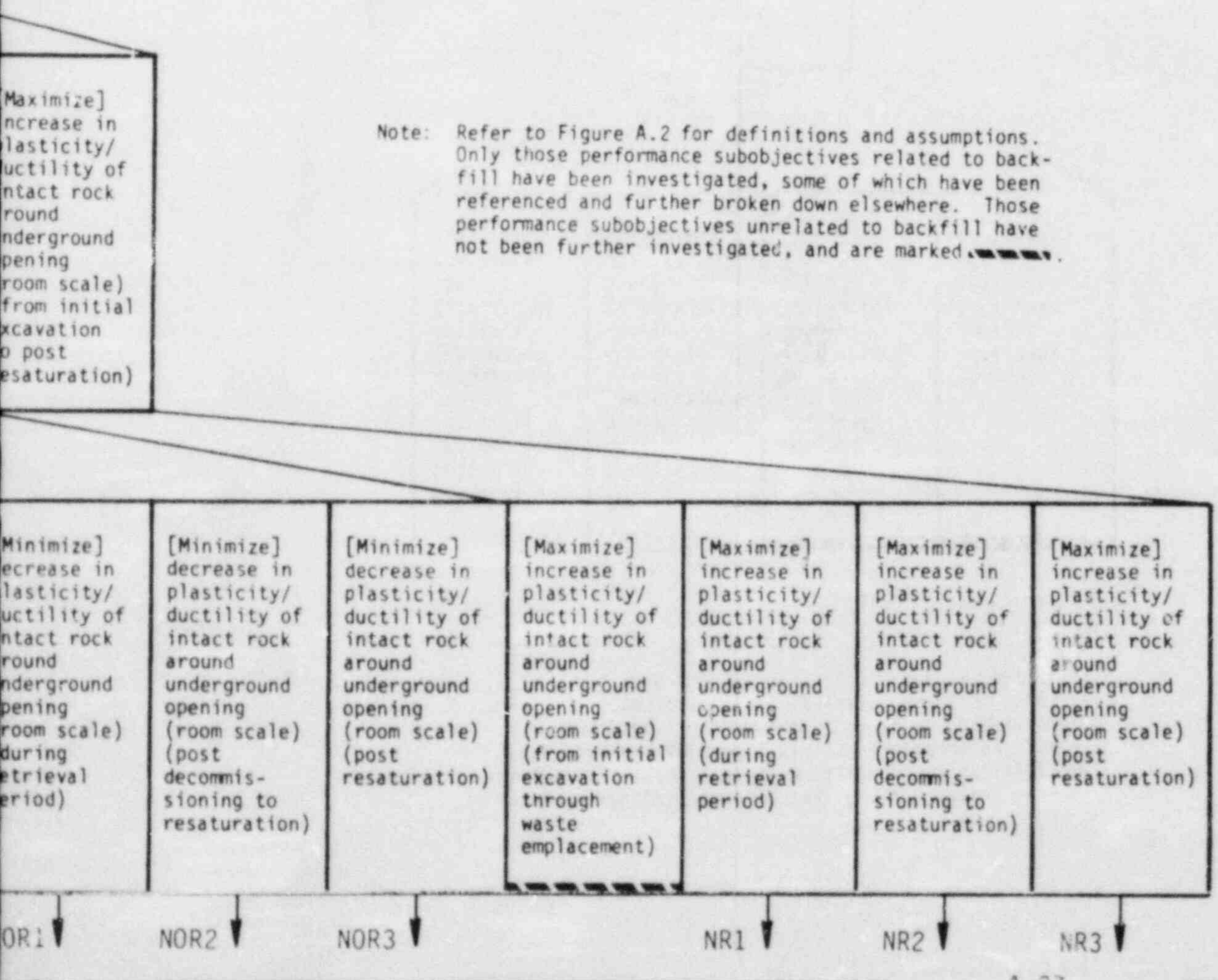


Note: Refer to Figure A.2 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down elsewhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▨▨▨▨.


CR3
[Minimize] additional fracturing in rock mass around underground opening (room scale) (post resaturation)
[Minimize] decrease in ratio of intact rock strength to stress in rock mass around underground opening (room scale) (post resaturation)
[Maximize] plasticity/ ductility of rock mass around underground opening (room scale) (post resaturation)
[Maximize] decrease in shear stress in rock mass around underground opening (room scale) (post resaturation)
[Minimize] increase in shear stress in rock mass around underground opening (room scale) (post resaturation)
[Minimize] decrease in intact rock strength around underground opening (room scale) (post resaturation)
[Maximize] initial plasticity/ ductility of intact rock around underground opening (room scale) [Site selection objective]
[Minimize] decrease in plasticity/ ductility of intact rock around underground opening (room scale) (from initial excavation to post resaturation)
AR3
[Minimize] additional damage (i.e., micro-cracking) to intact rock around underground opening (room scale) (post resaturation)
[Minimize] alteration/ solution of intact rock around underground opening (room scale) (post resaturation)
[Minimize] temperature increase in rock mass around underground opening (room scale) (post resaturation)
[Minimize] decrease in compressive stress in rock mass around underground opening (room scale) (post resaturation)
[Maximize] increase in compressive effective stress in rock mass around underground opening (room scale) (post resaturation)
[Minimize] decrease in plasticity/ ductility of intact rock around underground opening (room scale) (from initial excavation through waste emplacement)
DR3
JR3
KR3
BR3
AOR3

DEVELOPMENT OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES TO REFERENCED COMMON PERFORMANCE SUBOBJECTIVE CR3

Figure A.33



Note: Refer to Figure A.2 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down elsewhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▬▬▬.

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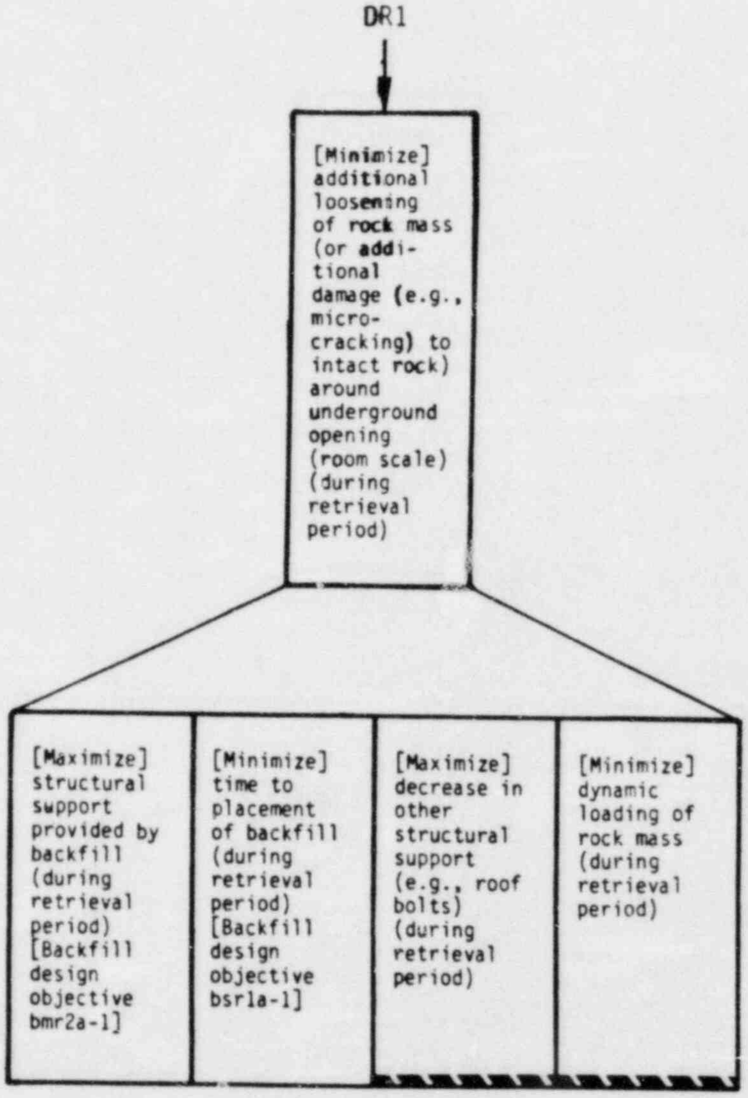
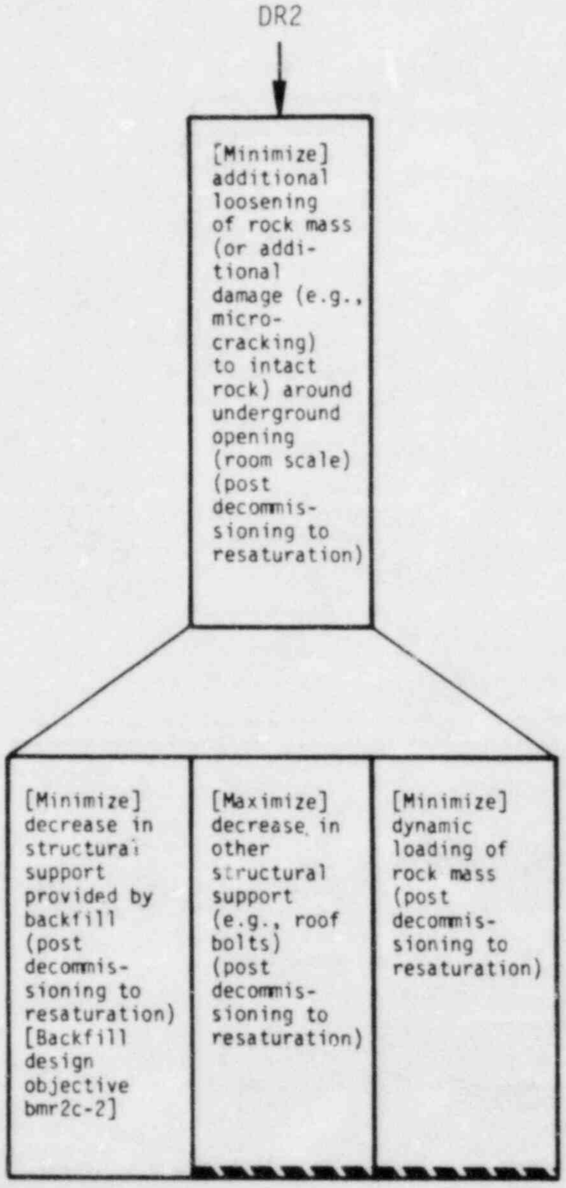
DEVELOPMENT OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES TO REFERENCED COMMON PERFORMANCE SUBOBJECTIVE DR1 Figure A.34



Note: Refer to Figure A.2 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down elsewhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▨.

DEVELOPMENT OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES TO REFERENCED COMMON PERFORMANCE SUBOBJECTIVE DR2

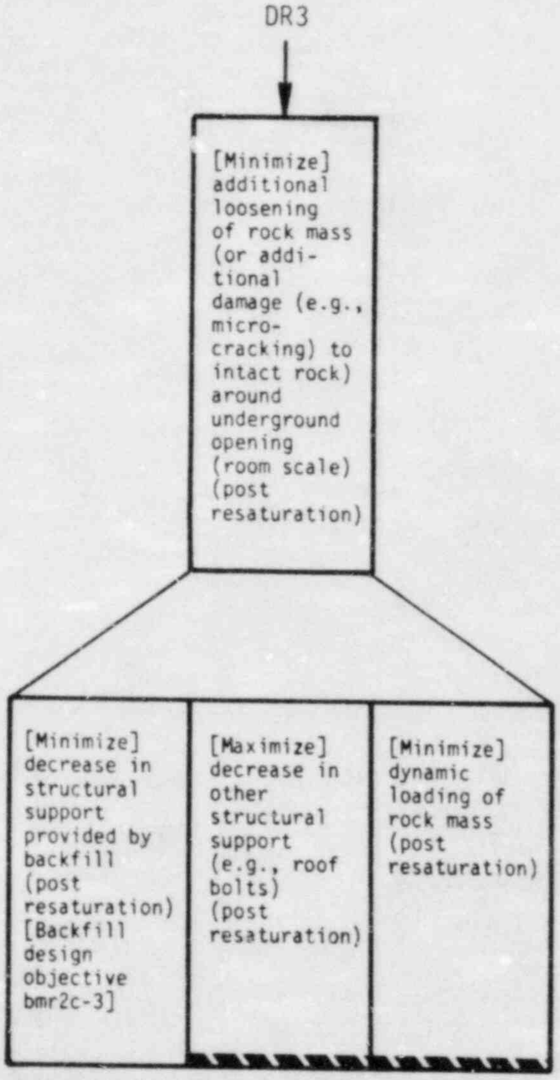
Figure A.35



Note: Refer to Figure A.2 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down elsewhere. Those performance subobjectives unrelated to backfill have not been futher investigated, and are marked ▬▬▬.

DEVELOPMENT OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES TO REFERENCED COMMON PERFORMANCE SUBOBJECTIVE DR3

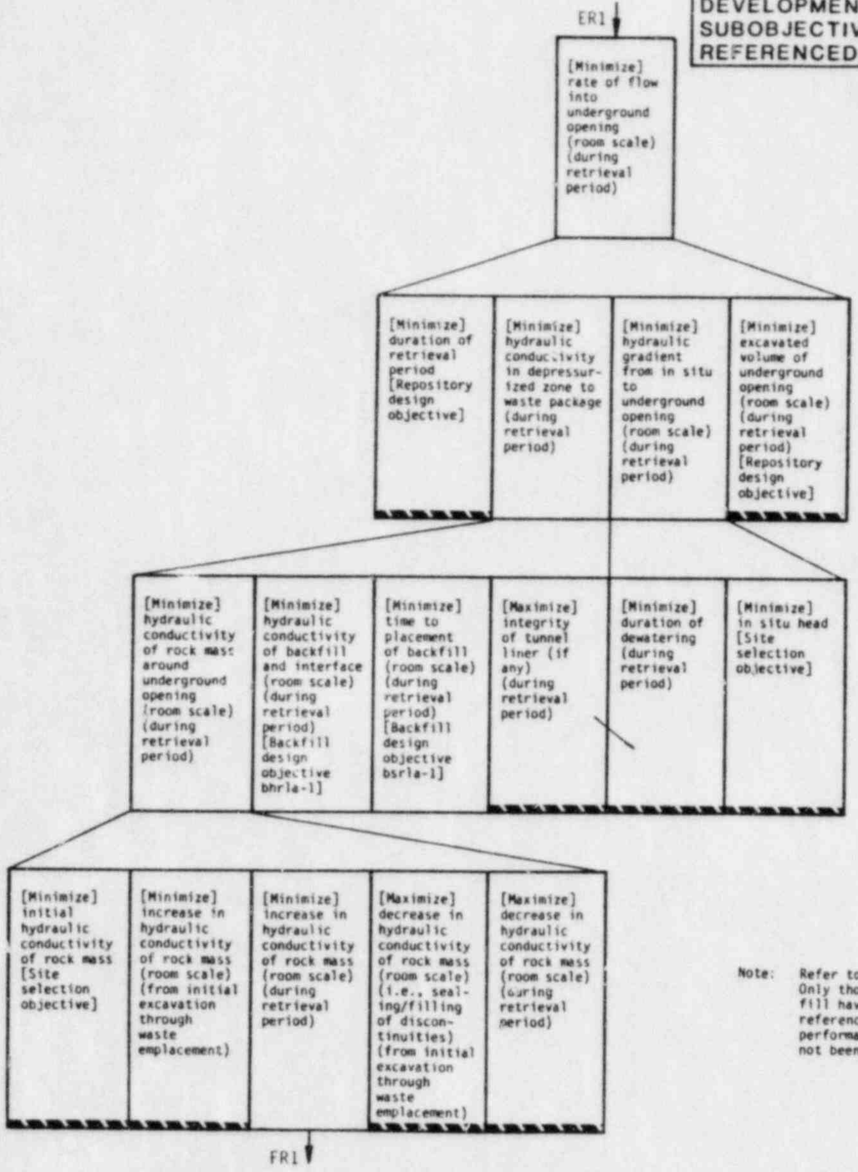
Figure A.36



Note: Refer to Figure A.2 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down elsewhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▬▬▬.

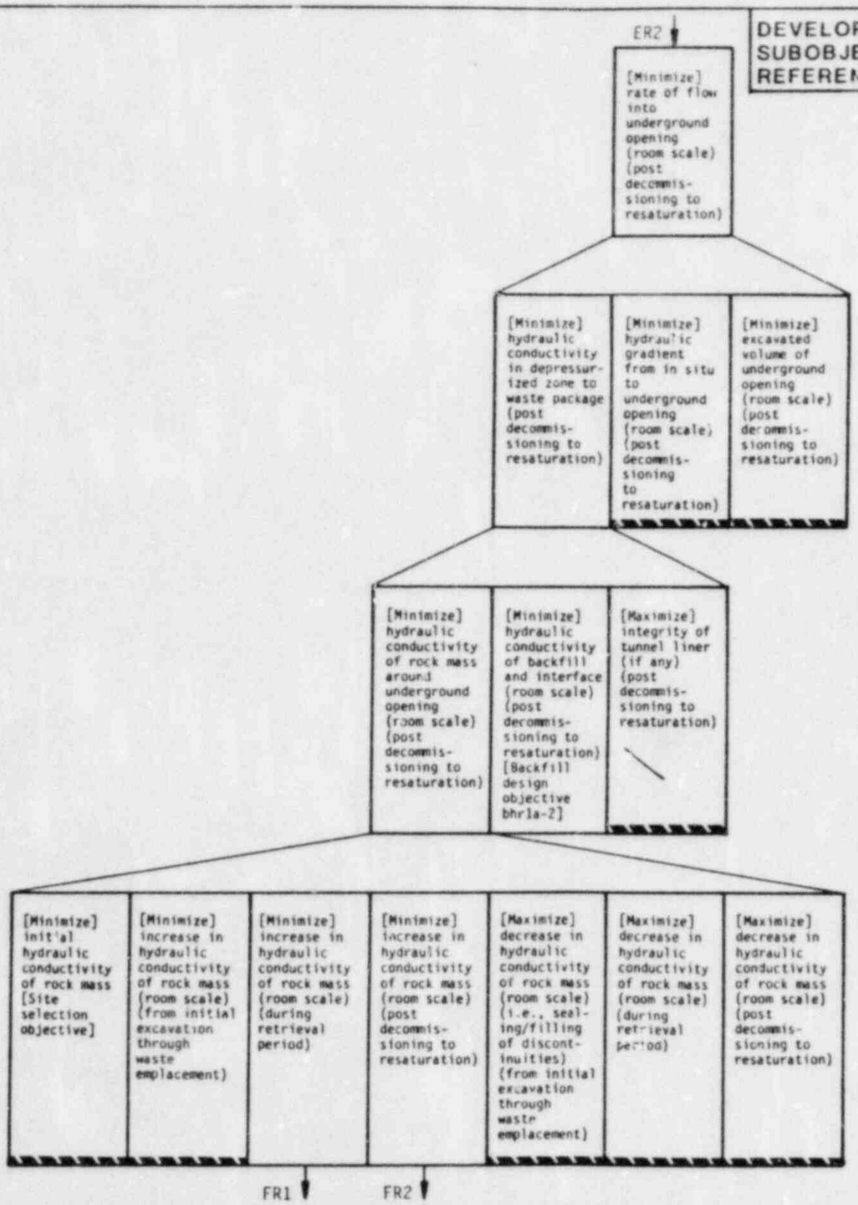
DEVELOPMENT OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES TO REFERENCED COMMON PERFORMANCE SUBOBJECTIVE ER1

Figure A.37



Note: Refer to Figure A.2 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down elsewhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▬▬▬.

DEVELOPMENT OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES TO REFERENCED COMMON PERFORMANCE SUBOBJECTIVE ER2 **Figure A.38**



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Note: Refer to Figure A.2 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down elsewhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▬▬▬.

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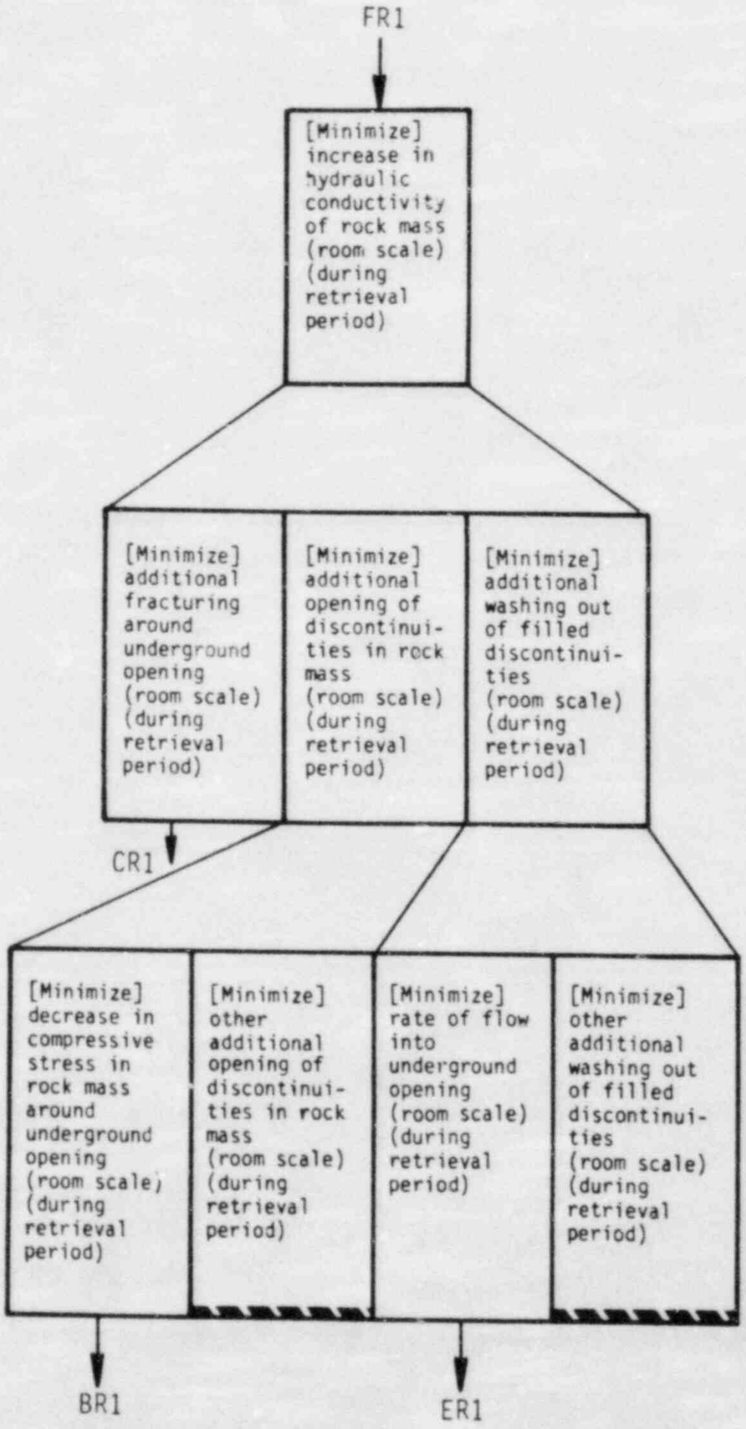
DEVELOPMENT OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES TO REFERENCED COMMON PERFORMANCE SUBOBJECTIVE FR1

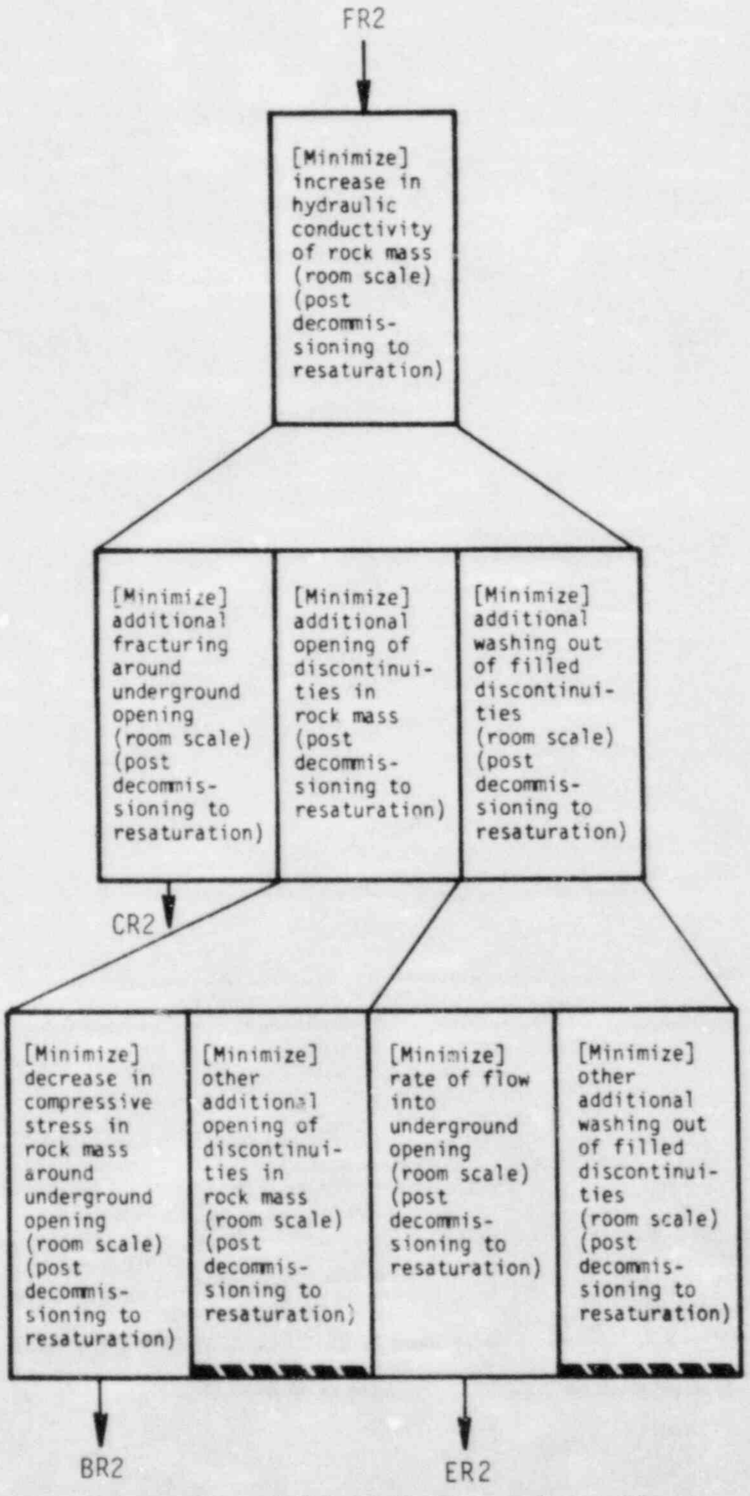
Figure A.39



Note: Refer to Figure A.2 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down elsewhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▨▨▨.

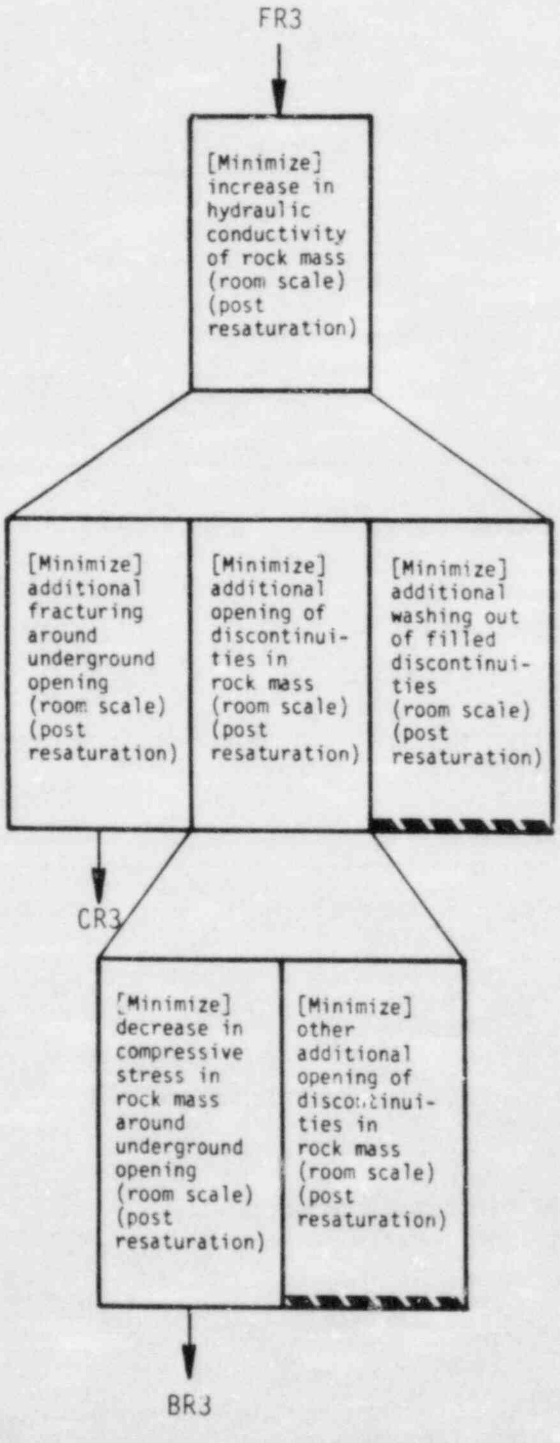
DEVELOPMENT OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES TO REFERENCED COMMON PERFORMANCE SUBOBJECTIVE FR2

Figure A.40



Note: Refer to Figure A.2 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down elsewhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▨▨▨.

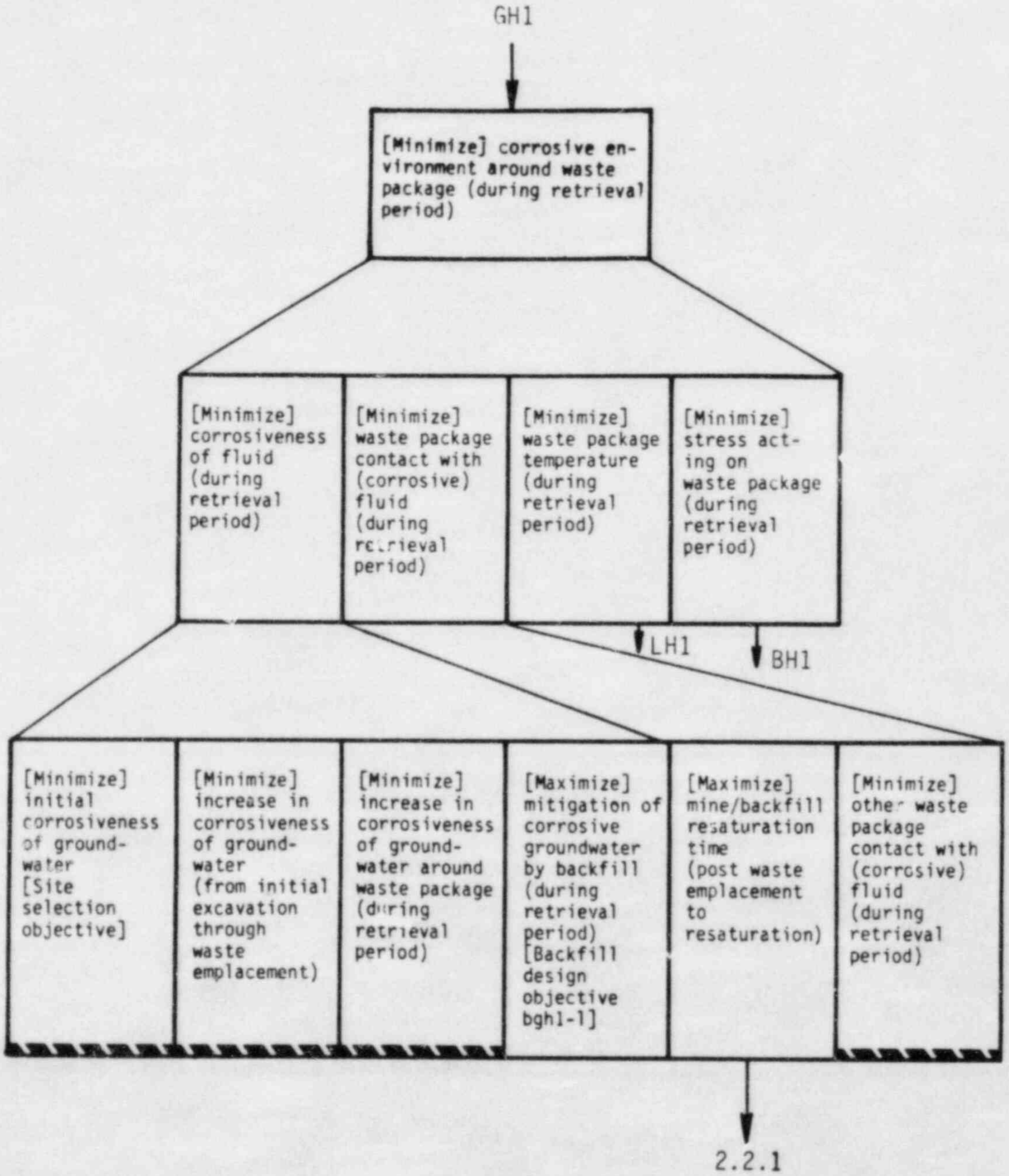
DEVELOPMENT OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES TO REFERENCED COMMON PERFORMANCE SUBOBJECTIVE FR3 **Figure A.41**



Note: Refer to Figure A.2 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down elsewhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▬▬▬.

DEVELOPMENT OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES TO REFERENCED COMMON PERFORMANCE SUBOBJECTIVE GH1

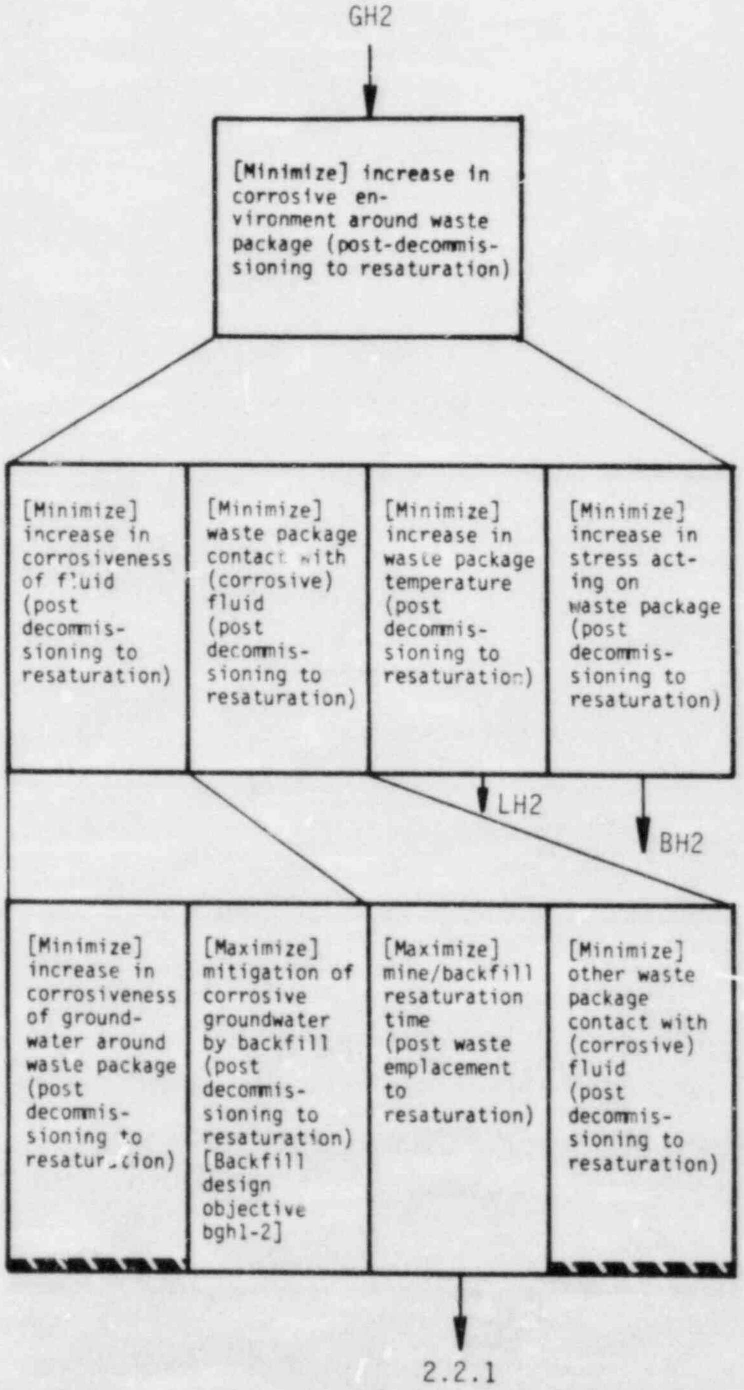
Figure A.42



Note: Refer to Figure A.2 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down elsewhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▨.

DEVELOPMENT OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES TO REFERENCED COMMON PERFORMANCE SUBOBJECTIVE GH2

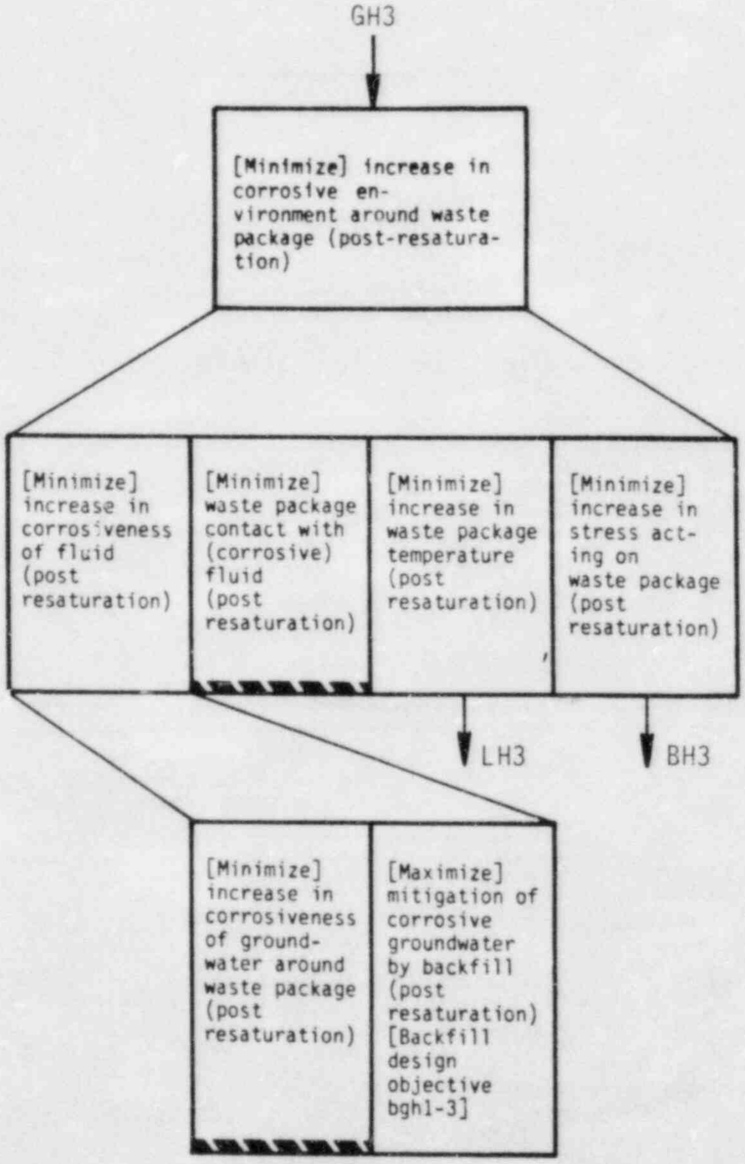
Figure A.43



Note: Refer to Figure A.2 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down elsewhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▬▬▬.

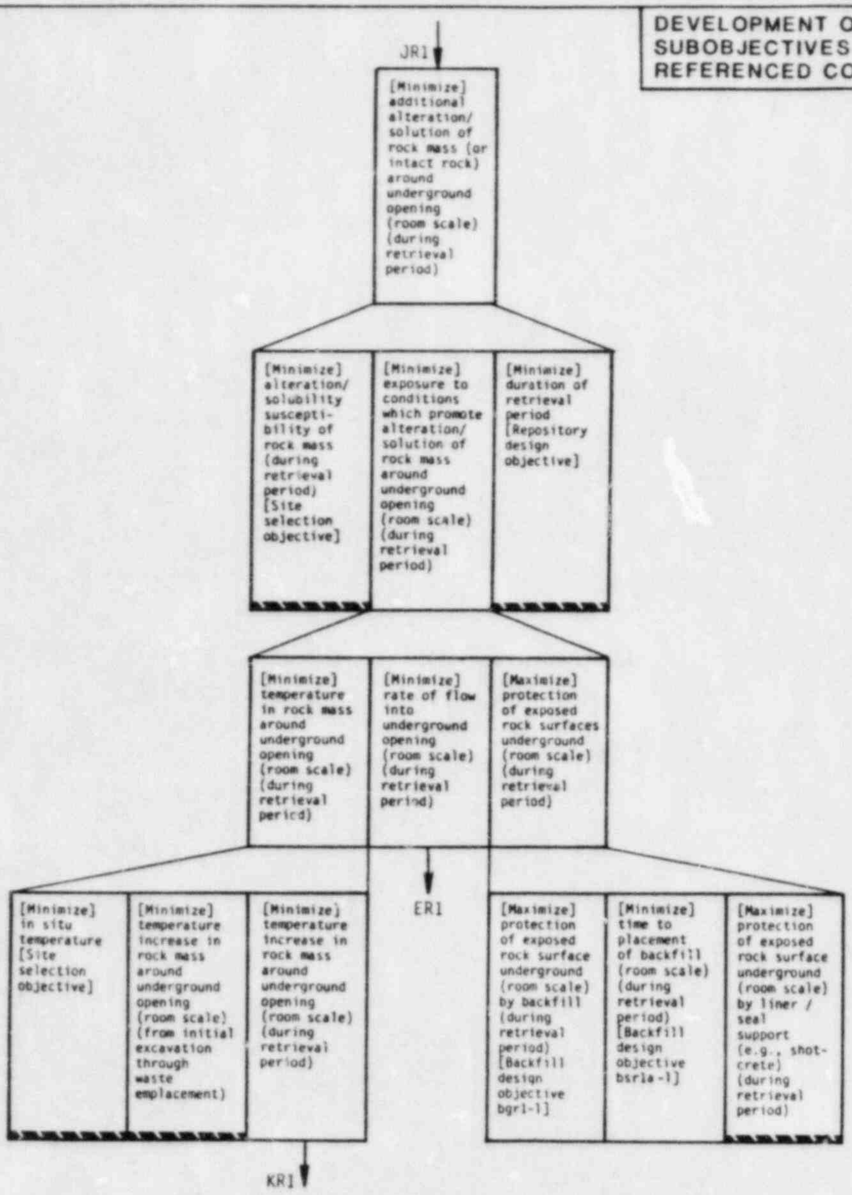
DEVELOPMENT OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES TO REFERENCED COMMON PERFORMANCE SUBOBJECTIVE GH3

Figure A.44



Note: Refer to Figure A.2 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down elsewhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▨.

DEVELOPMENT OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES TO REFERENCED COMMON PERFORMANCE SUBOBJECTIVE JR1 **Figure A.45**



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Note: Refer to Figure A.2 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down elsewhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▬▬▬.

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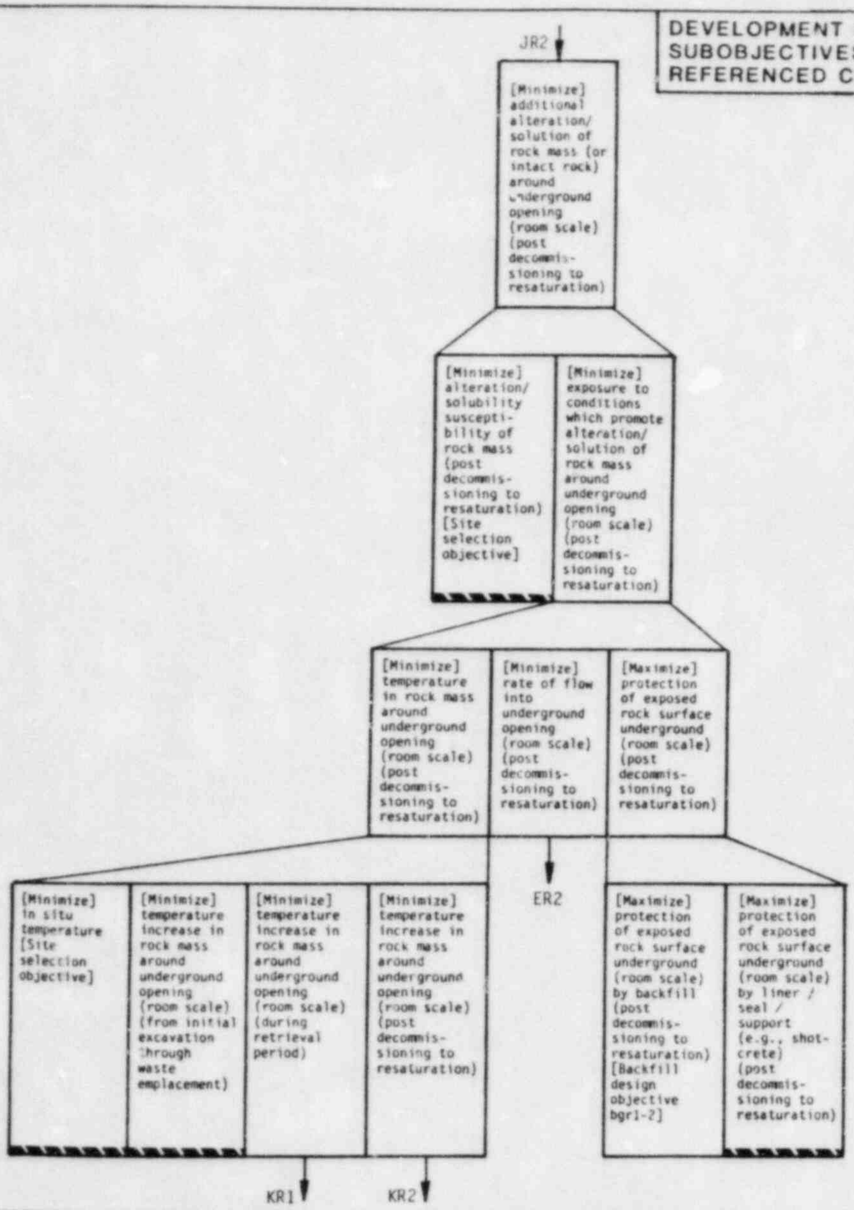
DEVELOPMENT OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES TO REFERENCED COMMON PERFORMANCE SUBOBJECTIVE JR2

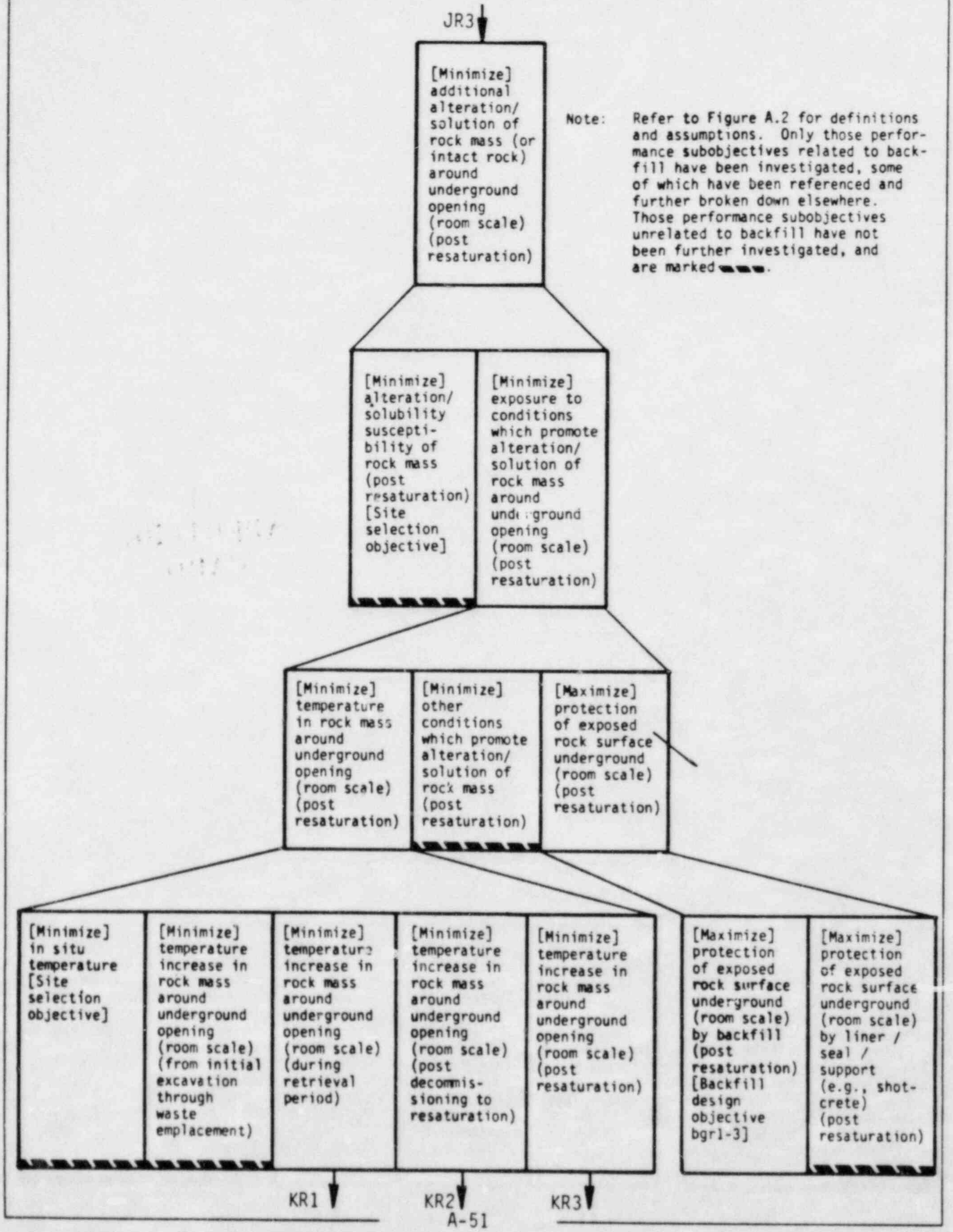
Figure A.46



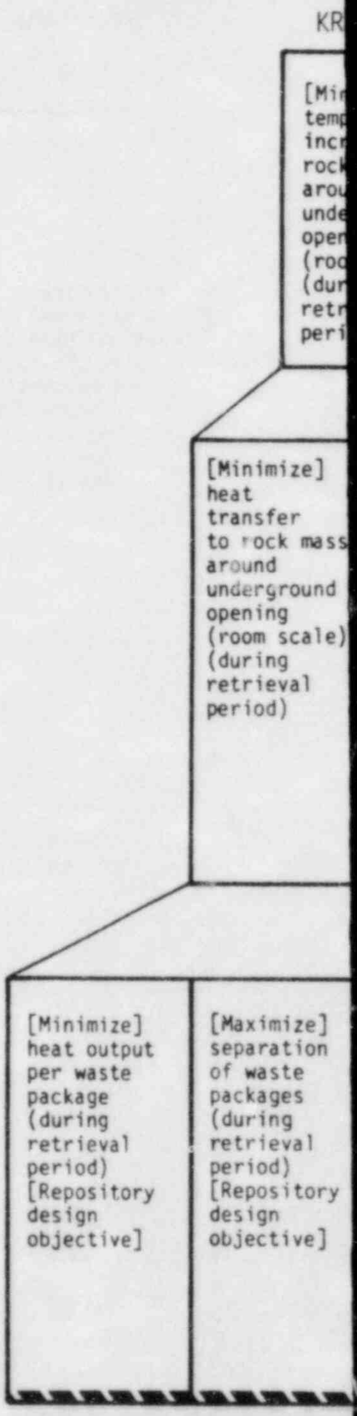
Note: Refer to Figure A.2 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down elsewhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▨.

DEVELOPMENT OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES TO REFERENCED COMMON PERFORMANCE SUBOBJECTIVE JR3

Figure A.47



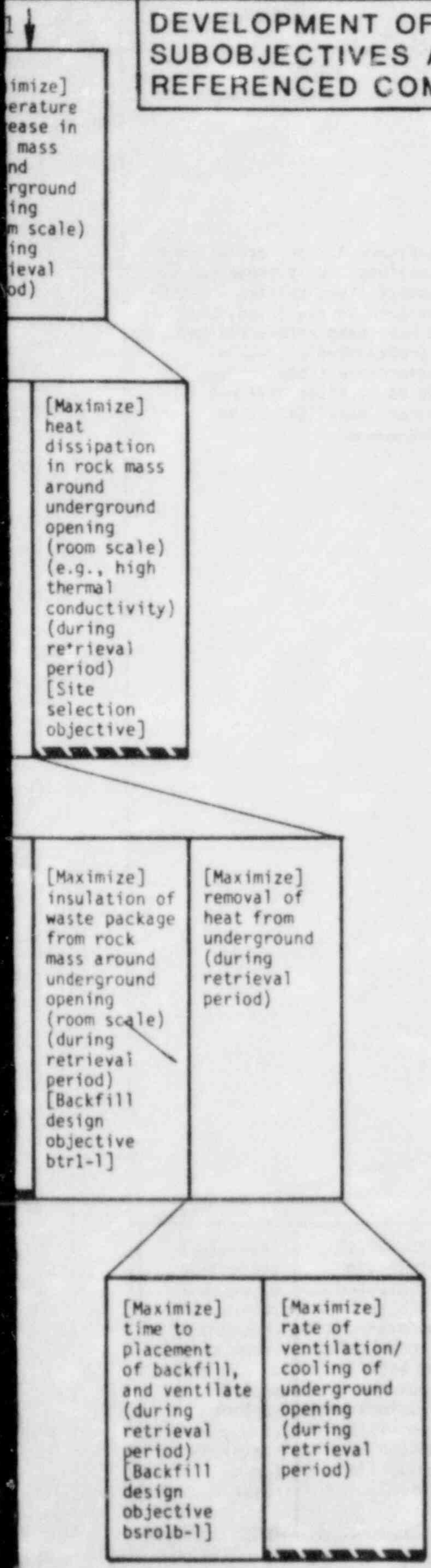
Note: Refer to Figure A.2 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down elsewhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▨▨▨.



Note: Refer to Figure A.2 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down elsewhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▬▬▬.

DEVELOPMENT OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES TO REFERENCED COMMON PERFORMANCE SUBOBJECTIVE KR1

Figure A.48



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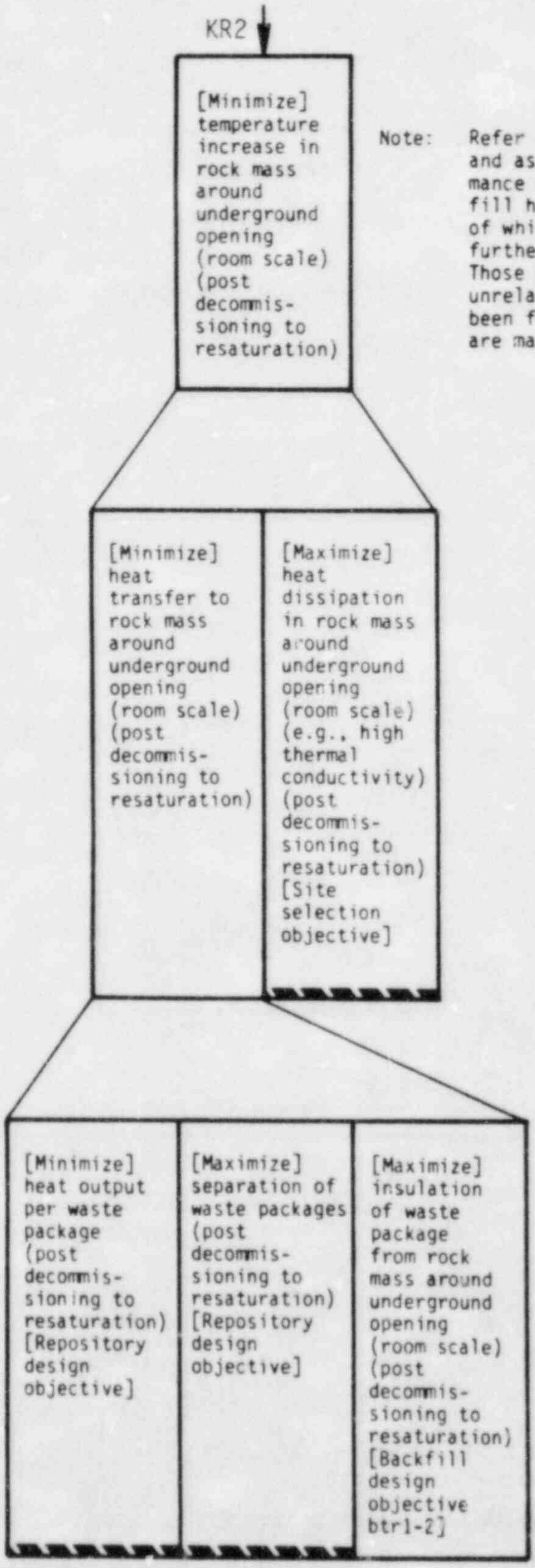
DEVELOPMENT OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES TO REFERENCED COMMON PERFORMANCE SUBOBJECTIVE KR2

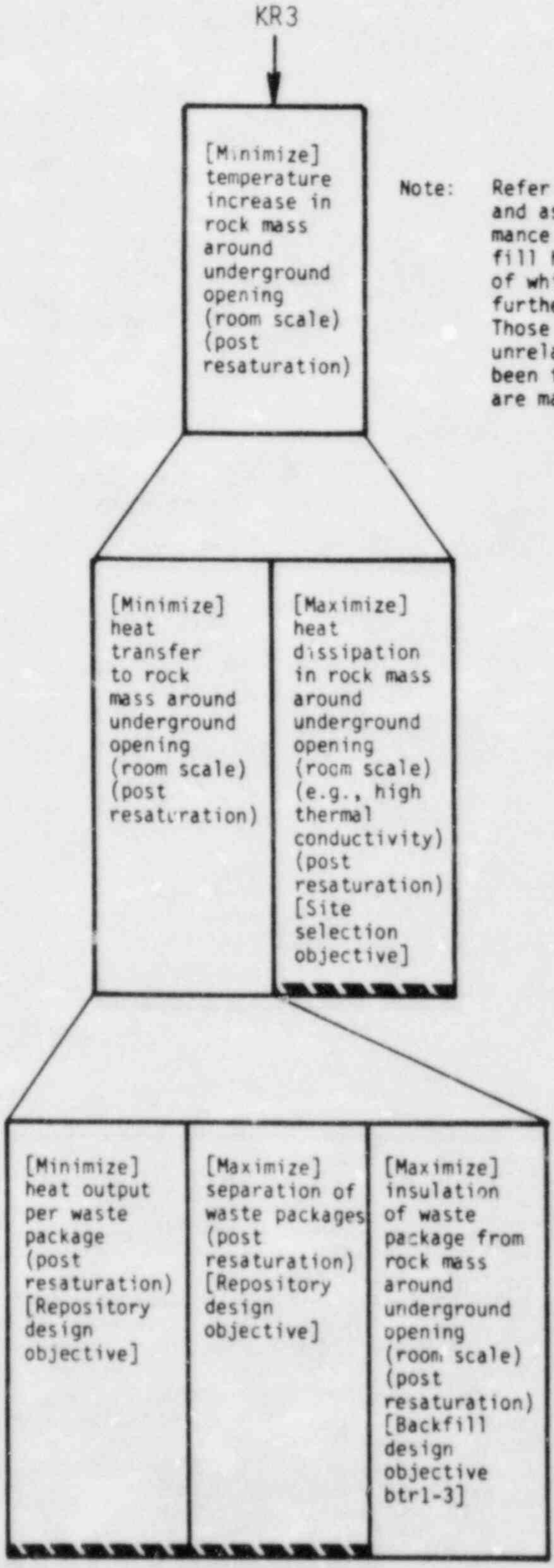
Figure A.49



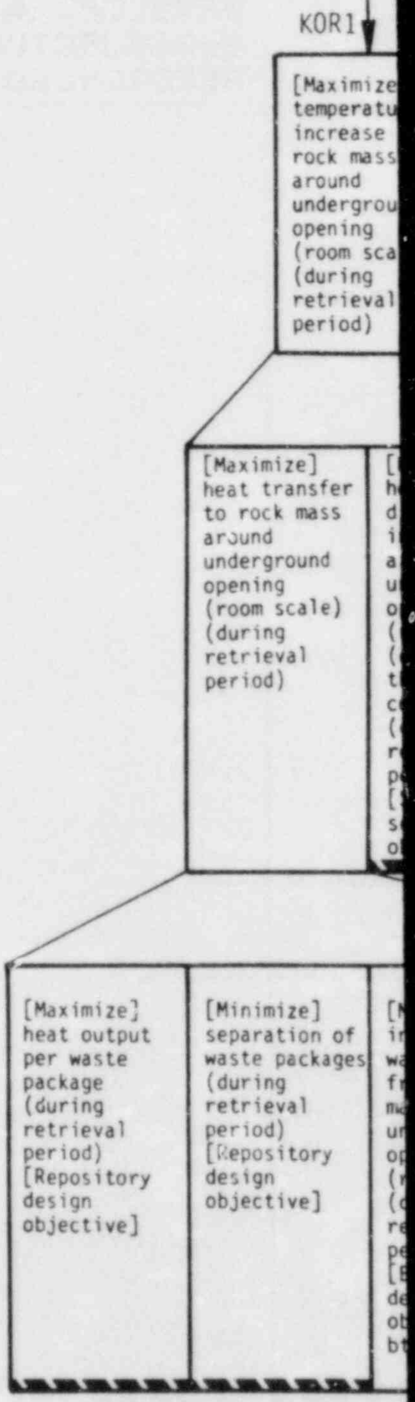
Note: Refer to Figure A.2 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down elsewhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▨▨▨.

DEVELOPMENT OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES TO REFERENCED COMMON PERFORMANCE SUBOBJECTIVE KR3

Figure A.50

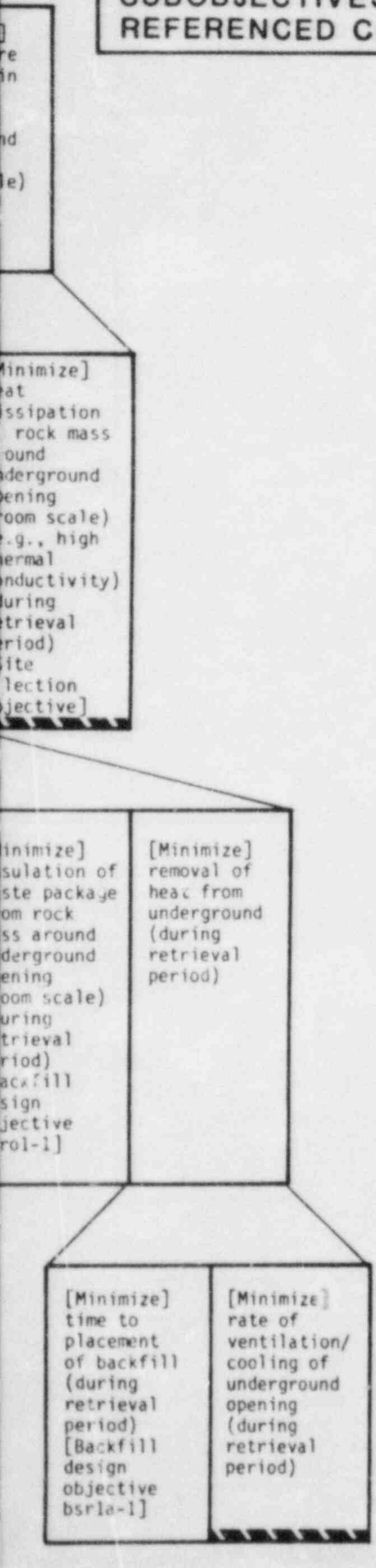


Note: Refer to Figure A.2 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down elsewhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▨.



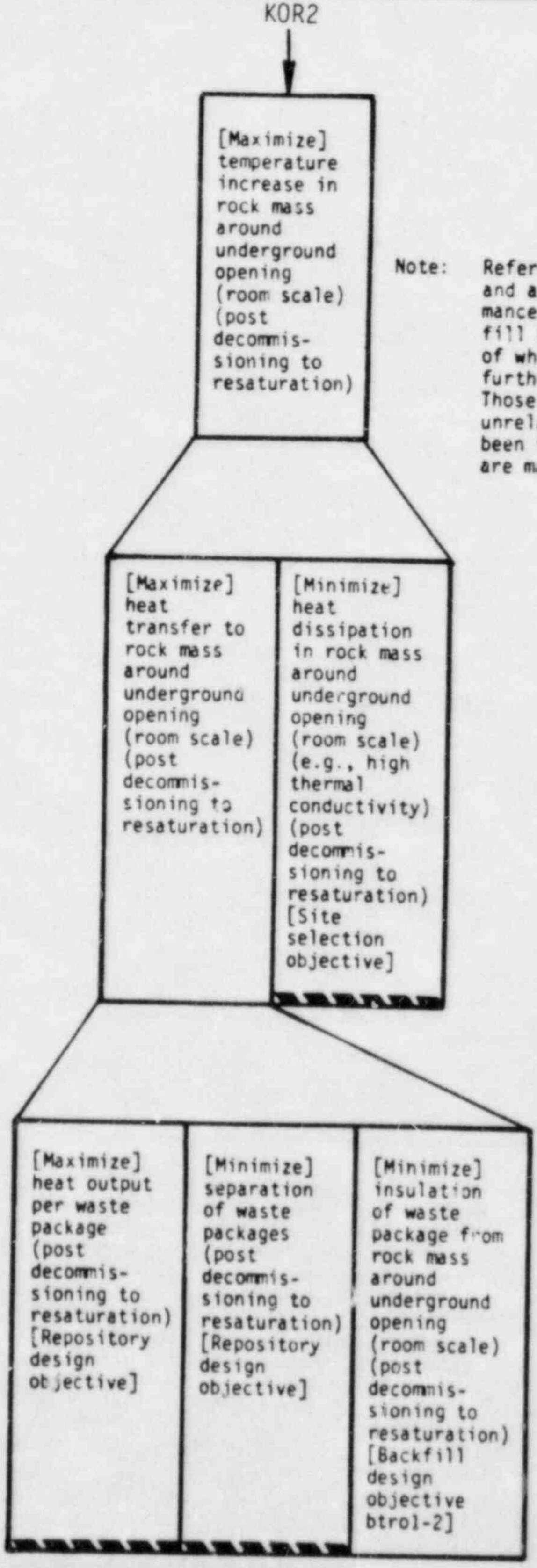
Note: Refer to Figure A.2 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down elsewhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▬▬▬.

DEVELOPMENT OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES TO REFERENCED COMMON PERFORMANCE SUBOBJECTIVE KOR1 **Figure A.51**



DEVELOPMENT OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES TO REFERENCED COMMON PERFORMANCE SUBOBJECTIVE KOR2

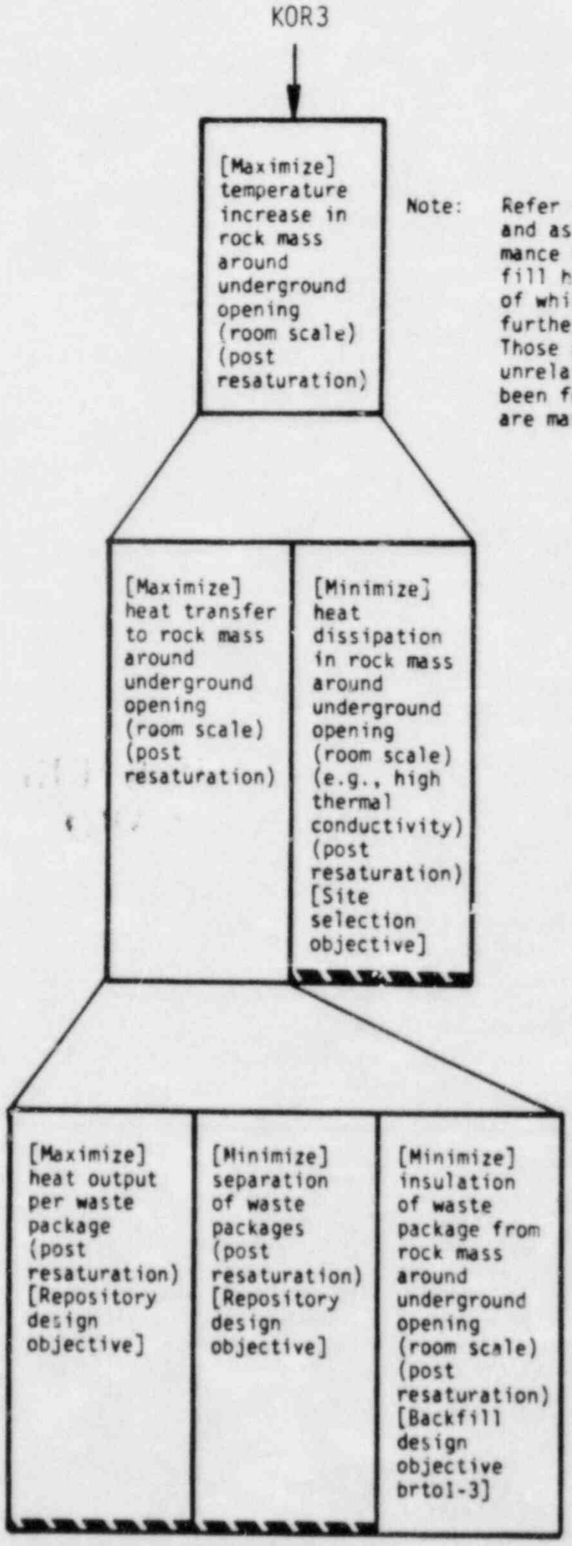
Figure A.52



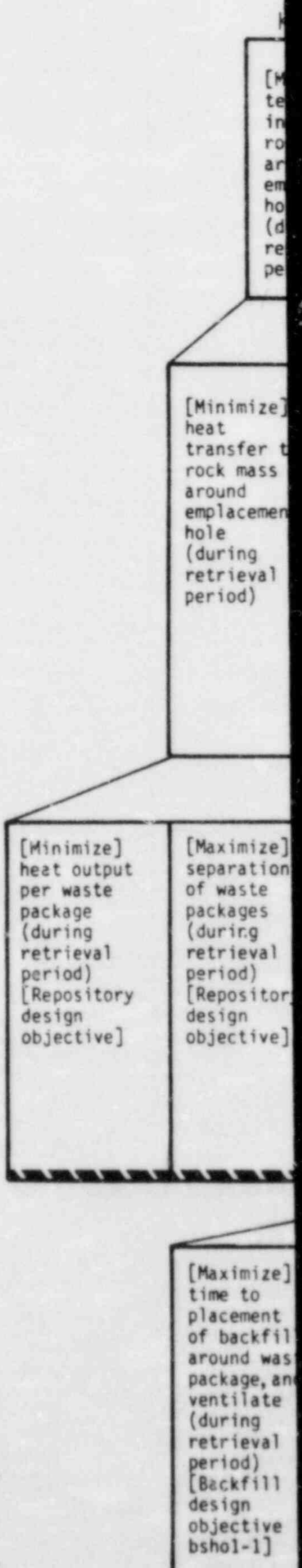
Note: Refer to Figure A.2 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down elsewhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▨▨▨▨.

DEVELOPMENT OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES TO REFERENCED COMMON PERFORMANCE SUBOBJECTIVE KOR3

Figure A.53



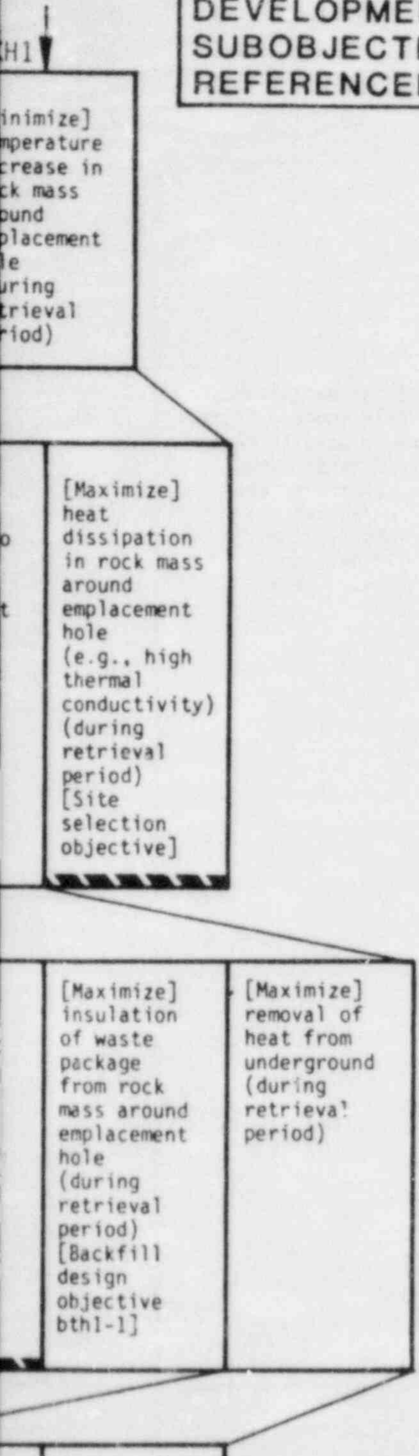
Note: Refer to Figure A.2 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down elsewhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▨.



Note: Refer to Figure A.2 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down elsewhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▬▬▬.

DEVELOPMENT OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES TO REFERENCED COMMON PERFORMANCE SUBOBJECTIVE KH1

Figure A.54



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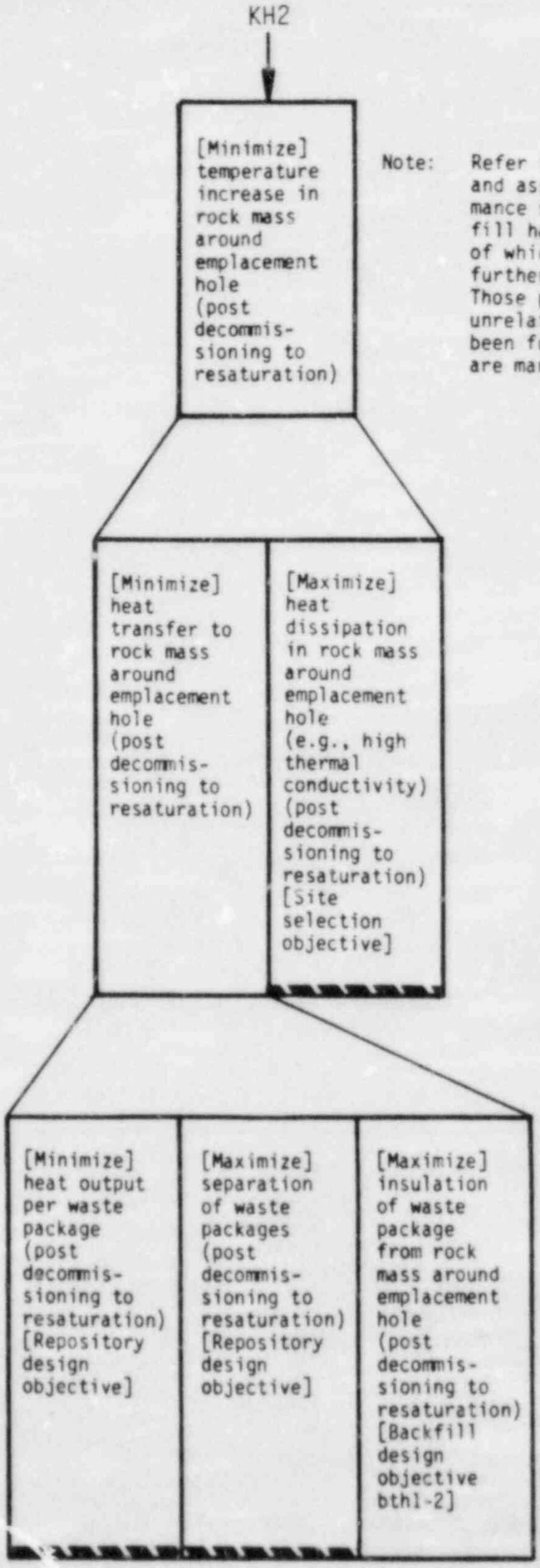
DEVELOPMENT OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES TO REFERENCED COMMON PERFORMANCE SUBOBJECTIVE KH2

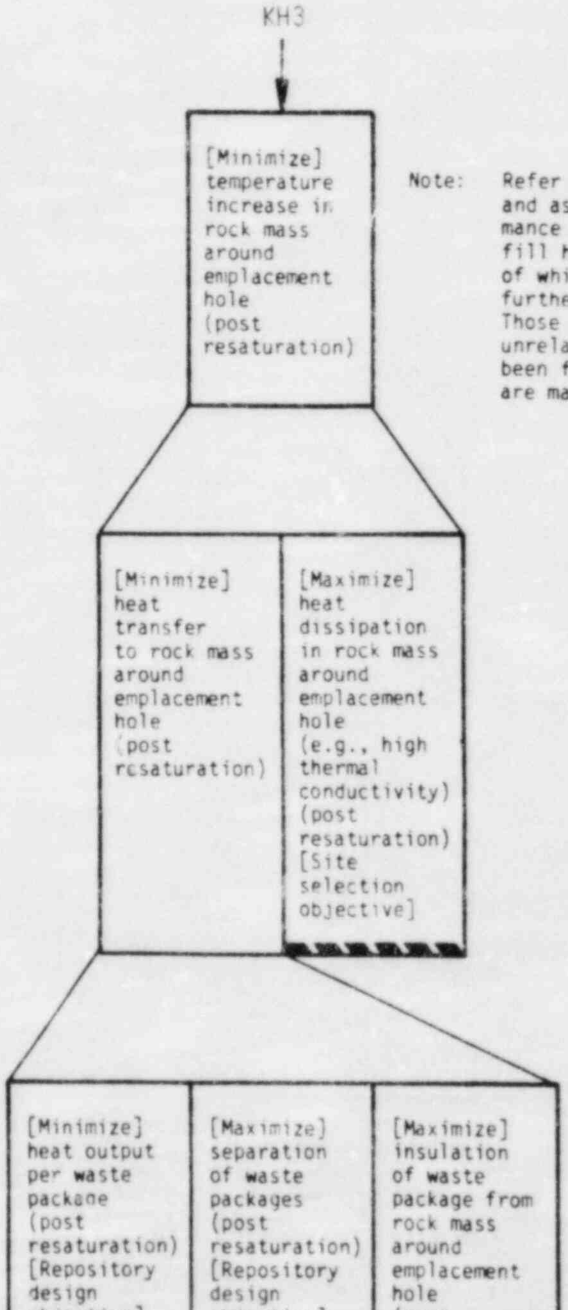
Figure A.55



Note: Refer to Figure A.2 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down elsewhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▬▬▬▬.

DEVELOPMENT OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES TO REFERENCED COMMON PERFORMANCE SUBOBJECTIVE KH3

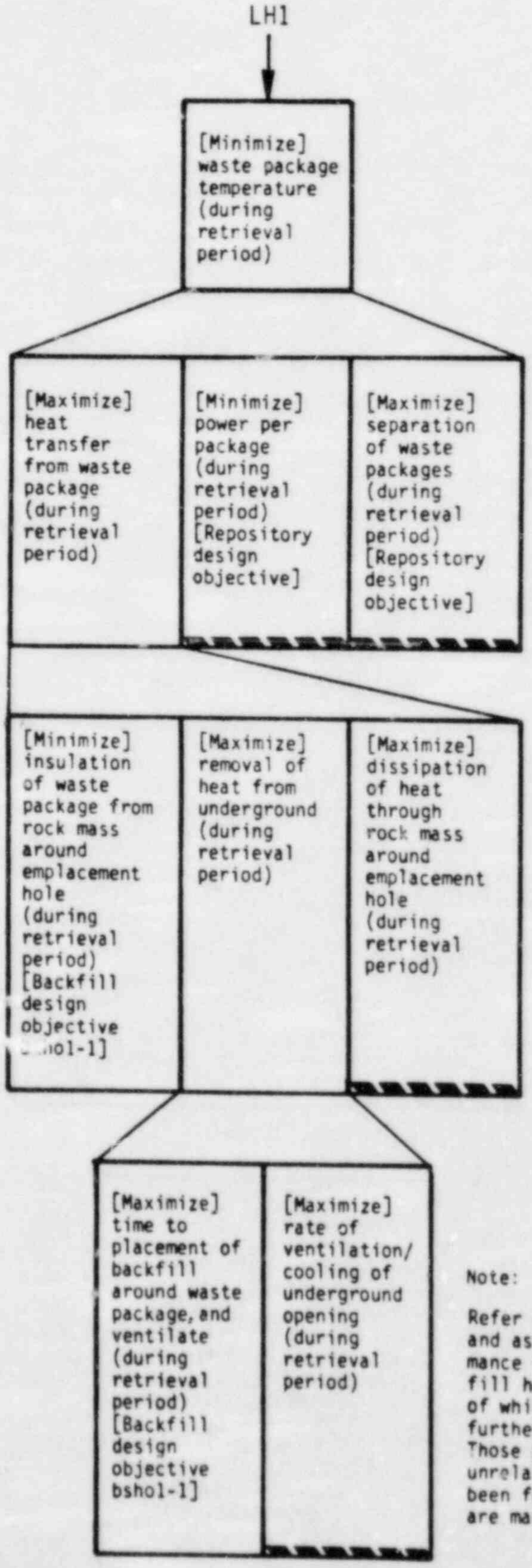
Figure A.56



Note: Refer to Figure A.2 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down elsewhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▬▬▬.

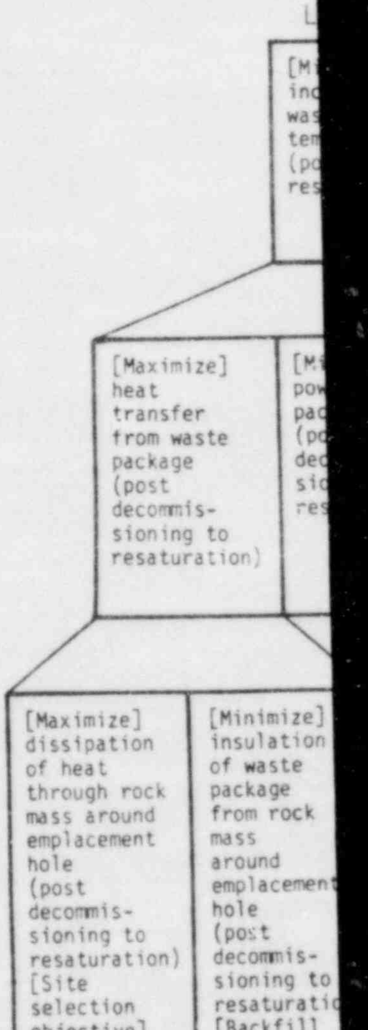
DEVELOPMENT OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES TO REFERENCED COMMON PERFORMANCE SUBOBJECTIVE LH1

Figure A.57



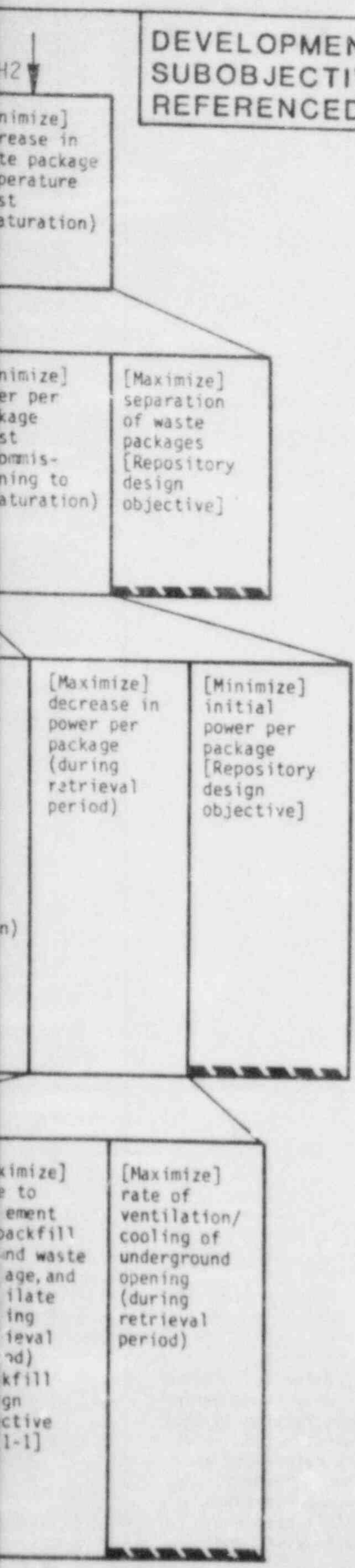
Note:

Refer to Figure A.2 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down elsewhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▨.


L
[Mi inc was tem (po res
[Maximize] heat transfer from waste package (post decommissioning to resaturation)
[Mi pow pac (po dec sic res
[Maximize] dissipation of heat through rock mass around emplacement hole (post decommissioning to resaturation) [Site selection objective]
[Minimize] insulation of waste package from rock mass around emplacement hole (post decommissioning to resaturatio [Backfill design objective bthol-2]
[Maximize] duration of retrieval period [Repository design objective]
[Ma tim pla of aro pac ven (du ret per [Bac des obj bsho

DEVELOPMENT OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES TO REFERENCED COMMON PERFORMANCE SUBOBJECTIVE LH2

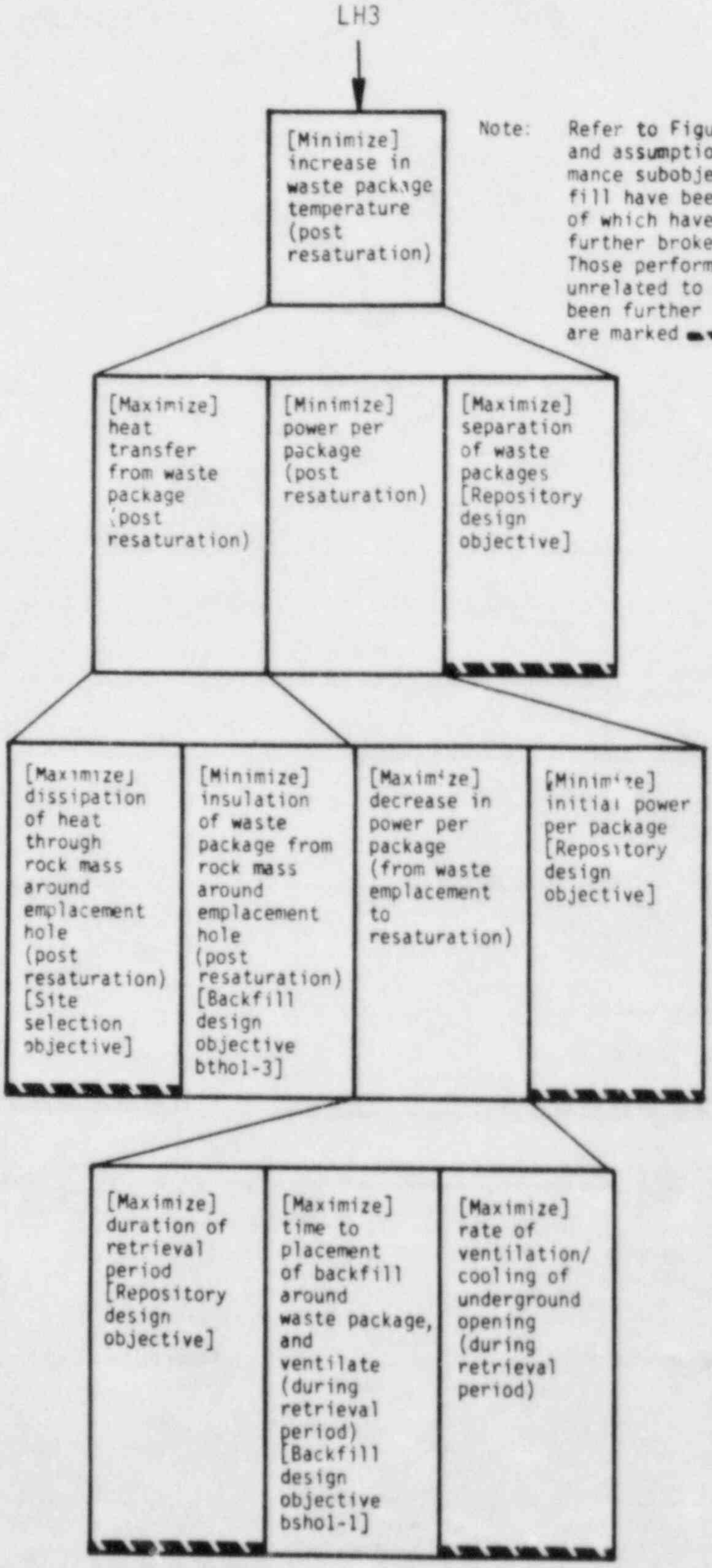
Figure A.58



Note: Refer to Figure A.2 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down elsewhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▬▬▬.

DEVELOPMENT OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES TO REFERENCED COMMON PERFORMANCE SUBOBJECTIVE LH3

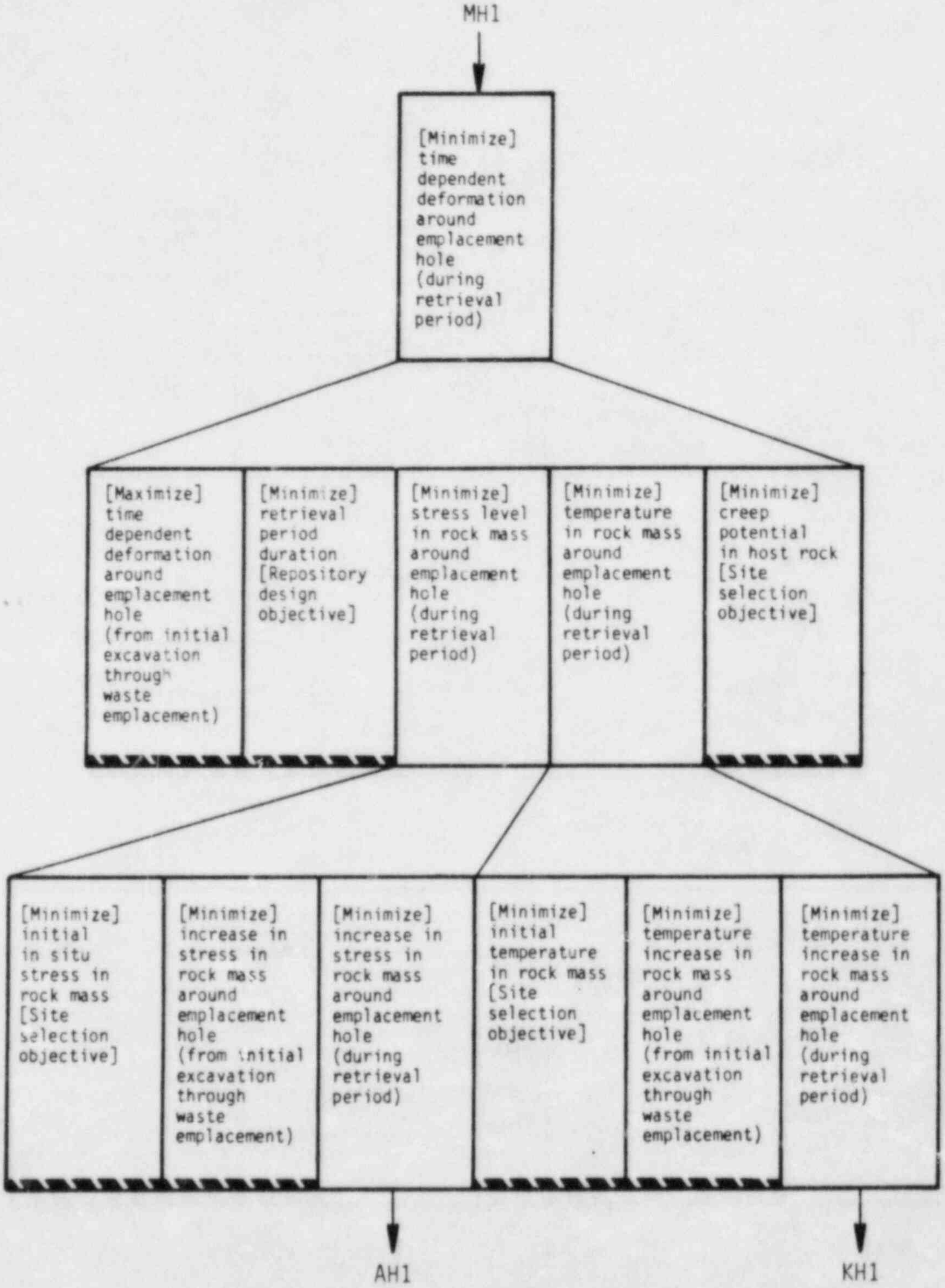
Figure A.59



Note: Refer to Figure A.2 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down elsewhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▬▬▬.

DEVELOPMENT OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES TO REFERENCED COMMON PERFORMANCE SUBOBJECTIVE MH1

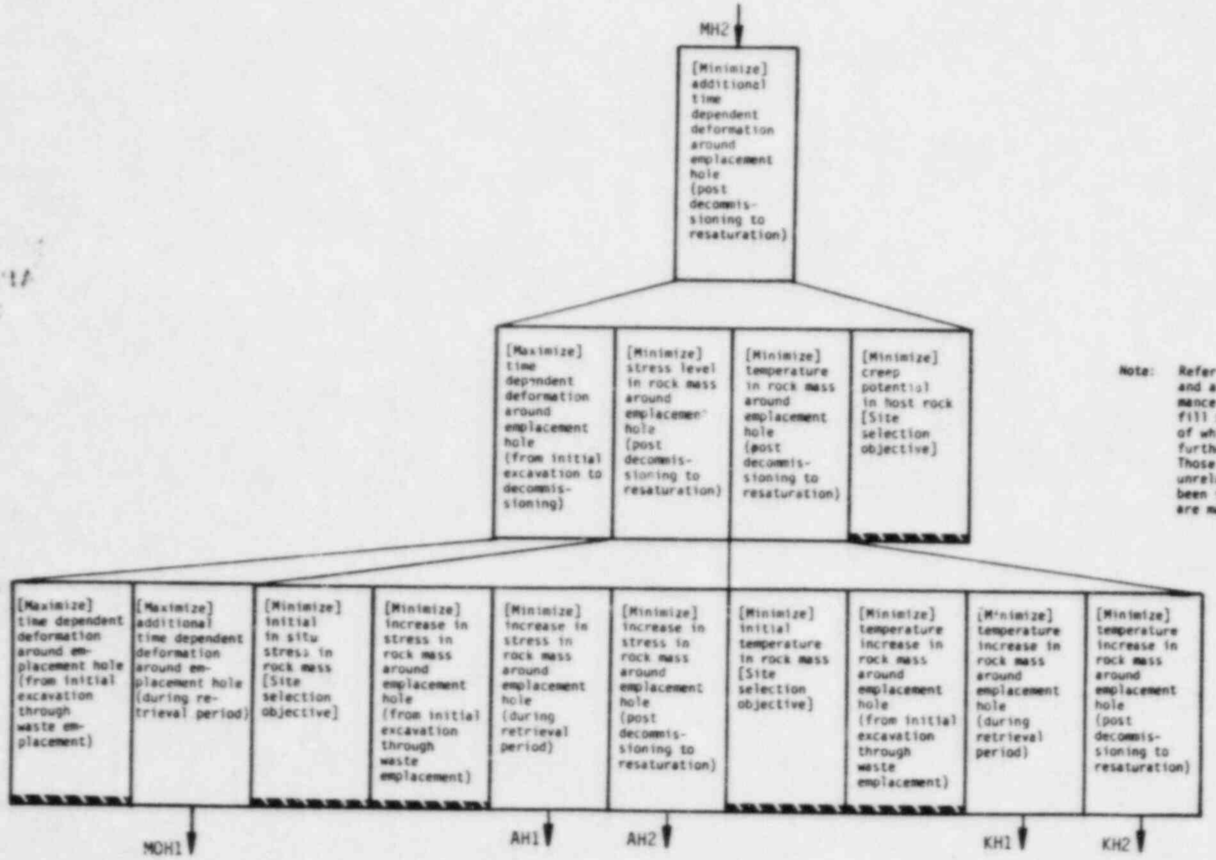
Figure A.60



Note: Refer to Figure A.2 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down elsewhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▬▬▬.

Figure A.61

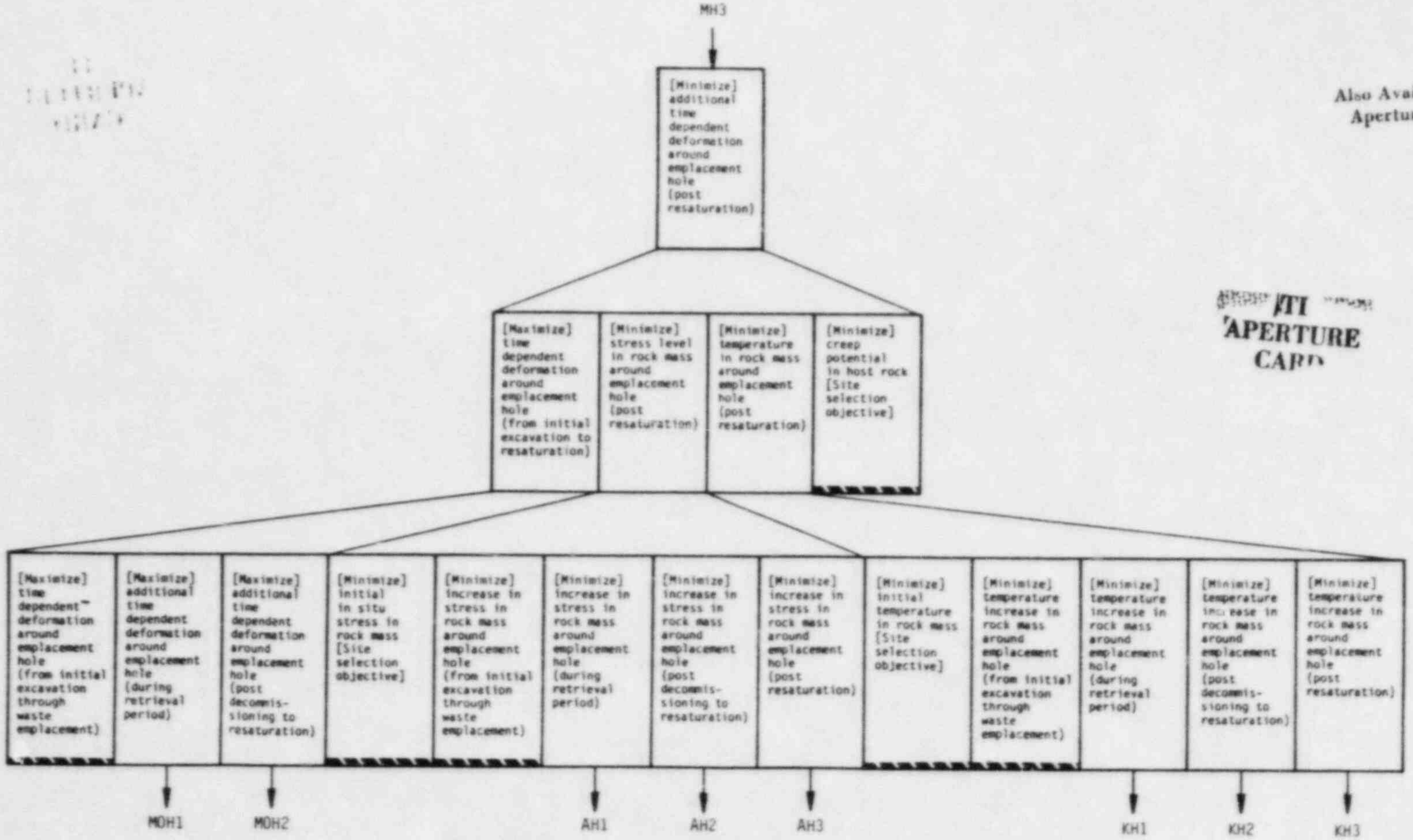
DEVELOPMENT OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES TO REFERENCED COMMON PERFORMANCE SUBOBJECTIVE MH2



Note: Refer to Figure A.2 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down elsewhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▨.

DEVELOPMENT OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES TO REFERENCED COMMON PERFORMANCE SUBOBJECTIVE MH3

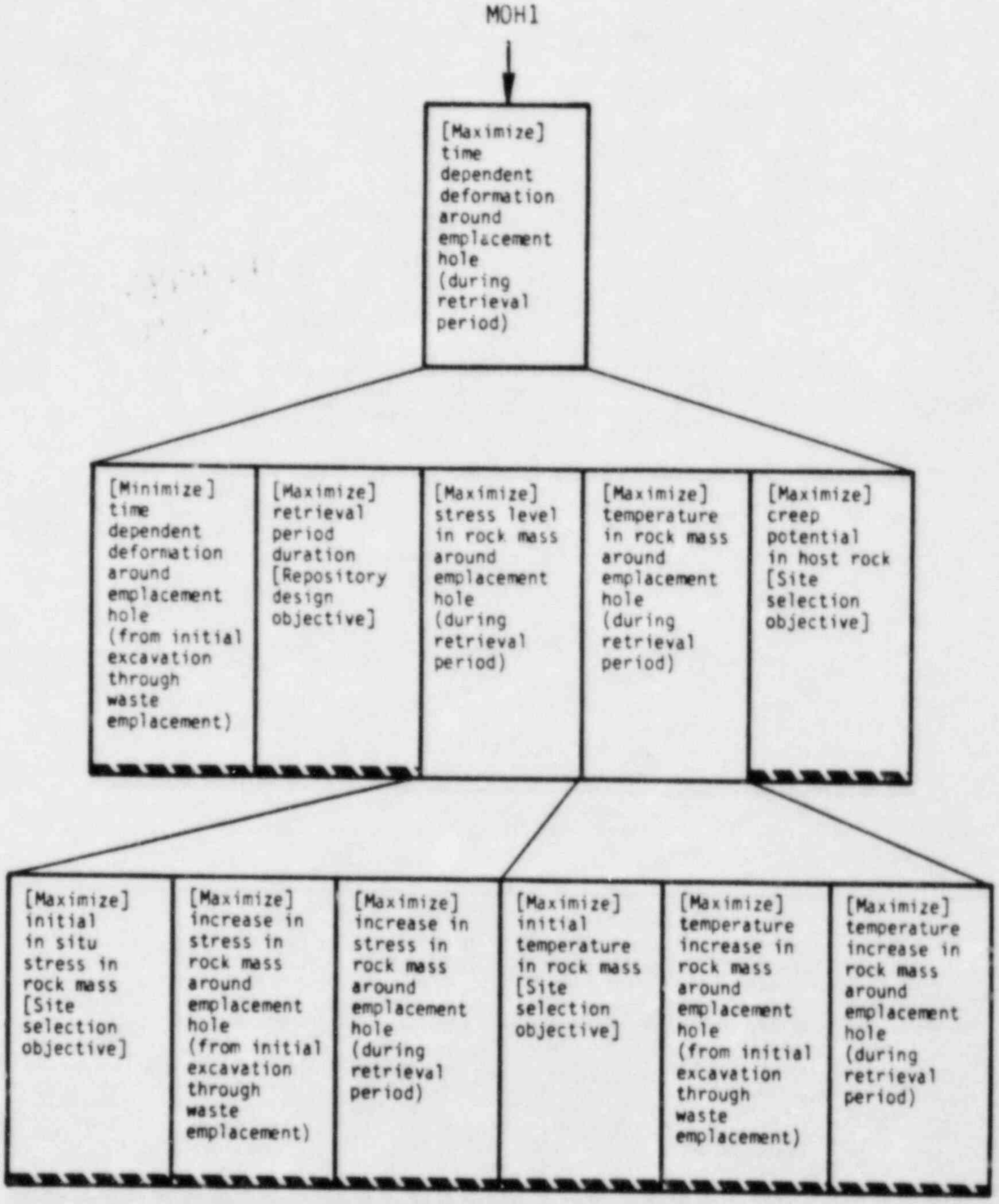
Figure A.62



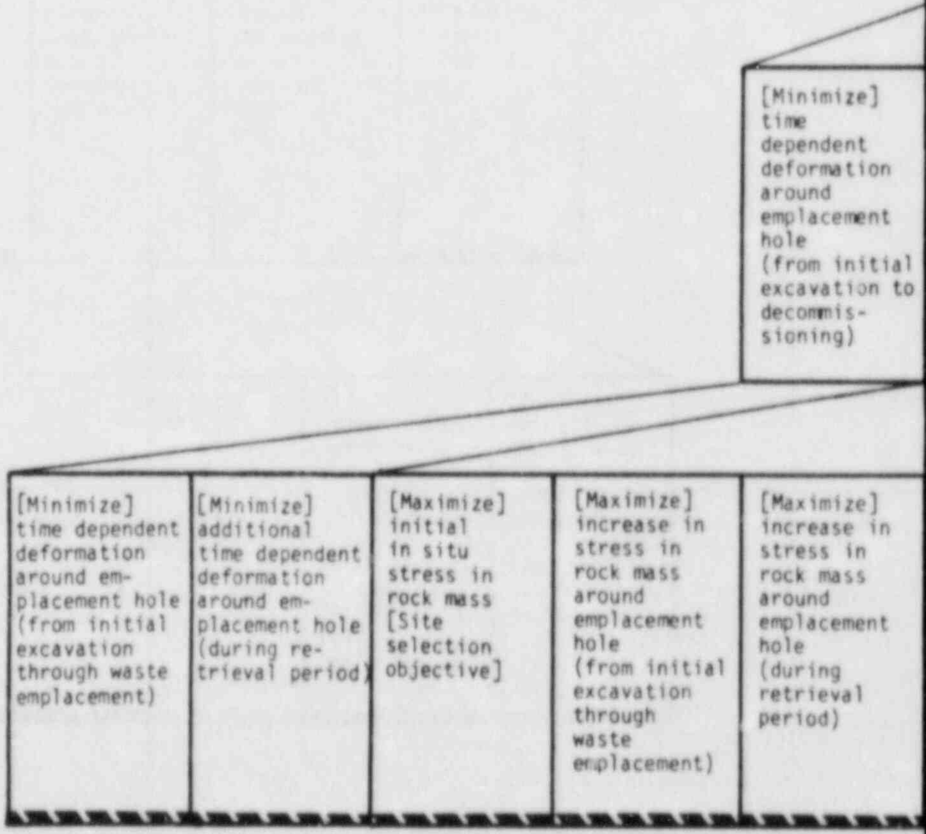
Note: Refer to Figure A.2 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down elsewhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▨▨▨

DEVELOPMENT OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES TO REFERENCED COMMON PERFORMANCE SUBOBJECTIVE MOH1

Figure A.63

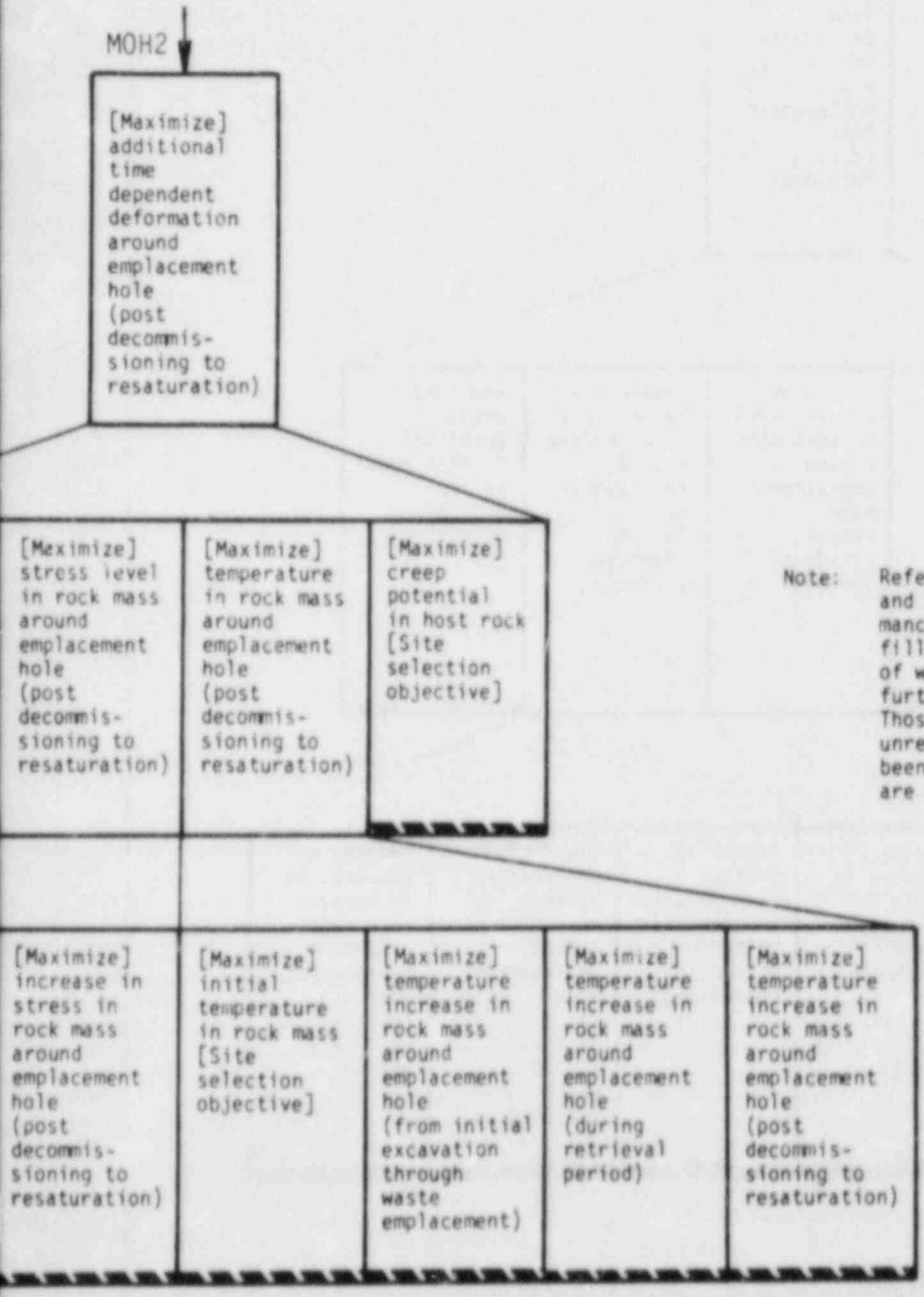


Note: Refer to Figure A.2 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down elsewhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▨▨▨.


[Minimize] time dependent deformation around emplacement hole (from initial excavation to decommis- sioning)
[Minimize] time dependent deformation around em- placement hole (from initial excavation through waste emplacement)
[Minimize] additional time dependent deformation around em- placement hole (during re- trieval period)
[Maximize] initial in situ stress in rock mass [Site selection objective]
[Maximize] increase in stress in rock mass around emplacement hole (from initial excavation through waste emplacement)
[Maximize] increase in stress in rock mass around emplacement hole (during retrieval period)

DEVELOPMENT OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES TO REFERENCED COMMON PERFORMANCE SUBOBJECTIVE MOH2

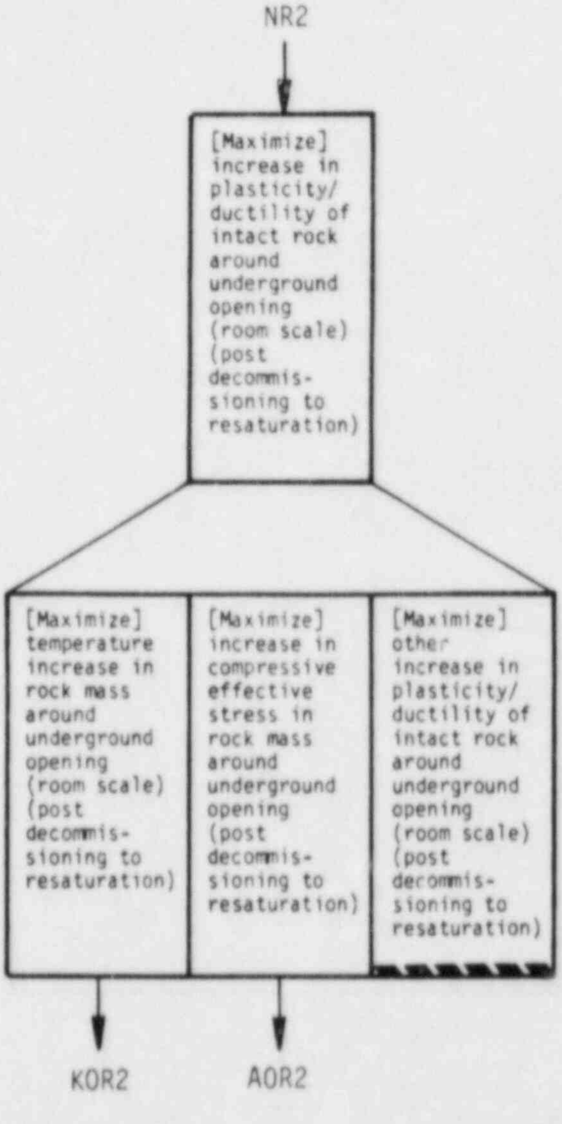
Figure A.64



Note: Refer to Figure A.2 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down elsewhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▬▬▬.

DEVELOPMENT OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES TO REFERENCED COMMON PERFORMANCE SUBOBJECTIVE NR2

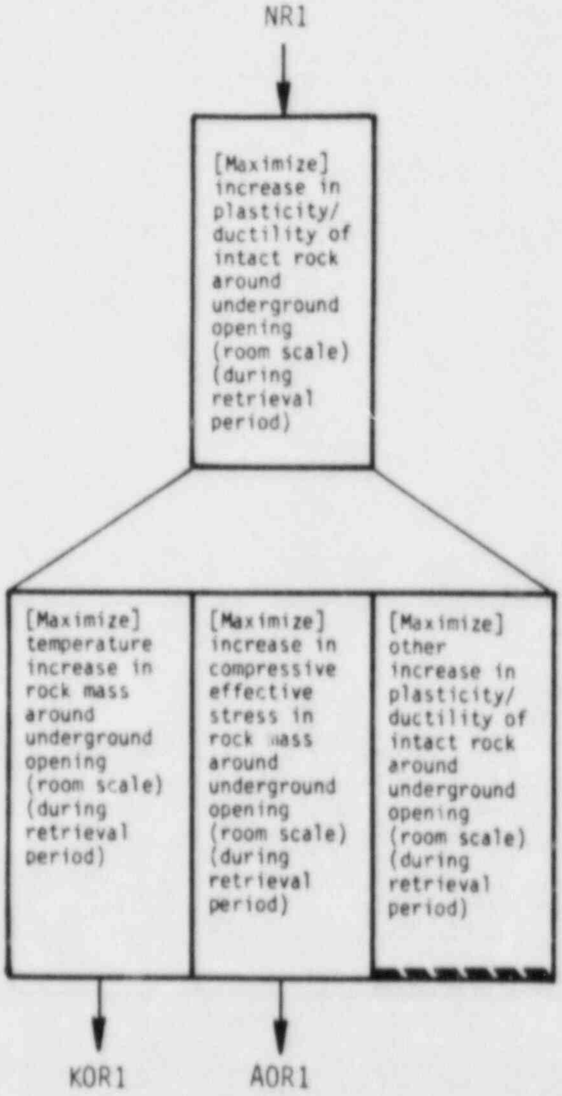
Figure A.66



Note: Refer to Figure A.2 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down elsewhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▬.

DEVELOPMENT OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES TO REFERENCED COMMON PERFORMANCE SUBOBJECTIVE NR1

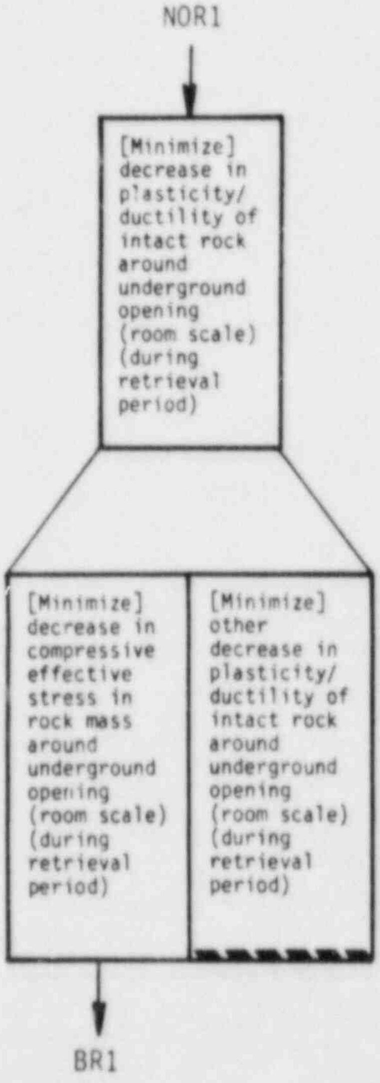
Figure A.65



Note: Refer to Figure A.2 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down elsewhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▬▬▬.

DEVELOPMENT OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES TO REFERENCED COMMON PERFORMANCE SUBOBJECTIVE NOR1

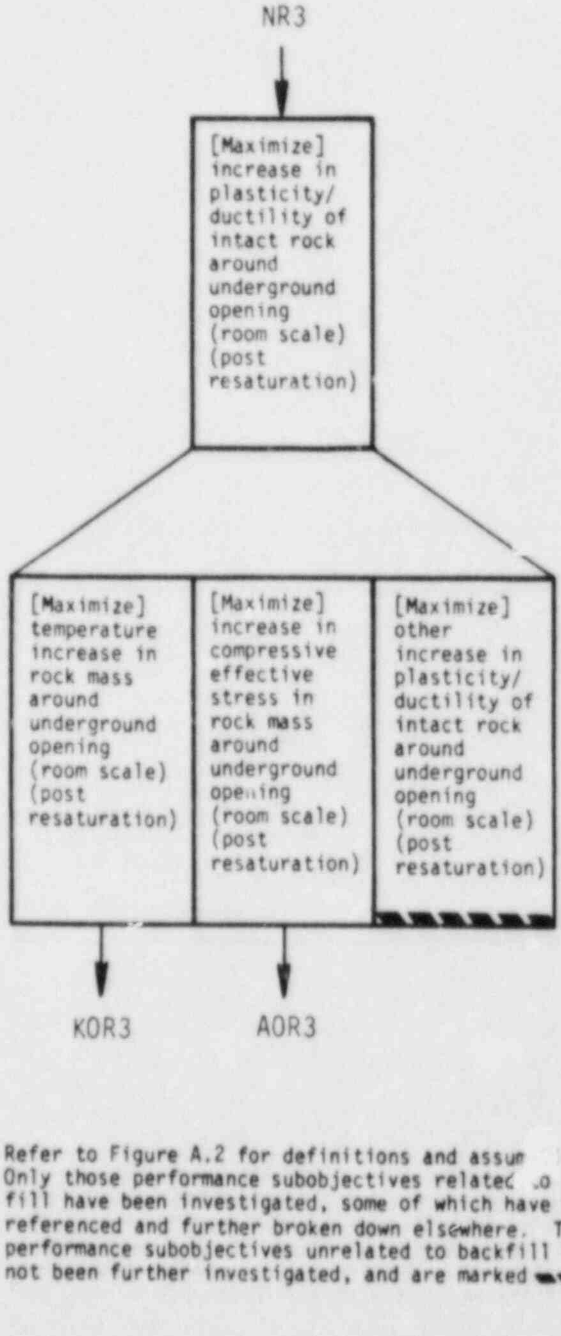
Figure A.68



Note: Refer to Figure A.2 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down elsewhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▬▬▬.

DEVELOPMENT OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES TO REFERENCED COMMON PERFORMANCE SUBOBJECTIVE NR3

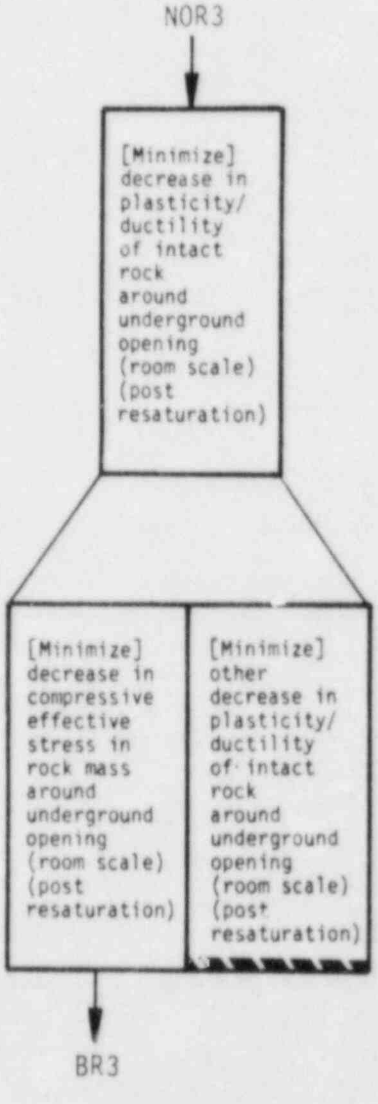
Figure A.67



Note: Refer to Figure A.2 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down elsewhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▨.

DEVELOPMENT OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES TO REFERENCED COMMON PERFORMANCE SUBOBJECTIVE NOR3

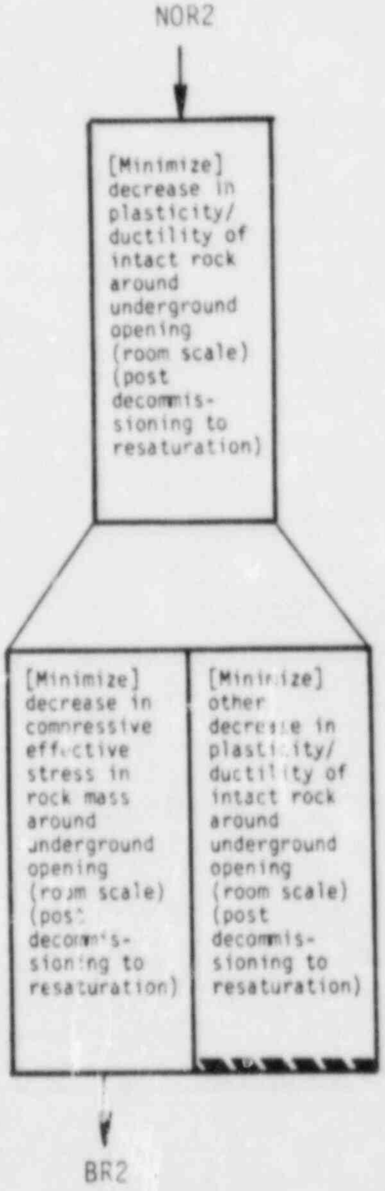
Figure A.70



Note: Refer to Figure A.2 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down elsewhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▬▬▬.

DEVELOPMENT OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES TO REFERENCED COMMON PERFORMANCE SUBOBJECTIVE NOR2

Figure A.69



Note: Refer to Figure A.2 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down elsewhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▬▬▬.

ANNOTATED HIERARCHY OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES TO THE TWO SUMMARY REPOSITORY SYSTEM PERFORMANCE OBJECTIVES

Table A.1
2 of 9

1. (cont.)	1.3 (cont.)	1.3.3 cont.)	JR1	bsrla-1 bsrolb-1 bmr2a-1 bmr02a-1 btrl-1 btrol-1 bhrla-1 bgrl-1
			KR1	bsrolb-1 btrl-1
			bsrla-1 bmr2a-1	
		1.3.4	BH1	bshol-1 bmhl-1 bmh2a-1 bthl-1
			LH1	bshol-1 bthol-1
			bsrla-1 bshl-1 bgr2-1 bgh2-1	
	1.4	1.4.1	bp2-1	
		1.4.2	bp3-1	

ANNOTATED HIERARCHY OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES TO THE TWO SUMMARY REPOSITORY SYSTEM PERFORMANCE OBJECTIVES

Table A.1
1 of 9

1.	1.1			
	1.2			
	1.3	1.3.1		
		1.3.2	bpl-1	
		1.3.3	AR1	bsrla-1 bsrolb-1 bmr2a-1 btrl-1
			AOR1	bsrla-1 bsrolb-1 bmro2a-1 btrol-1
			BR1	bsrla-1 bmr2a-1
			CR1	bsrla-1 bsrolb-1 bmr2a-1 bmr02a-1 btrl-1 btrol-1 bhrla-1 bgrl-1
			DR1	bsrla-1 bmr2a-1

ANNOTATED HIERARCHY OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DES'GN OBJECTIVES TO THE TWO SUMMARY REPOSITORY SYSTEM PERFORMANCE OBJECTIVES

Table A.1
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1. (cont.)	1.4 (cont.)	1.4.3	bsrlb-1		
		1.4.4	bsrla-1 bp4-1 bp5-1		
2.	2.1	2.1.1			
		2.1.2	1.3.3	AR1	bsrla-1 bsrolb-1 bmr2a-1 btrl-1
				AOR1	bsrla-1 bsrolb-1 bmro2a-1 btrol-1
				BR1	bsrla-1 bmr2a-1
				CR1	bsrla-1 bsrolb-1 bmr2a-1 bmro2a-1 btrl-1 btrol-1 bhrla-1 bgrl-1
				DR1	bsrla-1 bmr2a-1
				JR1	bsrla-1 bsrolb-1 bmr2a-1 bmrO2a-1

ANNOTATED HIERARCHY OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES TO THE TWO SUMMARY REPOSITORY SYSTEM PERFORMANCE OBJECTIVES

Table A.1
4 of 9

2. (cont.)	2.1 (cont.)	2.1.2 (cont.)	1.3.3 (cont.)	JR1 (cont.)	btrl-1 btrol-1 bhrla-1 bgrl-1
				KR1	bsrolb-1 btrl-1
				bsrla-1 bmr2a-1	
			AR1	bsrla-1 bsrolb-1 bmr2a-1 btrl-1	
			GH1	bsrla-1 bsrolb-1 bsrolc-1 bshol-1 bmr2a-1 bmr2b-2 bmr2c-2 bmr02a-1 bmr02c-2 bmhl-1 bmh2a-1 btrl-1 btrl-2 btrol-1 btrol-2 bthl-1 bthol-1 bhrla-1 bhrla-2 bhr2-1 bhr2-2 bgrl-1 bgrl-2 bghl-1	

ANNOTATED HIERARCHY OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES TO THE TWO SUMMARY REPOSITORY SYSTEM PERFORMANCE OBJECTIVES

2. (cont.)	2.1 (cont.)	2.1.2 (cont.)	KR1	bsrolb-1 btrl-1
			bsrla-1 bsrola-1 bprl-1 bmrl-1 bmr2a-1	
		2.1.3	GH1	bsrla-1 bsrolb-1 bsrolc-1 bshol-1 bmr2a-1 bmr2b-2 bmr2c-2 bmr02a-1 bmr02c-2 bmhl-1 bmh2a-1 btrl-1 btrl-2 btrol-1 btrol-2 bthl-1 bthol-1 bhrla-1 bhrla-2 bhr2-1 bhr2-2 bgrl-1 bgrl-2 bghl-1
			GH2	bsrla-1 bsrolb-1 bsrolc-1 bshol-1

ANNOTATED HIERARCHY OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES TO THE TWO SUMMARY REPOSITORY SYSTEM PERFORMANCE OBJECTIVES

Table A.1
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2. (cont.)	2.1 (cont.)	2.1.3 (cont.)	GH2 (cont.)	bmr2a-1 bmr2b-2 bmr2c-2 bmro2a-1 bmro2c-2 bmh1-2 bmh2b-2 btr1-1 btr1-2 btro1-1 btro1-2 bth1-1 bth1-2 btho1-2 bhr1a-1 bhr1a-2 bhr2-1 bhr2-2 bgr1-1 bgr1-2 bgh1-2
			GH3	bsho1-1 bmh1-3 bmh2b-3 bth1-1 bth1-2 bth1-3 bth01-3 bgh1-3
	2.2	2.2.1	FR1	bsr1a-1 bsro1b-1 bmr2a-1 bmr02a-1 btr1-1 btro1-1 bhr1a-1 bgr1-1

ANNOTATED HIERARCHY OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES TO THE TWO SUMMARY REPOSITORY SYSTEM PERFORMANCE OBJECTIVES

Table A.1
8 of 9

2. (cont.)	2.2 (cont.)	2.2.2 (cont.)	FR2 (cont.)	bmr02c-2 btr1-1 btr1-2 btro1-1 btro1-2 bhr1a-1 bhr1a-2 bgr1-1 bgr1-2
			FR3	bsr1a-1 bsro1b-1 bmr2a-1 bmr2b-2 bmr2b-3 bmr2c-2 bmr2c-3 bmro2a-1 bmro2c-2 bmr02c-3 btr1-1 btr1-2 btr1-3 btro1-1 btro1-2 btro1-3 bgr1-3
			bhr1a-3 bhr1b-3 bh1-3	
	2.3	2.3.1	bg1-3 bg2-3 bg3-3	
		2.3.2	bg4-3	

ANNOTATED HIERARCHY OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES TO THE TWO SUMMARY REPOSITORY SYSTEM PERFORMANCE OBJECTIVES

Table A.1
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2. (cont.)	2.2 (cont.)	2.2.1 (cont.)	FR2	bsrla-1 bsrolb-1 bmr2a-1 bmr2b-2 bmr2c-2 bmro2a-1 bmro2c-2 btrl-1 btrl-2 btrol-1 btrol-2 bhrla-1 bhrla-2 bgrl-1 bgrl-2
			bsrolc-1 bhrla-2 bhr2-1 bhr2-2	
		2.2.2	FR1	bsrla-1 bsrolb-1 bmr2a-1 bmr02a-1 btrl-1 btrol-1 bhrla-1 bgrl-1
			FR2	bsrla-1 bsrolb-1 bmr2a-1 bmr2b-2 bmr2c-2 bmr02a-1

ANNOTATED HIERARCHY OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES TO THE TWO SUMMARY REPOSITORY SYSTEM PERFORMANCE OBJECTIVES

Table A.1
9 of 9

2. (cont.)	2.4	2.4.1
		2.4.2

NOTE: These performance subobjectives and backfill design objectives have been explicitly derived from the two summary repository system performance objectives (see Figures A.2 to A.70). This development has been based on preconceived repository design concepts (specifically vertical emplacement) and performance assessment methodology (see Section 2 - Main Text); should these premises change, this hierarchy may change. The breakdown of referenced common performance subobjectives down to backfill design objectives (Figures A.16 to A.70) has simply been summarized, as this breakdown sometimes proceeds through numerous levels and, in some cases, loops.

SUMMARY OF BACKFILL DESIGN OBJECTIVES

Table A.2
1 of 4

	BACKFILL DESIGN OBJECTIVES			SOVEREIGN REPOSITORY PERFORMANCE SUBOBJECTIVE(S) (see Figures A.3 to A.70)		
				PERIOD OF CONCERN		
	Scale	Code	Objective	-1) During Retrieval Period	-2) Post Decommissioning To Resaturation	-3) Post Resaturation
SCHEDULE	Room Scale	bsr1a	[Minimize] time to placement of backfill		1.3.3 1.3.4 1.4.4 2.1.2 AR1 BR1 DR1 ER1 JR1 KOR1	
		bsr1b	[Delay and minimize] backfilling of tunnels along possible egress routes	1.4.3		
		bsro1a	[Maximize] time to placement of backfill (room scale)	2.1.2 AOR1		
		bsro1b	[Maximize] time to placement of backfill (room scale), and ventilate	KR1		
		bsro1c	[Maximize] time to start resaturation process (i.e., maximize time to placement of backfill, room scale, while dewatering)	2.2.1		
	Waste Package Scale	bsh1	[Minimize] time to placement of backfill around waste package	1.3.4		
		bsho1	[Maximize] time to placement of backfill around waste package and ventilate	KH1 LH1 LH2 LH3		
PROCEDURES	Room Scale	bor1	[Minimize] volume of backfill (room scale) (if placed during retrieval period)	2.1.2		
	Room and Waste Package Scale	bp1	[Maximize] use of safe/reliable equipment for backfilling	1.3.2		
		bp2	[Maximize] monitoring of potentially hazardous underground conditions as backfilling occurs	1.4.1		
		bp3	[Maximize] quick and efficient mitigation of detected underground hazards as backfilling occurs	1.4.2		
		bp4	[Minimize] personnel requirements for backfilling (i.e., maximize mechanization and remote operations)	1.4.4		
		bp5	[Minimize] total effort required for backfilling (e.g., no backfilling)	1.4.4		

(SEE KEY AT END OF TABLE)

SUMMARY OF BACKFILL DESIGN OBJECTIVES

Table A.2
2 of 4

	BACKFILL DESIGN OBJECTIVES			SOVEREIGN REPOSITORY PERFORMANCE SUBOBJECTIVE(S) (see Figures A.3 to A.70)		
				PERIOD OF CONCERN		
	Scale	Code	Objective	-1) During Retrieval Period	-2) Post Decommissioning To Resaturation	-3) Post Resaturation
MECHANICAL CHARACTERISTICS	Room Scale	bmr1	[Minimize] integrity (compaction) of backfill (room scale) (if placed, during retrieval period)	2.1.2		
		bmr2a	[Maximize] support pressure (or structural support) provided by backfill (room scale)	1.3.3 2.1.2 AR1 BR1 DR1		
		bmr2b	[Maximize] increase in support pressure (or structural support) provided by backfill (room scale)		AR2 BR2	AR3 BR3
		bmr2c	[Minimize] decrease in support pressure (or structural support) provided by backfill (room scale)		AR2 BR2 DR2	AR3 BR3 DR3
		bmro2a	[Minimize] support pressure (or structural support) provided by backfill (room scale)	AOR1		
		bmro2c	[Maximize] decrease in support pressure (or structural support) provided by backfill (room scale)		AOR2	AOR3
	Waste Package Scale	bmh1	[Minimize] stress transfer through backfill around waste package	BH1	BH2	BH3
		bmh2a	[Minimize] swelling pressure of backfill around waste package	BH1		
		bmh2b	[Minimize] increase in swelling pressure of backfill around waste package		BH2	BH3
THERMAL CHARACTERISTICS	Room Scale	btr1	[Maximize] insulation of waste package from rock mass around underground opening (room scale)	KR1	KR2	KR3
		btro1	[Minimize] insulation of waste package from rock mass around underground opening (room scale)	KOR1	KOR2	KOR3
	Waste Package Scale	bth1	[Maximize] insulation of waste package from rock mass around emplacement hole	KH1	KH2	KH3
		btho1	[Minimize] insulation of waste package from rock mass around emplacement hole	LH1	LH2	LH3

(SEE KEY AT END OF TABLE)

SUMMARY OF BACKFILL DESIGN OBJECTIVES

Table A.2
3 of 4

	BACKFILL DESIGN OBJECTIVES			SOVEREIGN REPOSITORY PERFORMANCE SUBOBJECTIVE(S) (see Figures A.3 to A.70)		
				PERIOD OF CONCERN		
	Scale	Code	Objective	-1) During Retrieval Period	-2) Post Decommissioning To Resaturation	-3) Post Resaturation
HYDROLOGIC CHARACTERISTICS	Room Scale	bhr1a	[Minimize] hydraulic conductivity (and effective porosity) of backfill and interface (room scale)	ER1	ER2	2.2.2
		bhr1b	[·imize] decrease in hydraulic conductivity (and effective porosity) of rock mass (room scale) (i.e., sealing/filling of discontinuities) by backfill			2.2.2
		bhr2	[Maximize] porosity of backfill (room scale)	2.2.1	2.2.1	
	Room and Waste Package Scale	bh1	[Maximize] distance from waste package through repository along flow path due to backfill			2.2.2
GEOCHEMICAL CHARACTERISTICS	Room Scale	bgr1	[Maximize] protection of exposed rock surface underground (room scale) by backfill	JR1	JR2	JR3
		bgr2	[Maximize] thickness/adsorption of backfill (room scale)	1.3.4		
	Waste Package Scale	bgh1	[Maximize] mitigation of corrosive groundwater by backfill	GH1	GH2	GH3
		bgh2	[Maximize] thickness/adsorption of backfill around waste package	1.1.[illegible]		
	Room and Waste Package Scale	bg1	[Maximize] length of flow path from waste package through backfill adsorbing material			2.3.1
		bg2	[Maximize] cross-sectional area of flow path from waste package through backfill adsorbing material (i.e., maximize volume of backfill)			2.3.1
		bg3	[Maximize] surface area per unit volume of backfill adsorbing material along flow path from waste package			2.3.1
		bg4	[Maximize] adsorption potential of backfill along flow path from waste package to accessible environment			2.3.2

(SEE KEY AT END OF TABLE)

KEY FOR CODE:

	Subject of Concern	Scale	Opposite to Identifier No.	Identifier No.	Similarity with Identifier No.		Time Period
b	s=schedule p=procedure m=mechanical t=thermal h=hydrologic g=geochemical	r=room scale h=waste package scale blank=room and waste package scale	blank o=opposite objective	1 2 3 . . .	blank a=similar b= " c= " . .	=	1=during retrieval period 2=post decommissioning to resaturation 3=post resaturation

For example:

b	s	r		1	a	=	1

Note: These backfill design objectives have been explicitly derived from the repository system performance objectives (see Table A.1). This development has been based on preconceived repository design concepts (specifically vertical waste emplacement) and performance assessment methodology (see Section 2 - Main Text); should these premises change, the objectives may change.

APPENDIX B
WEIGHTING OF BACKFILL DESIGN OBJECTIVES

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LIST OF FIGURES (Cont.)

LIST OF FIGURES (Cont.)

LIST OF FIGURES (Cont.)

LIST OF TABLES

LIST OF FIGURES (Cont.)

APPENDIX B - WEIGHTING OF BACKFILL DESIGN OBJECTIVES

In the absence of accepted backfill designs, or even objectives, it has been necessary to generate a reasonable comprehensive backfill design basis for the purpose of this study. However, backfill (if used) will be an integral component of a very complex repository system. Due to this complexity, a systematic and trackable, albeit simple, approach has been adopted to generate this backfill design basis. This approach (see Section 3 - Main Text) consists of assessing the relative weights for the comprehensive set of backfill design objectives previously identified (see Appendix A). This can be accomplished by first assessing the relative weight of each performance subobjective in a comprehensive (and yet tractable) set with respect to achieving its immediate sovereign subobjective, and then compounding the relative weights of subjectives through the hierarchy of repository performance subobjectives.

This assessment can be based on each subobjective's perceived potential contribution to achieving its immediate sovereign subobjective, relative to the other subordinate subobjectives in the comprehensive set. This potential contribution will in turn be based on both the relationship, or sensitivity, of the sovereign subobjective to that subordinate subobjective, as evidenced in the performance assessment methodology, and the possible range in achieving the subordinate subobjective. As some of the subordinate subobjectives are achieved to a certain degree with time, e.g., by site selection or repository design, the weights of the remaining subobjectives in the comprehensive set must be adjusted. Hence, only the remaining subobjectives (i.e., variables) would subsequently be considered.

The relative weight of any subobjective in the hierarchy with respect to achieving the repository system performance objectives can subsequently be assessed by simply multiplying the relative weight of that subobjective with respect to achieving its sovereign subobjective by the relative weight of that sovereign subobjective with respect to achieving its sovereign subobjective, and so on up the hierarchy. For a comprehensive set of subobjectives to the repository system performance objectives, the relative weights of these subobjectives (with respect to achieving the repository system performance objectives) must sum to one. For any subobjective which occurs in more than one place (i.e., for different reasons), its effective relative weight with respect to achieving the repository system performance objectives will equal the summation of its relative weight for each occurrence. These weights will be based on preconceived repository design concepts and performance assessment methodology, as well as on any already satisfied objectives (e.g., media/site specific conditions) (see Section 2 - Main Text).

For <u>example</u> (ref. Figure A.1):

> The effects of potential changes in "l", "m", and "n" on "a" might be assessed, with changes in "n" potentially contributing most to

the objective of minimizing "a" (see Figure B.1). By comparing these perceived potential contributions, the relative weight of each subobjective with respect to achieving its immediate sovereign subobjective can be roughly assessed; e.g., the relative weights of achieving the objectives of decreasing "l" and "n" and increasing "m", with respect to achieving their sovereign objective of minimizing "a", might be subjectively assessed to be about (0.1), (0.6), and (0.3), respectively. Even though the relationship between each subobjective and its sovereign subobjective will not typically be linear nor always monotonic, such an assessment will give an indication of the relative significance of each subobjective and is deemed sufficient for the purposes of this study.

The relative weight of each subobjective in the hierarchy of repository performance subobjectives with respect to achieving its immediate sovereign subobjective can be assessed in this manner.

The weights of each subobjective with respect to achieving the repository system performance objectives can then be found by multiplication; e.g., the relative weights of achieving the subobjectives of decreasing "l" and "n" and increasing "m", with respect to achieving the repository system performance objectives, would be (0.014), (0.042), and (0.084), respectively (see Figure B.2).

Using the above approach, the relative weights of less detailed performance subobjectives have been subjectively assessed, both with respect to achieving their sovereign subobjective and subsequently with respect to achieving the repository system performance objectives (see Figure B.3). These weights have been based on assumed repository design concepts, performance assessment methodology and generic site conditions (see Section 2 - Main Text); should these premises change, these weights may change, especially at the more detailed level. Similarly, as specific subobjectives are achieved to some degree and are no longer variable, the weights of the remaining subobjectives must be modified. Hence, these assessed weights will change with time as repository development proceeds through site screening/selection and repository design/construction/operation.

The performance subobjectives at the most detailed level in the hierarchy have been further broken down until backfill design objectives or common performance subobjectives have been identified; similarly, the referenced common performance subobjectives have also been further broken down (see Appendix A). However, in both cases only those performance subobjectives which are perceived to be significantly related to backfill have been pursued. If all performance subobjectives had been broken down completely and weighted, then comprehensive sets of weighted objectives related solely to either site screening/selection or repository design/construction/operation (i.e., the repository variables) would have been identified; weighted backfill design objectives constitute a subset of the weighted repository design/construction/operation objectives.

In this Appendix B, the performance subobjectives and backfill design objectives which are subordinate to the following performance subobjectives (Figure B.3) have been weighted, both with respect to achieving their immediate sovereign subobjective and subsequently with respect to achieving the repository system performance objectives:

1.3.2 (see Figure B.4)
1.3.3 (see Figure B.5)
1.3.4 (see Figure B.6)
1.4.1 (see Figure B.7)
1.4.2 (see Figure B.8)
1.4.3 (see Figure B.9)
1.4.4 (see Figure B.10)
2.1.2 (see Figure B.11)
2.1.3 (see Figure B.12)
2.2.1 (see Figure B.13)
2.2.2 (see Figure B.14)
2.3.1 (see Figure B.15)
2.3.2 (see Figure B.16).

The performance subobjectives and backfill design objectives which are subordinate to referenced common performance subobjectives have also been weighted, both with respect to achieving their immediate sovereign subobjective and subsequently with respect to achieving the referenced subobjective (see Figures B.17 to B.71).

Using the assessed weights of each of the referenced common performance subobjectives and backfill design objectives with respect to achieving their sovereign subobjectives (Figures B.4 to B.71), the weights of performance subobjectives and backfill design objectives within the annotated hierarchy with respect to achieving the two summary repository system performance objectives (ref. Table A.1) have been determined (see Table B.1). These weights have been determined by simply compounding down through the hierarchy. Where a loop has formed in the hierarchy, enough iterations have been taken through the loop to achieve an accuracy of at least 10^{-8}.

Hence, the weight of each occurrence of a backfill design objective with respect to achieving the repository system performance objectives has been explicitly assessed in a trackable manner (Table B.1). The cumulative weight of each backfill design objective with respect to achieving the repository system performance objectives has been subsequently determined by summing the weights of each occurrence of that objective throughout the annotated hierarchy. These relative weights of backfill design objectives have been summarized, categorized by area of concern of the objective (see Table B.2) and prioritized by relative weight of the objective (see Table B.3).

It must be emphasized that the relative weights of performance subobjectives, culminating in weights of backfill design objectives, have been subjectively assessed based on assumed repository design concepts (specifically vertical waste emplacement), performance assessment methodology, and generic site conditions (see Section 2 - Main Text). These weights will change as these premises change, which will necessarily occur with time as specific subobjectives are achieved and are no longer variable, e.g., once a site has been selected those subobjectives related to site selection are partially achieved and become premises for the others. Hence, the weights of the identified backfill design objectives should be considered valid only for the given repository design concepts, performance assessment methodology, and site conditions.

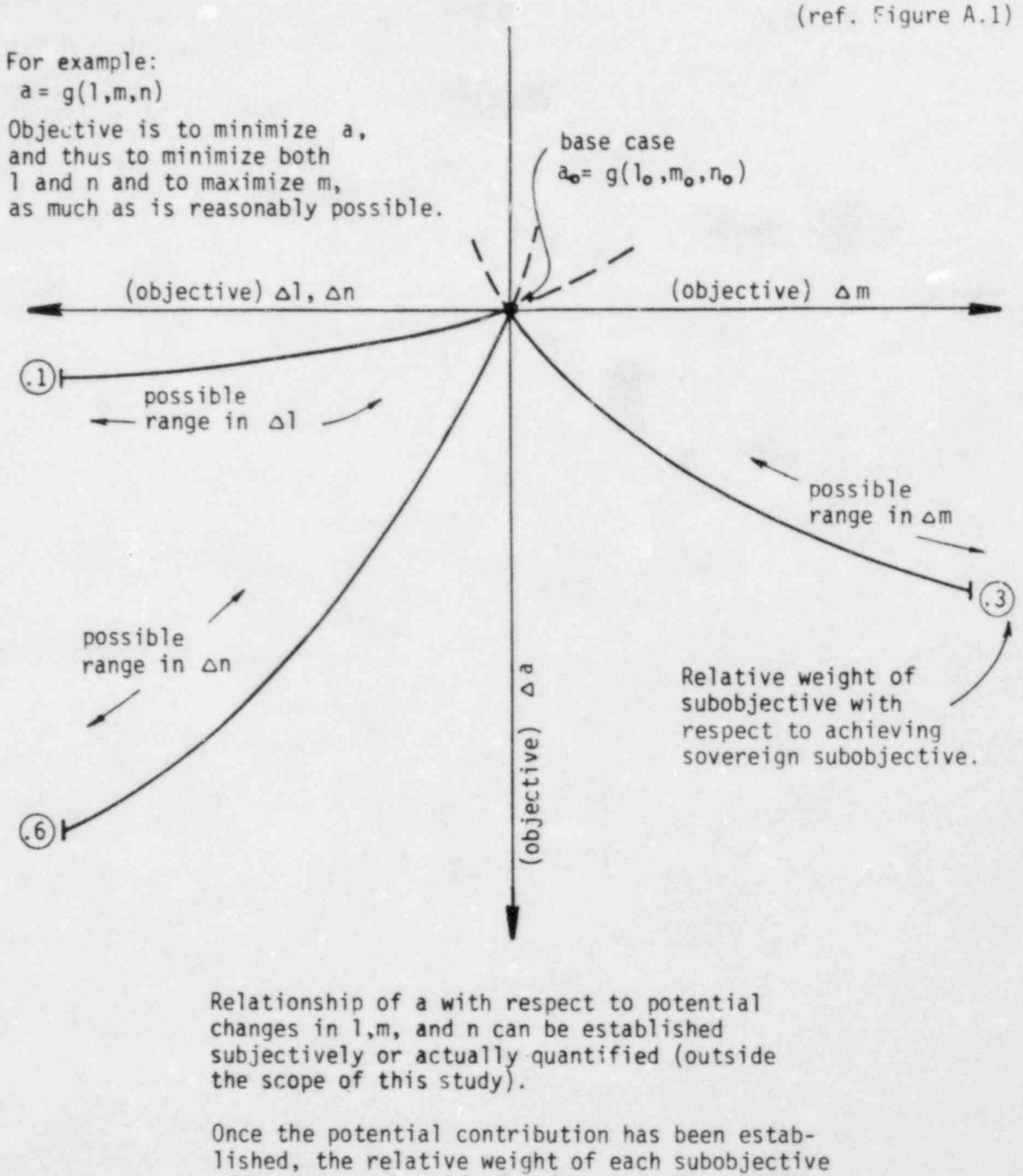
Areas of technical disagreement regarding the significance, or weights, of backfill design objectives can be identified and resolved, e.g., by doing sensitivity analyses and subsequently modifying the assessed weights. Similarly, updating the weights, as more information becomes available or as decisions regarding repository variables are made, can easily be done.

In addition, due to the subjective nature of the weight assessments, these weights entail significant inherent uncertainty. This uncertainty can be reduced, for example, by doing sensitivity analyses. However, in the meantime, these weights (Tables B.2 and B.3) should be considered as only qualitative indicators of the relative significance of each backfill design objective with respect to achieving the repository system performance objectives for generic site conditions.

Hence, the weights of a comprehensive set of backfill design objectives, with respect to achieving the repository system performance objectives, have been subjectively but explicitly assessed (Tables B.2 and B.3). These weights have been explicitly determined within the context of backfill as an integral component of the repository system (Table B.1). This comprehensive set of weighted backfill design objectives constitutes the generic backfill design basis which will be used in this study to comparatively evaluate alternative backfill schemes with respect to the implementation and verification of design. Although sufficient for this purpose, this backfill design basis would have to be refined and verified on a site-specific basis by quantitative performance assessment for design purposes.

WEIGHTING OF SUBORDINATE PERFORMANCE SUBOBJECTIVES WITH RESPECT TO THEIR SOVEREIGN SUBOBJECTIVE (EXAMPLE)

Figure B.1



(ref. Figure A.1)

For example:

$a = g(l, m, n)$

Objective is to minimize a, and thus to minimize both l and n and to maximize m, as much as is reasonably possible.

base case

$a_o = g(l_o, m_o, n_o)$

Relative weight of subobjective with respect to achieving sovereign subobjective.

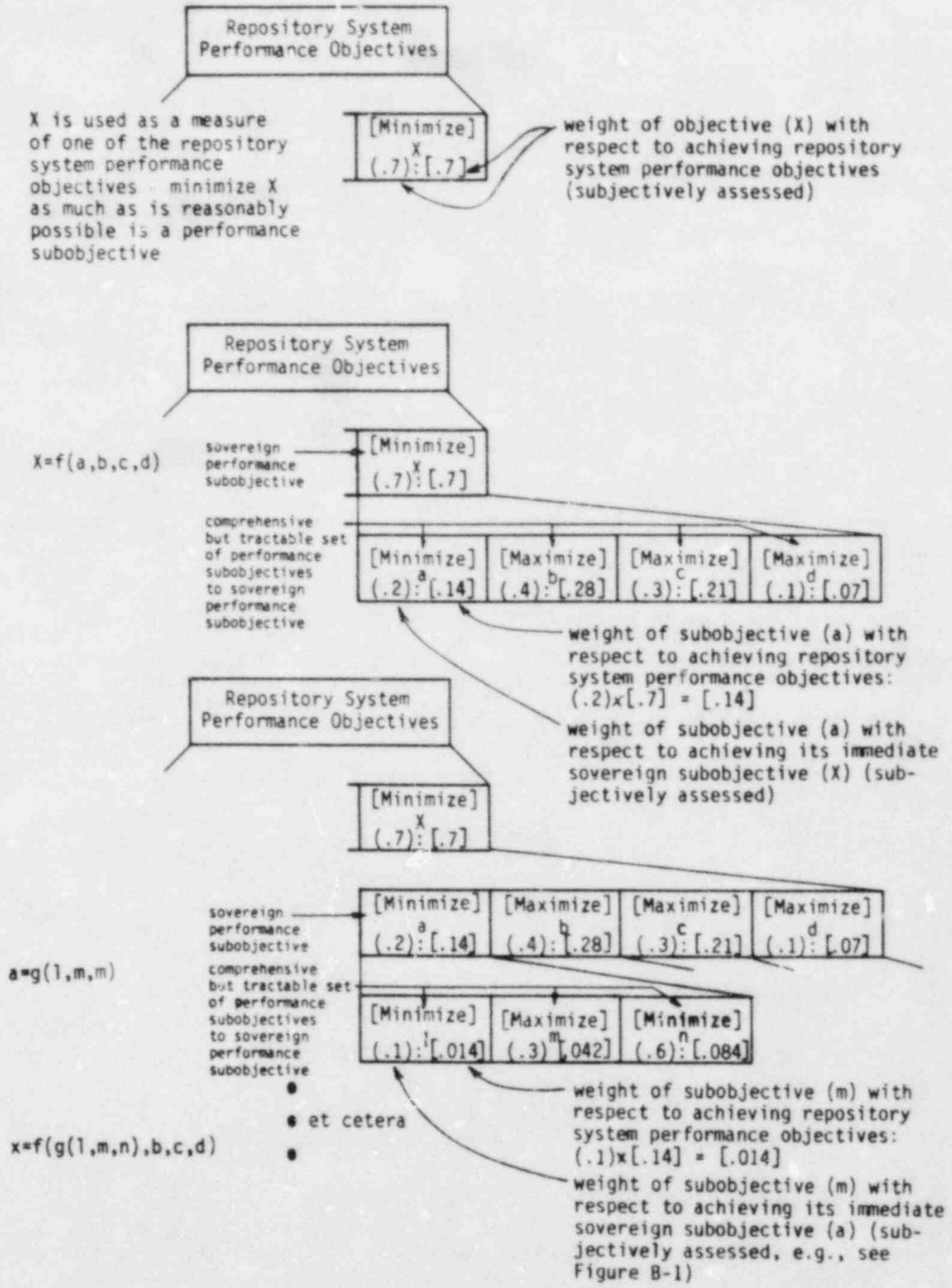
Relationship of a with respect to potential changes in l,m, and n can be established subjectively or actually quantified (outside the scope of this study).

Once the potential contribution has been established, the relative weight of each subobjective with respect to achieving its sovereign subobjective can be subjectively assessed as a fraction of 1.0. This relative weight should be considered as only a rough indicator of relative significance.

WEIGHTING OF PERFORMANCE SUBOBJECTIVES (EXAMPLE)

Figure B.2

(ref. Figure A.1)



Note: Weights of a comprehensive set of subobjectives with respect to any sovereign subobjective must sum to 1.0. The relative weight of each subobjective to achieving the repository system performance objectives so derived is based on preconceived repository design concepts, site conditions, and performance assessment methodology; should these premises change, the weights may change. Also, the weights entail significant subjectivity in their assessment, and should thus be considered only as approximate indicators of relative significance.

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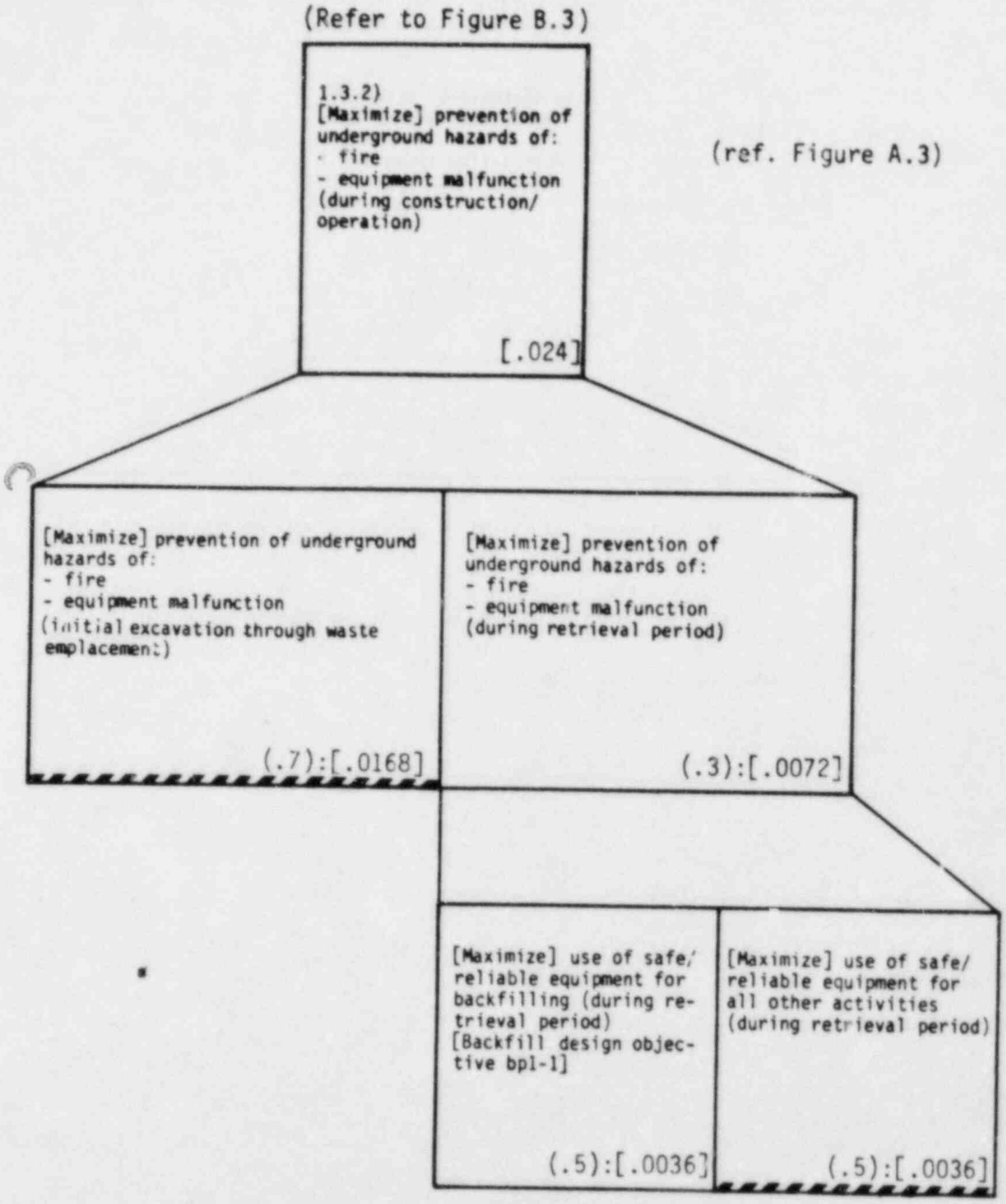
WEIGHTS OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES WITH RESPECT TO PERFORMANCE SUBOBJECTIVE 1.3.2

Figure B.4



Note: Refer to Figure B.3 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down eleswhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▨.

The relative weight of each subobjective to achieving the repository system performance objective is based on preconceived repository design concepts, generic site conditions, and performance assessment methodology (see Section 2 of Main Text); should these premises change, the weights may change. Also, the weights entail significant subjectivity in their assessment, and should thus be considered only as approximate indicators of relative significance.

Note: Refer to Figure B.3 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down elsewhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▬▬.

The relative weight of each subobjective to achieving the repository system performance objective is based on preconceived repository design concepts, generic site conditions, and performance assessment methodology (see Section 2 of Main Text); should these premises change, the weights may change. Also, the weights entail significant subjectivity in their assessment, and should thus be considered only as approximate indicators of relative significance.

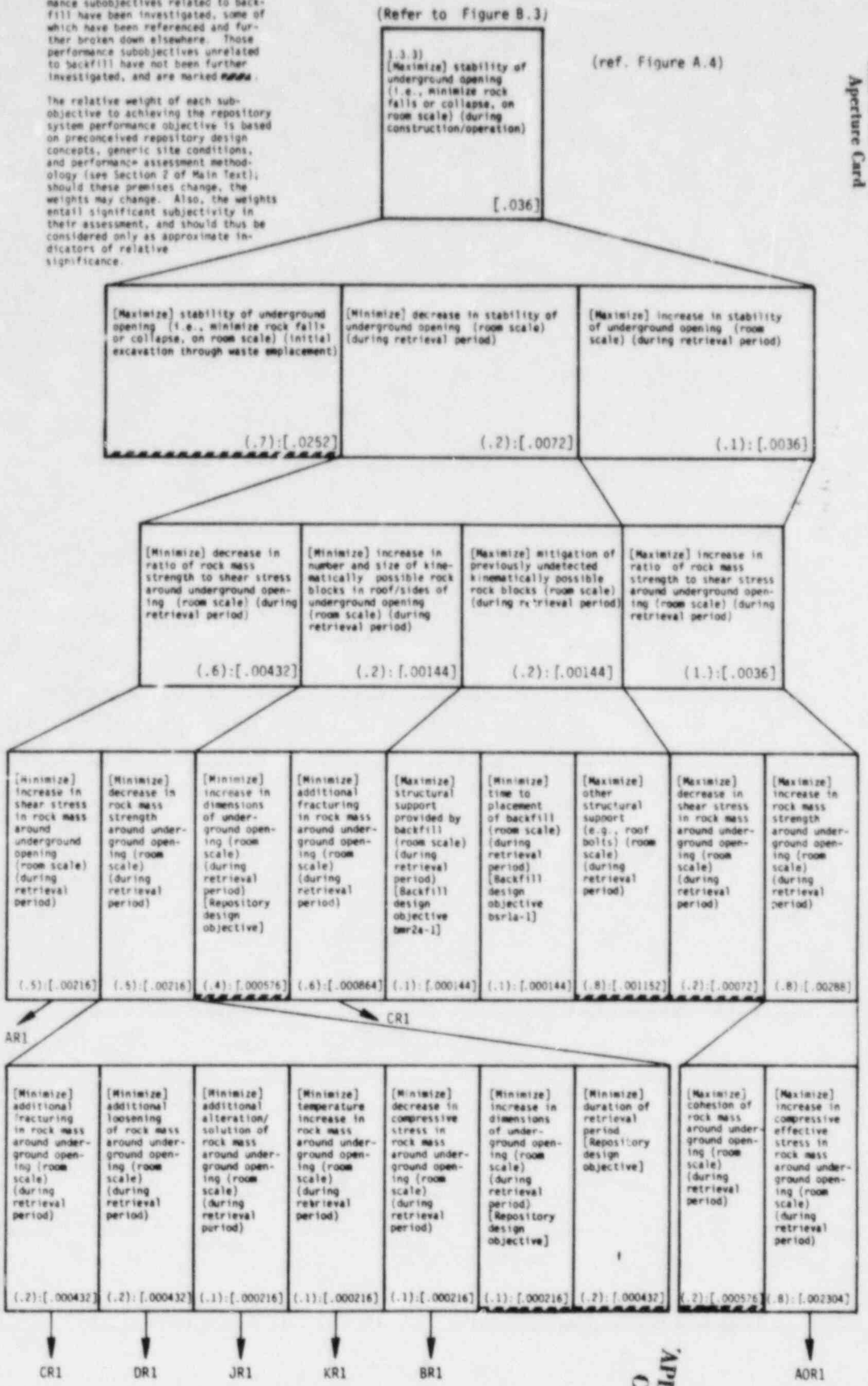


Figure B.5 WEIGHTS OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES WITH RESPECT TO PERFORMANCE SUBOBJECTIVE 1.3.3

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Note: Refer to Figure B.3 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down elsewhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▨▨▨▨ .

The relative weight of each subobjective to achieving the repository system performance objective is based on preconceived repository design concepts, generic site conditions, and performance assessment methodology (see Section 2 of Main Text); should these premises change, the weights may change. Also, the weights entail significant subjectivity in their assessment, and should thus be considered only as approximate indicators of relative significance.

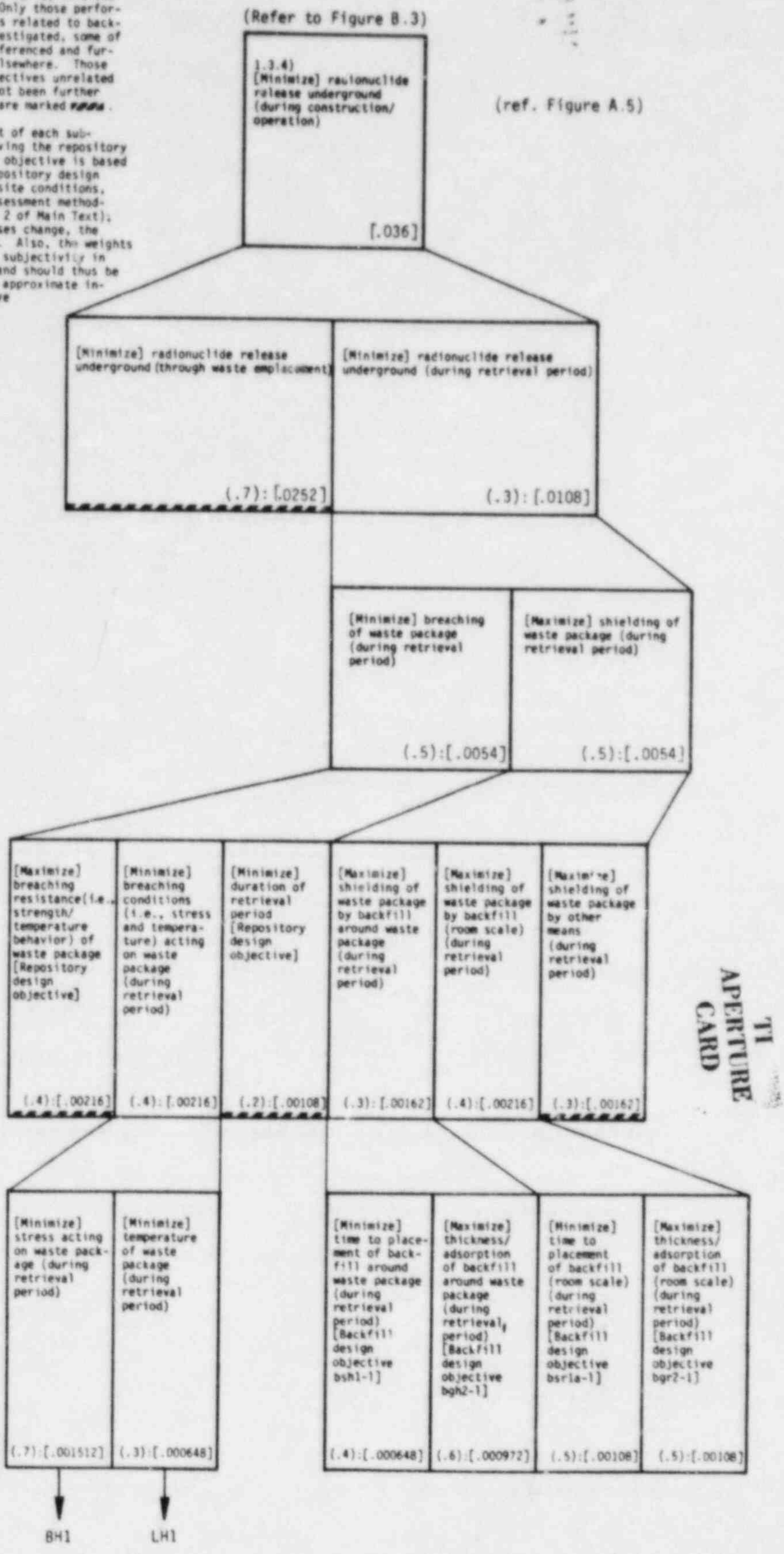
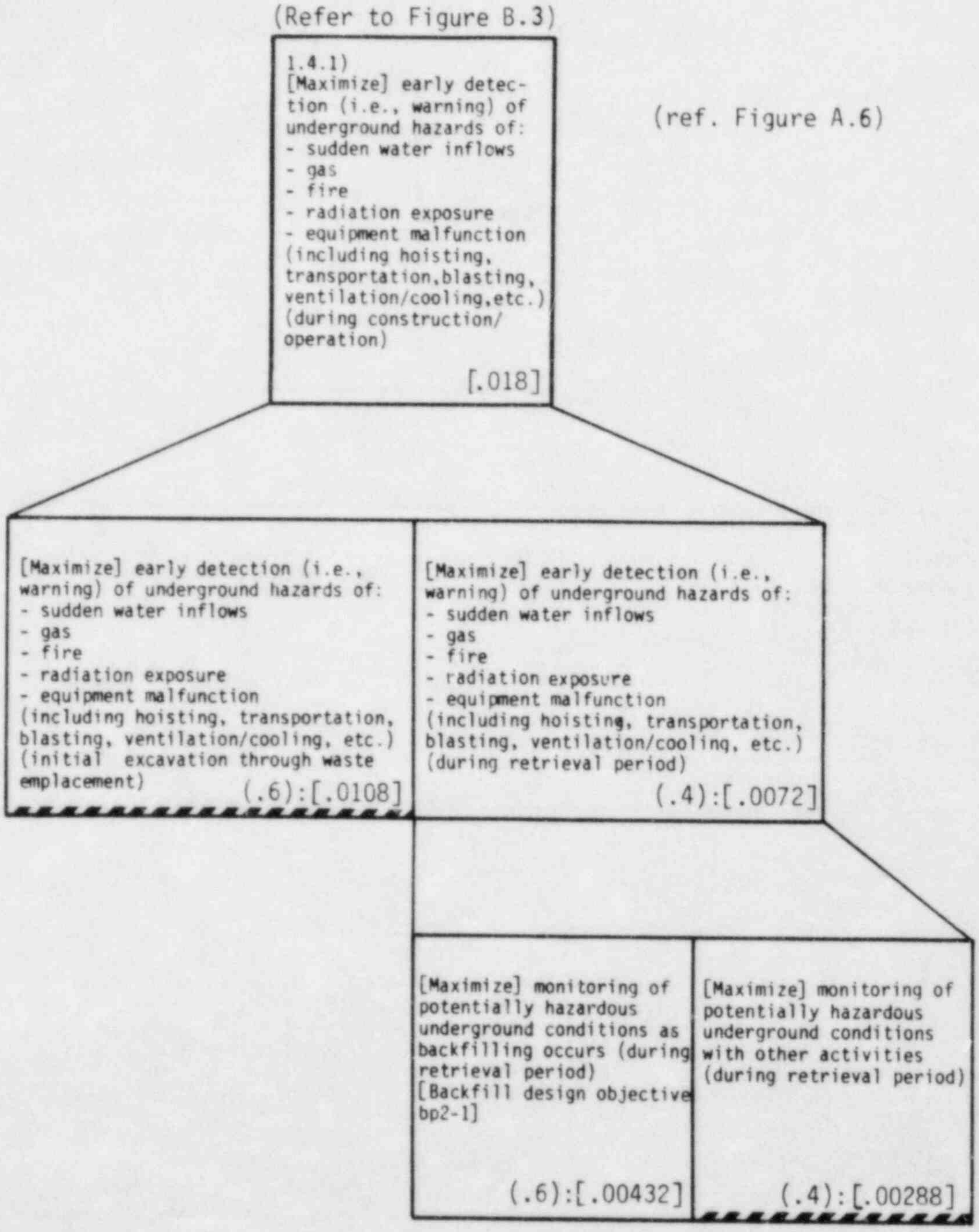


Figure B.6 WEIGHTS OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES WITH RESPECT TO PERFORMANCE SUBOBJECTIVE 1.3.4

WEIGHTS OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES WITH RESPECT TO PERFORMANCE SUBOBJECTIVE 1.4.1

Figure B . 7



(Refer to Figure B.3)

1.4.1)
[Maximize] early detection (i.e., warning) of underground hazards of:
- sudden water inflows
- gas
- fire
- radiation exposure
- equipment malfunction

(including hoisting, transportation, blasting, ventilation/cooling, etc.) (during construction/ operation)

[.018]

(ref. Figure A.6)

[Maximize] early detection (i.e., warning) of underground hazards of:
- sudden water inflows
- gas
- fire
- radiation exposure
- equipment malfunction

(including hoisting, transportation, blasting, ventilation/cooling, etc.) (initial excavation through waste emplacement)

(.6):[.0108]

[Maximize] early detection (i.e., warning) of underground hazards of:
- sudden water inflows
- gas
- fire
- radiation exposure
- equipment malfunction

(including hoisting, transportation, blasting, ventilation/cooling, etc.) (during retrieval period)

(.4):[.0072]

[Maximize] monitoring of potentially hazardous underground conditions as backfilling occurs (during retrieval period)
[Backfill design objective bp2-1]

(.6):[.00432]

[Maximize] monitoring of potentially hazardous underground conditions with other activities (during retrieval period)

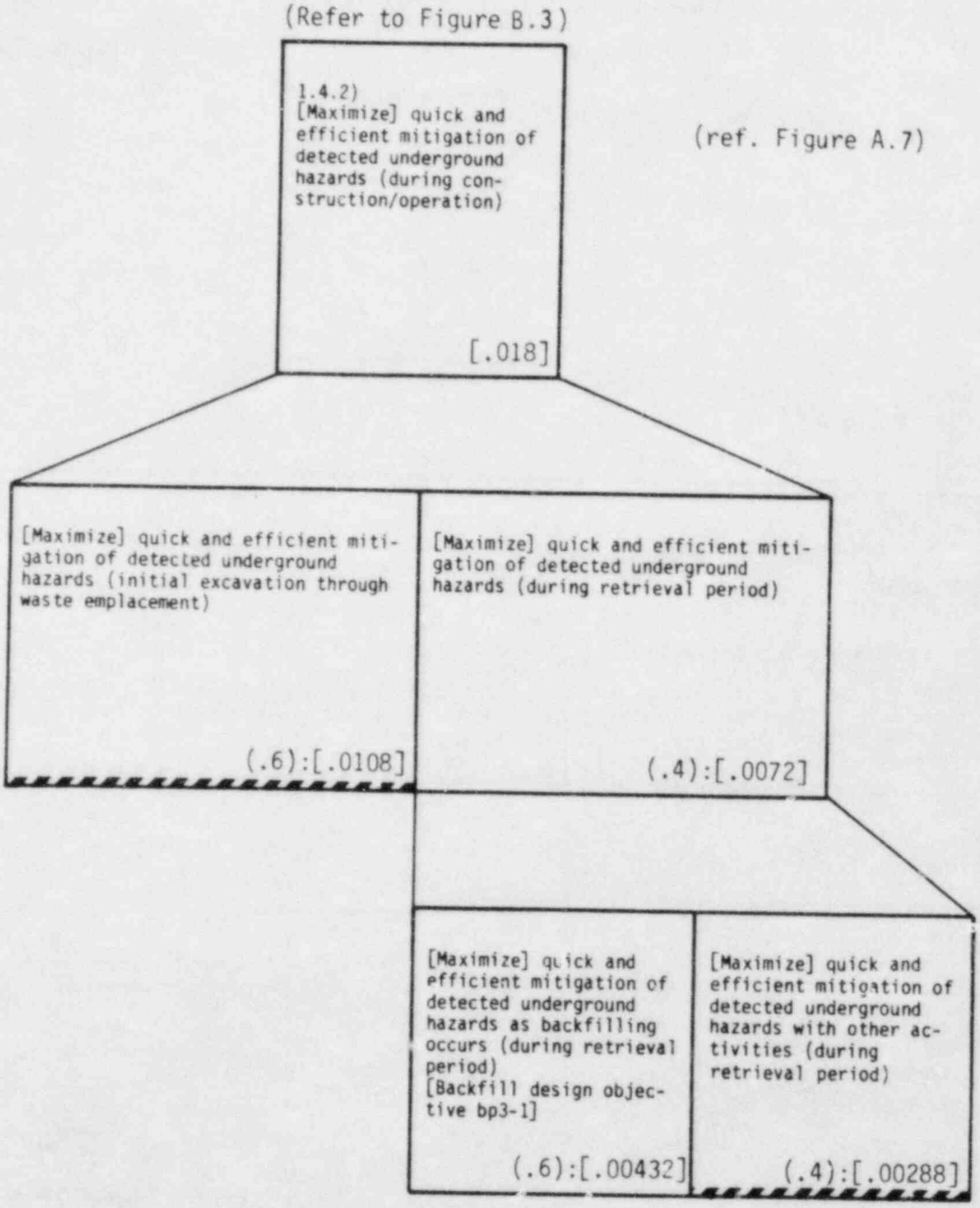
(.4):[.00288]

Note: Refer to Figure B.3 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down elsewhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▰▰▰▰.

The relative weight of each subobjective to achieving the repository system performance objective is based on preconceived repository design concepts, generic site conditions, and performance assessment methodology (see Section 2 of Main Text); should these premises change, the weights may change. Also, the weights entail significant subjectivity in their assessment, and should thus be considered only as approximate indicators of relative significance.

WEIGHTS OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES WITH RESPECT TO PERFORMANCE SUBOBJECTIVE 1.4.2

Figure B . 8


(Refer to Figure B.3)

1.4.2)
[Maximize] quick and efficient mitigation of detected underground hazards (during construction/operation)
[.018]

(ref. Figure A.7)

[Maximize] quick and efficient mitigation of detected underground hazards (initial excavation through waste emplacement)
(.6):[.0108]

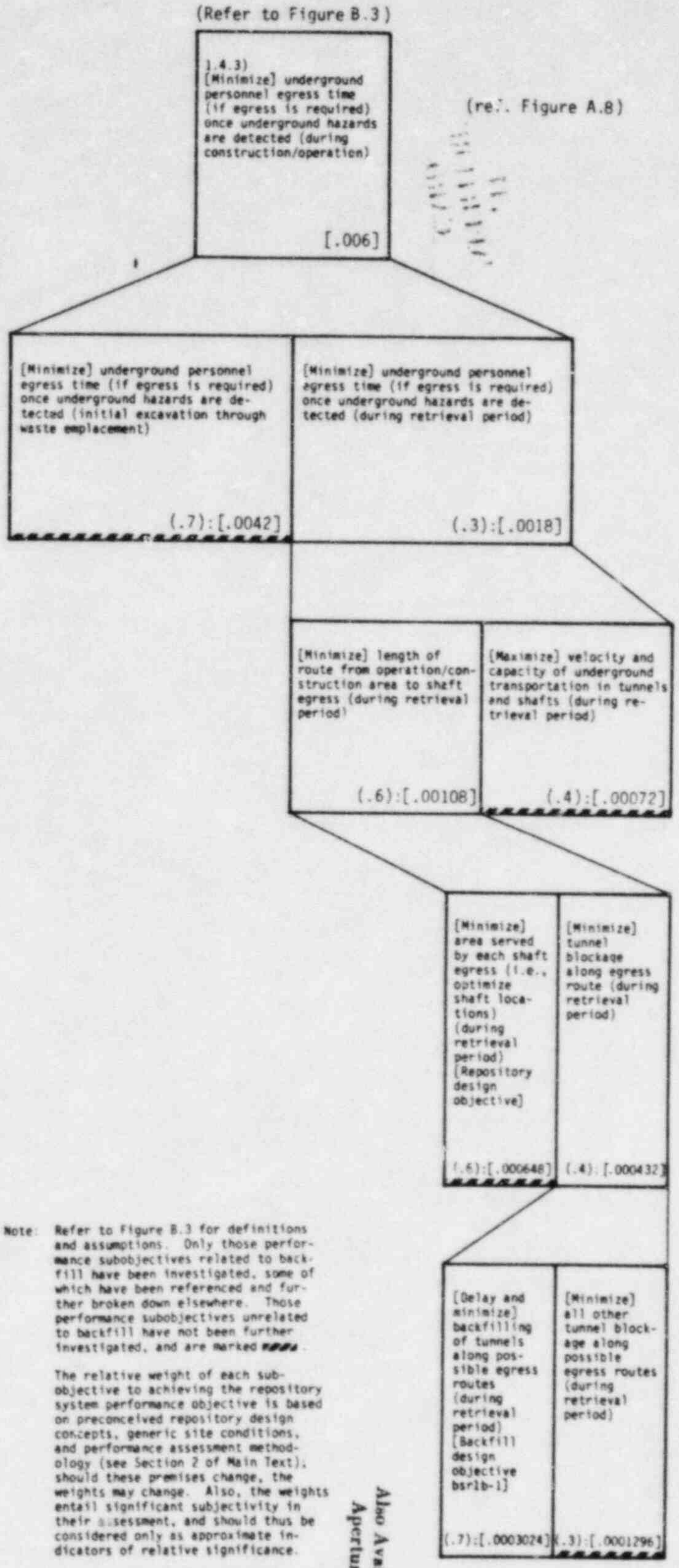
[Maximize] quick and efficient mitigation of detected underground hazards (during retrieval period)
(.4):[.0072]

[Maximize] quick and efficient mitigation of detected underground hazards as backfilling occurs (during retrieval period)
[Backfill design objective bp3-1]
(.6):[.00432]

[Maximize] quick and efficient mitigation of detected underground hazards with other activities (during retrieval period)
(.4):[.00288]

Note: Refer to Figure B.3 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down elsewhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▨▨▨.

The relative weight of each subobjective to achieving the repository system performance objective is based on preconceived repository design concepts, generic site conditions, and performance assessment methodology (see Section 2 of Main Text); should these premises change, the weights may change. Also, the weights entail significant subjectivity in their assessment, and should thus be considered only as approximate indicators of relative significance.

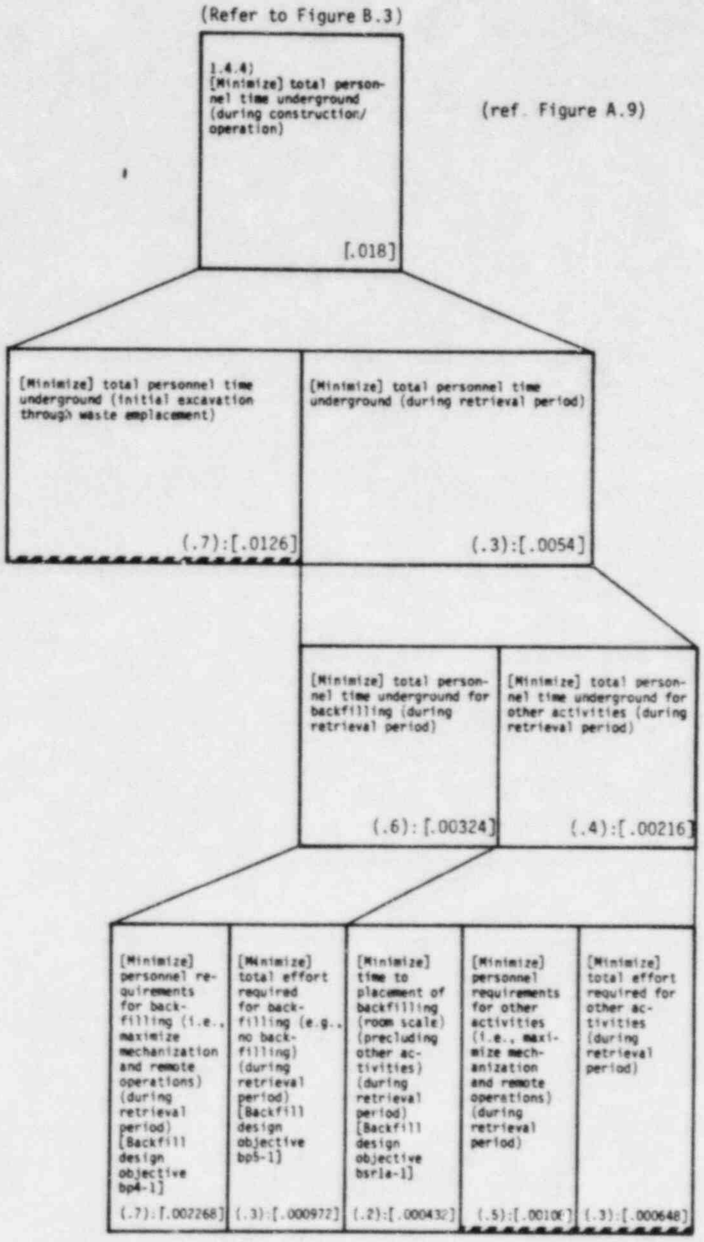


Note: Refer to Figure B.3 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down elsewhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▨.

The relative weight of each subobjective to achieving the repository system performance objective is based on preconceived repository design concepts, generic site conditions, and performance assessment methodology (see Section 2 of Main Text); should these premises change, the weights may change. Also, the weights entail significant subjectivity in their assessment, and should thus be considered only as approximate indicators of relative significance.

WEIGHTS OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES WITH RESPECT TO PERFORMANCE SUBOBJECTIVE 1.4.3

Figure B.9



WEIGHTS OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES WITH RESPECT TO PERFORMANCE SUBOBJECTIVE 1.4.4 **Figure B.10**

Note: Refer to Figure B.3 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down elsewhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▰▰▰▰.

The relative weight of each subobjective to achieving the repository system performance objective is based on preconceived repository design concepts, generic site conditions, and performance assessment methodology (see Section 2 of Main Text); should these premises change, the weights may change. Also, the weights entail significant subjectivity in their assessment, and should thus be considered only as approximate indicators of relative significance.

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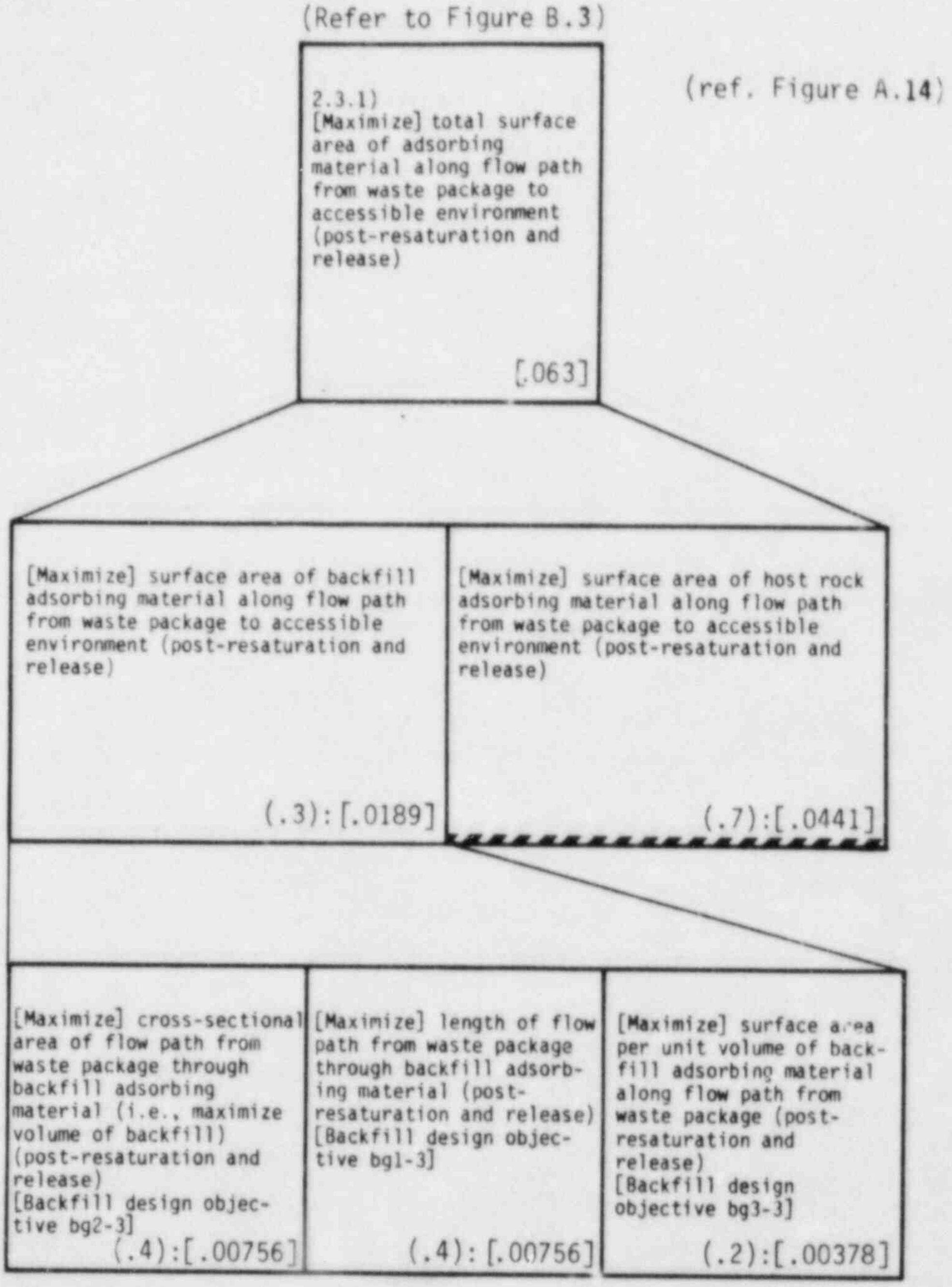
WEIGHTS OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES WITH RESPECT TO PERFORMANCE SUBOBJECTIVE 2.3.1

Figure B.15

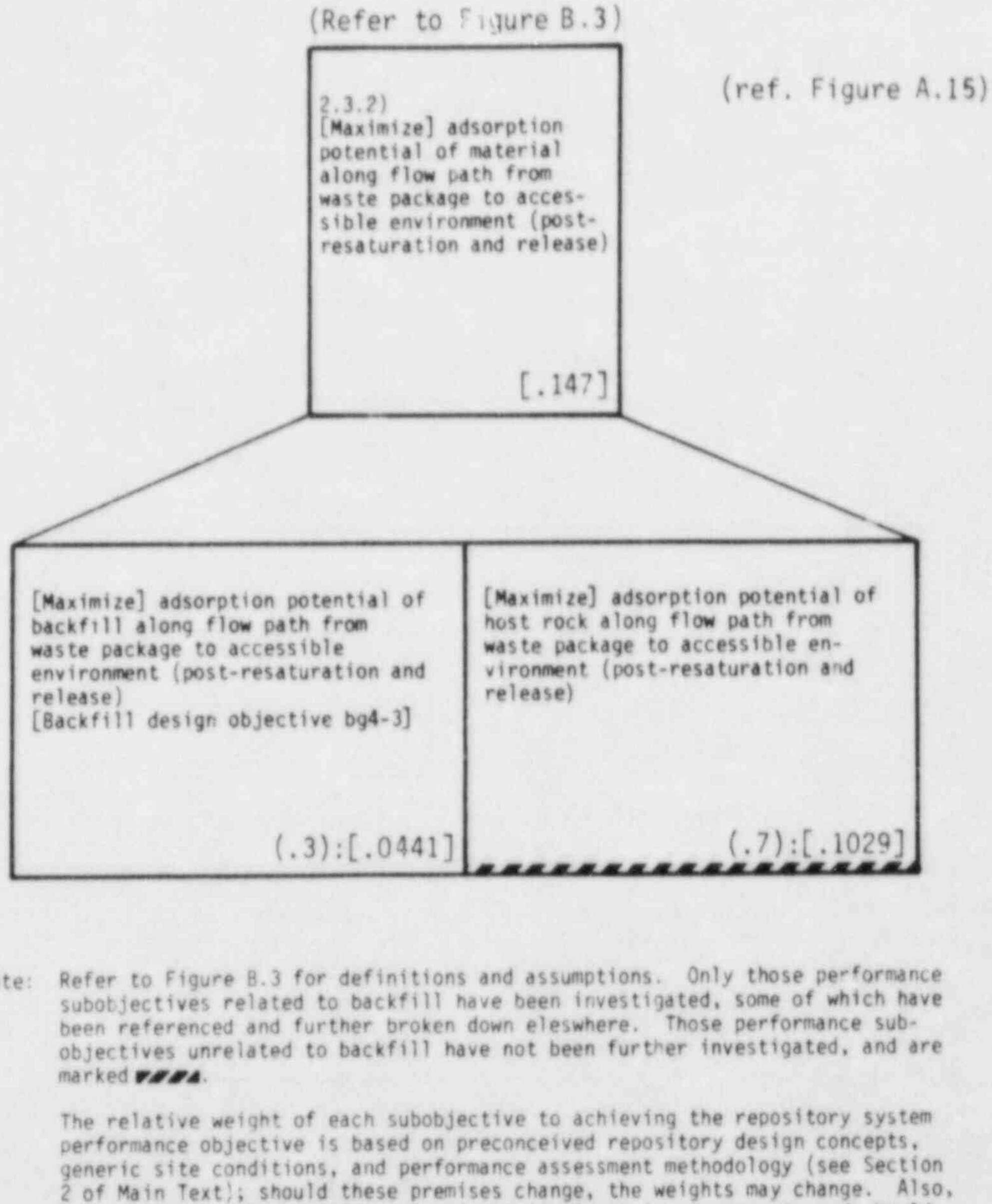


Note: Refer to Figure B.3 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down elsewhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▨.

The relative weight of each subobjective to achieving the repository system performance objective is based on preconceived repository design concepts, generic site conditions, and performance assessment methodology (see Section 2 of Main Text); should these premises change, the weights may change. Also, the weights entail significant subjectivity in their assessment, and should thus be considered only as approximate indicators of relative significance.

WEIGHTS OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES WITH RESPECT TO PERFORMANCE SUBOBJECTIVE 2.3.2

Figure B.16



Note: Refer to Figure B.3 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down eleswhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▨▨▨▨.

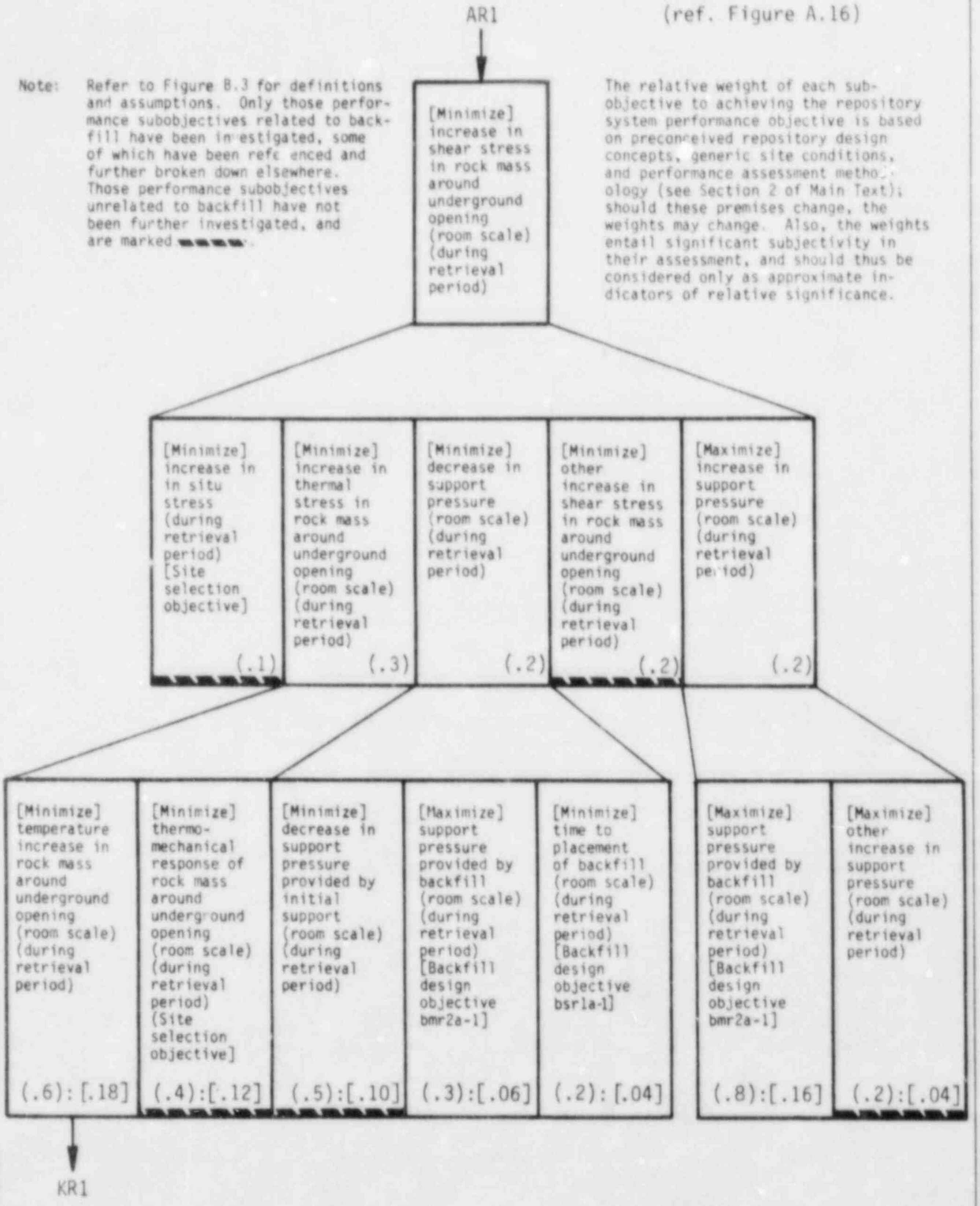
The relative weight of each subobjective to achieving the repository system performance objective is based on preconceived repository design concepts, generic site conditions, and performance assessment methodology (see Section 2 of Main Text); should these premises change, the weights may change. Also, the weights entail significant subjectivity in their assessment, and should thus be considered only as approximate indicators of relative significance.

WEIGHTS OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES WITH RESPECT TO REFERENCED COMMON PERFORMANCE SUBOBJECTIVE AR1

Figure B.17

Note: Refer to Figure B.3 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down elsewhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▬▬▬.

The relative weight of each subobjective to achieving the repository system performance objective is based on preconceived repository design concepts, generic site conditions, and performance assessment methodology (see Section 2 of Main Text); should these premises change, the weights may change. Also, the weights entail significant subjectivity in their assessment, and should thus be considered only as approximate indicators of relative significance.



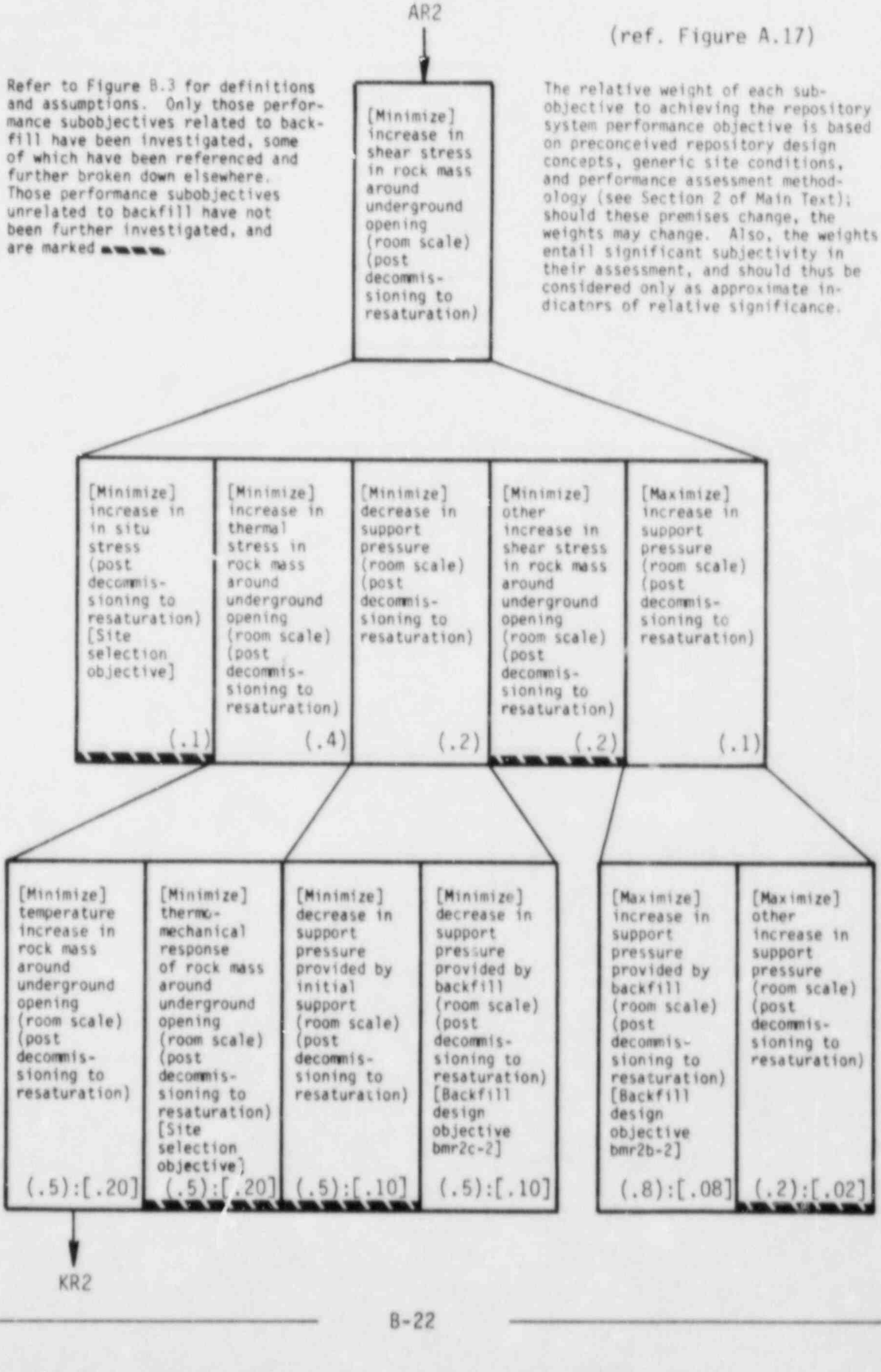
WEIGHTS OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES WITH RESPECT TO REFERENCED COMMON PERFORMANCE SUBOBJECTIVE AR2

Figure B.18

(ref. Figure A.17)

Note: Refer to Figure B.3 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down elsewhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▨▨▨.

The relative weight of each subobjective to achieving the repository system performance objective is based on preconceived repository design concepts, generic site conditions, and performance assessment methodology (see Section 2 of Main Text); should these premises change, the weights may change. Also, the weights entail significant subjectivity in their assessment, and should thus be considered only as approximate indicators of relative significance.

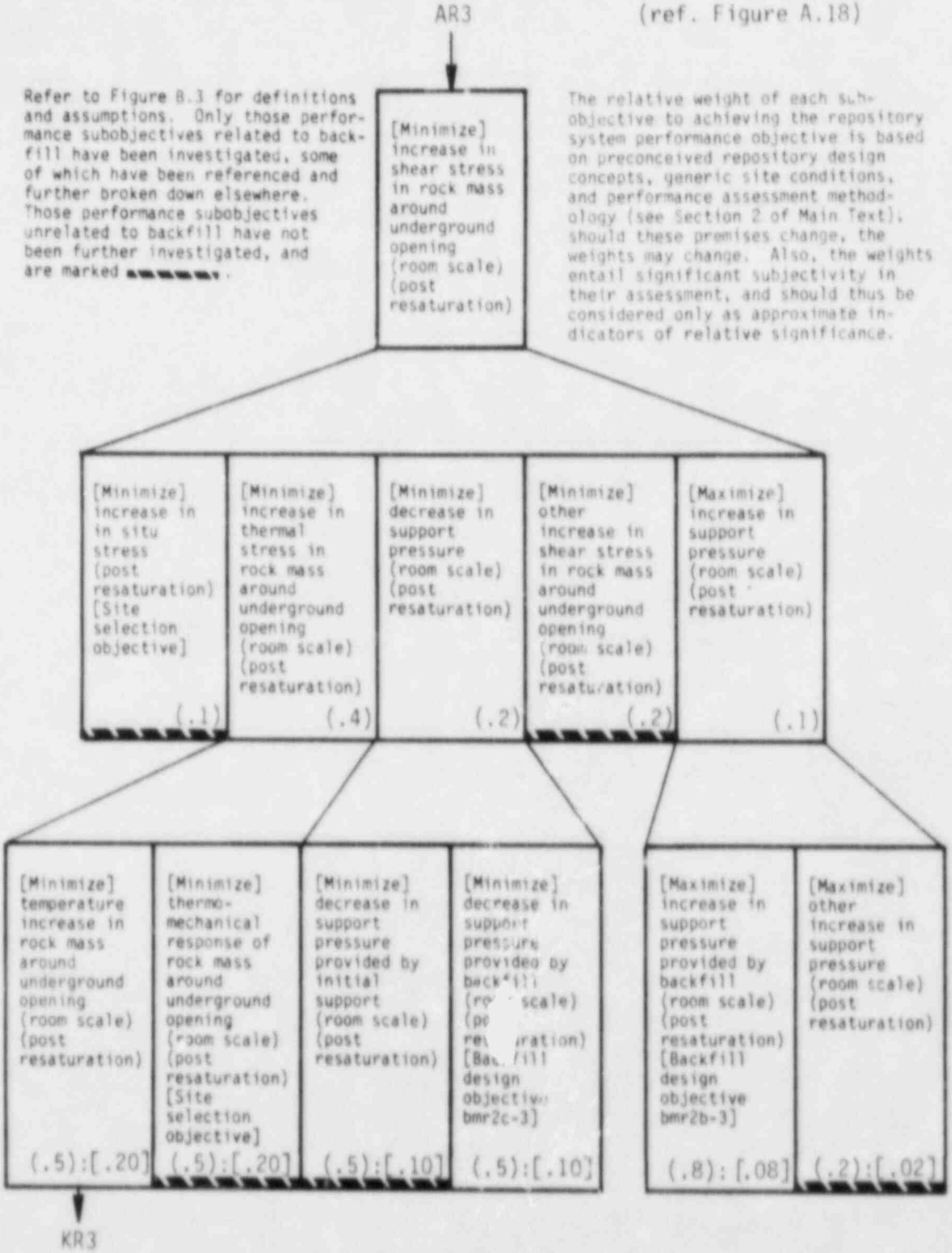


WEIGHTS OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES WITH RESPECT TO REFERENCED COMMON PERFORMANCE SUBOBJECTIVE AR3

Figure B.19

Note: Refer to Figure B.3 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down elsewhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▬▬▬▬.

The relative weight of each subobjective to achieving the repository system performance objective is based on preconceived repository design concepts, generic site conditions, and performance assessment methodology (see Section 2 of Main Text); should these premises change, the weights may change. Also, the weights entail significant subjectivity in their assessment, and should thus be considered only as approximate indicators of relative significance.



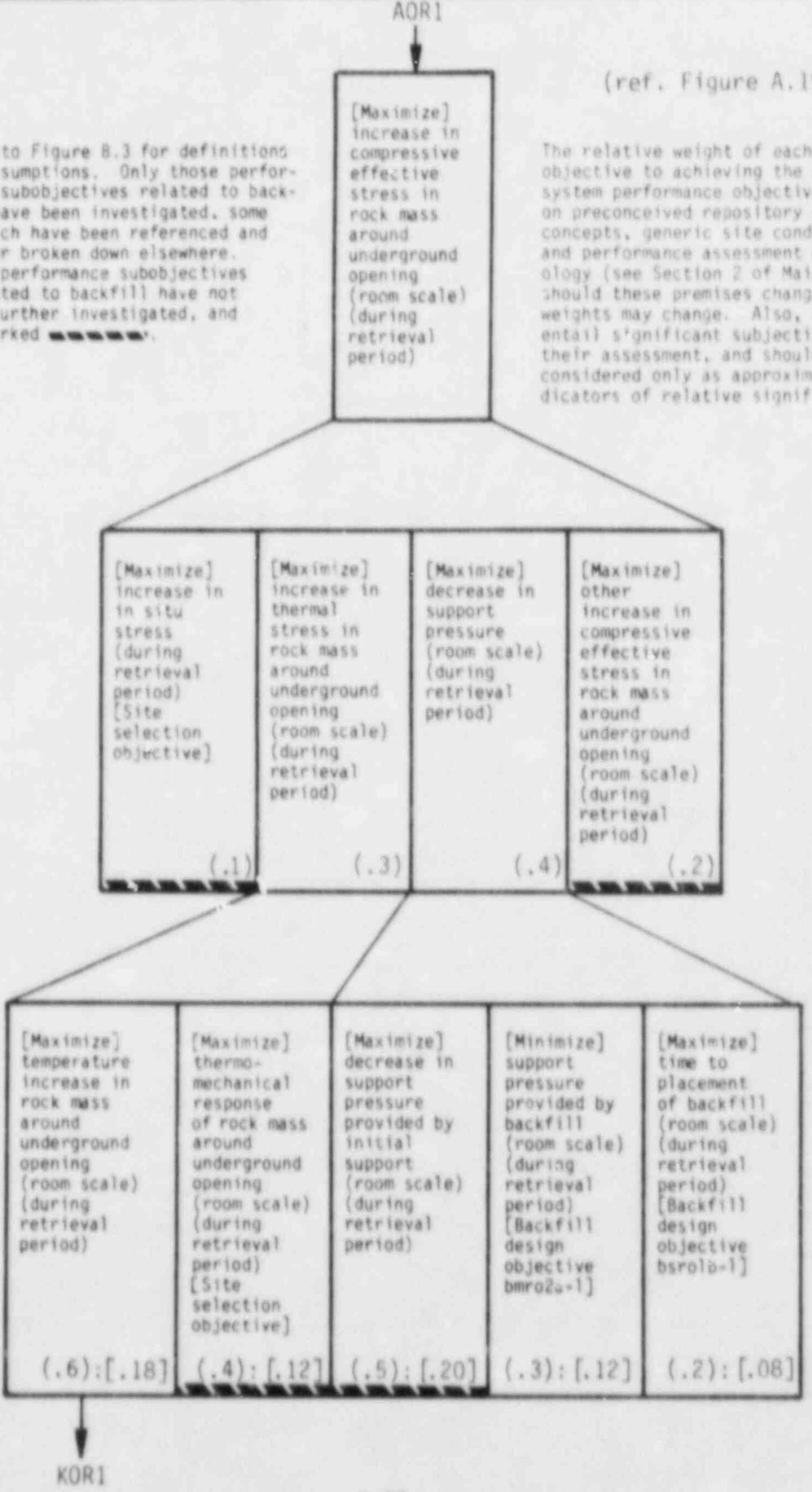
WEIGHTS OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES WITH RESPECT TO REFERENCED COMMON PERFORMANCE SUBOBJECTIVE AOR1

Figure B.20

(ref. Figure A.19)

Note: Refer to Figure B.3 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down elsewhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▨▨▨▨▨.

The relative weight of each subobjective to achieving the repository system performance objective is based on preconceived repository design concepts, generic site conditions, and performance assessment methodology (see Section 2 of Main Text); should these premises change, the weights may change. Also, the weights entail significant subjectivity in their assessment, and should thus be considered only as approximate indicators of relative significance.

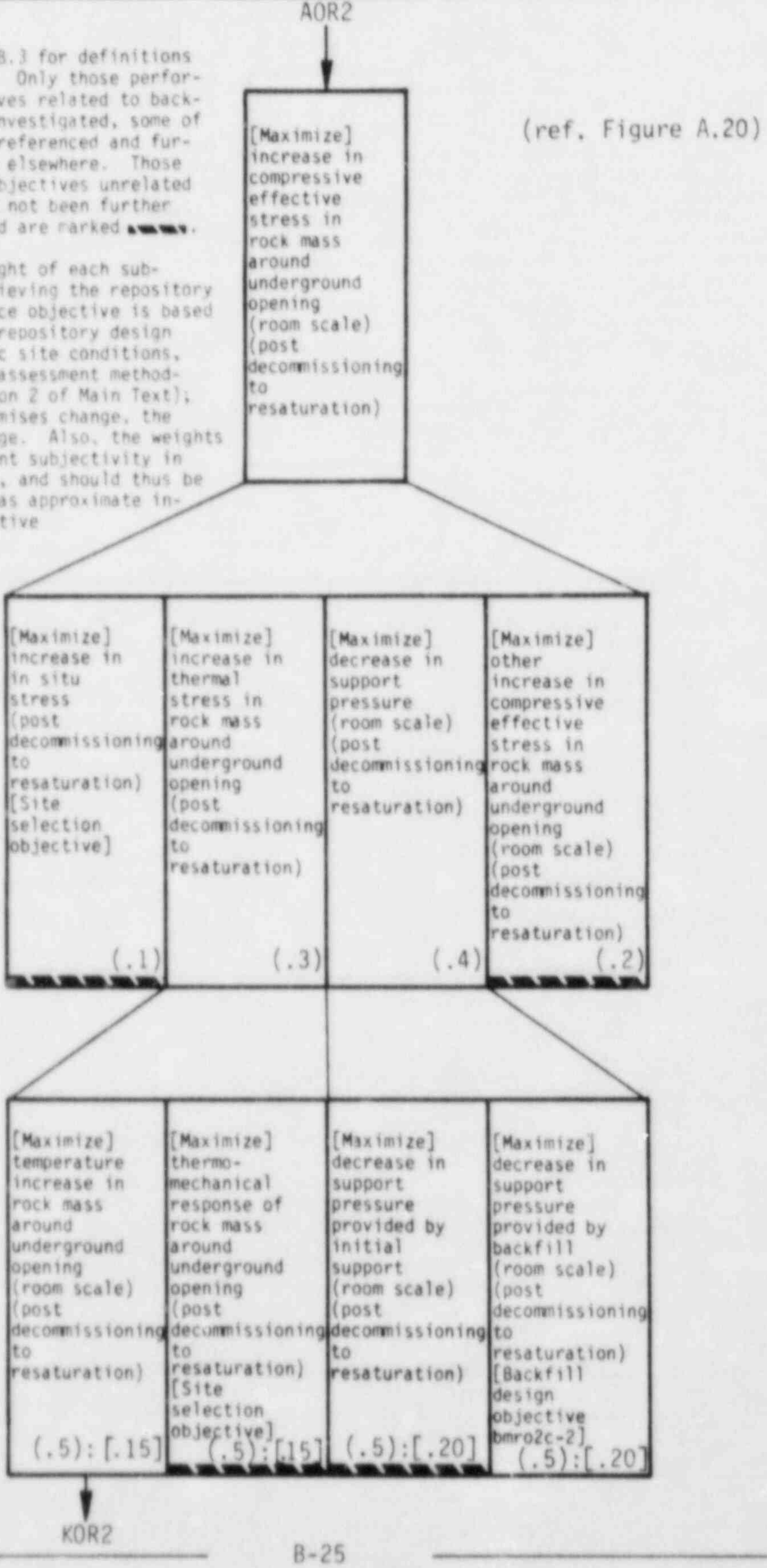


WEIGHTS OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES WITH RESPECT TO REFERENCED COMMON PERFORMANCE SUBOBJECTIVE AOR2

Figure B.21

Note: Refer to Figure B.3 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down elsewhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▬▬▬.

The relative weight of each subobjective to achieving the repository system performance objective is based on preconceived repository design concepts, generic site conditions, and performance assessment methodology (see Section 2 of Main Text); should these premises change, the weights may change. Also, the weights entail significant subjectivity in their assessment, and should thus be considered only as approximate indicators of relative significance.

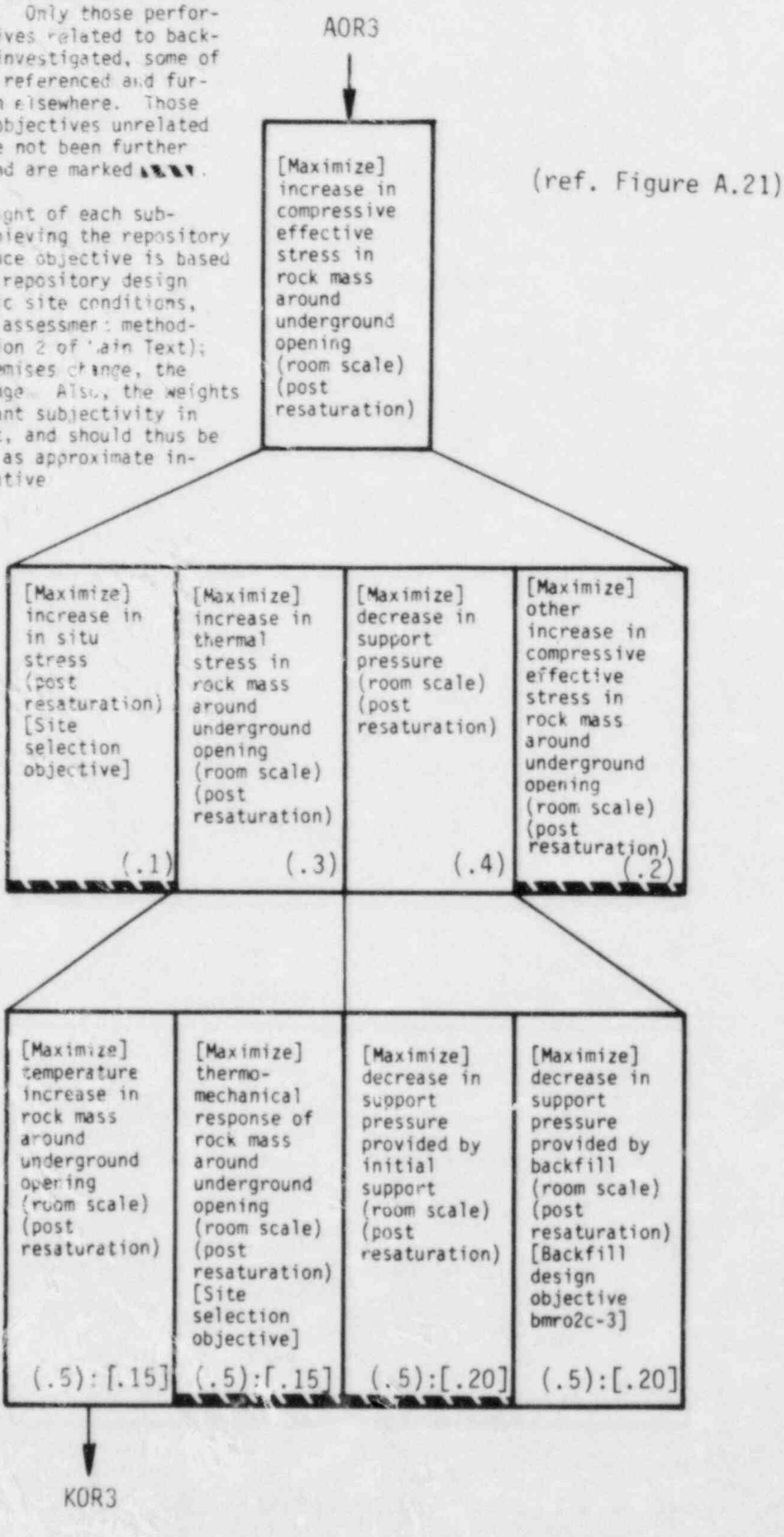


WEIGHTS OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES WITH RESPECT TO REFERENCED COMMON PERFORMANCE SUBOBJECTIVE AOR3

Figure B.22

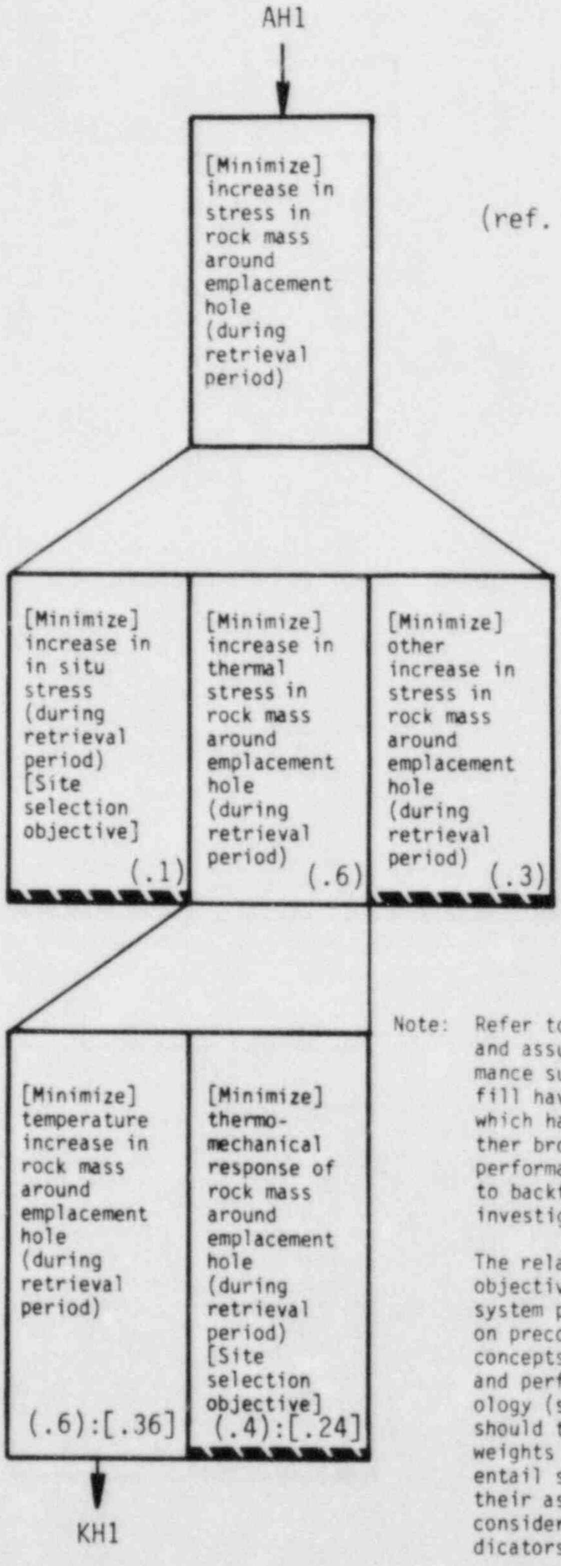
Note: Refer to Figure B.3 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down elsewhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▨▨▨.

The relative weight of each subobjective to achieving the repository system performance objective is based on preconceived repository design concepts, generic site conditions, and performance assessment methodology (see Section 2 of Main Text); should these premises change, the weights may change. Also, the weights entail significant subjectivity in their assessment, and should thus be considered only as approximate indicators of relative significance.



WEIGHTS OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES WITH RESPECT TO REFERENCED COMMON PERFORMANCE SUBOBJECTIVE AH1

Figure B.23



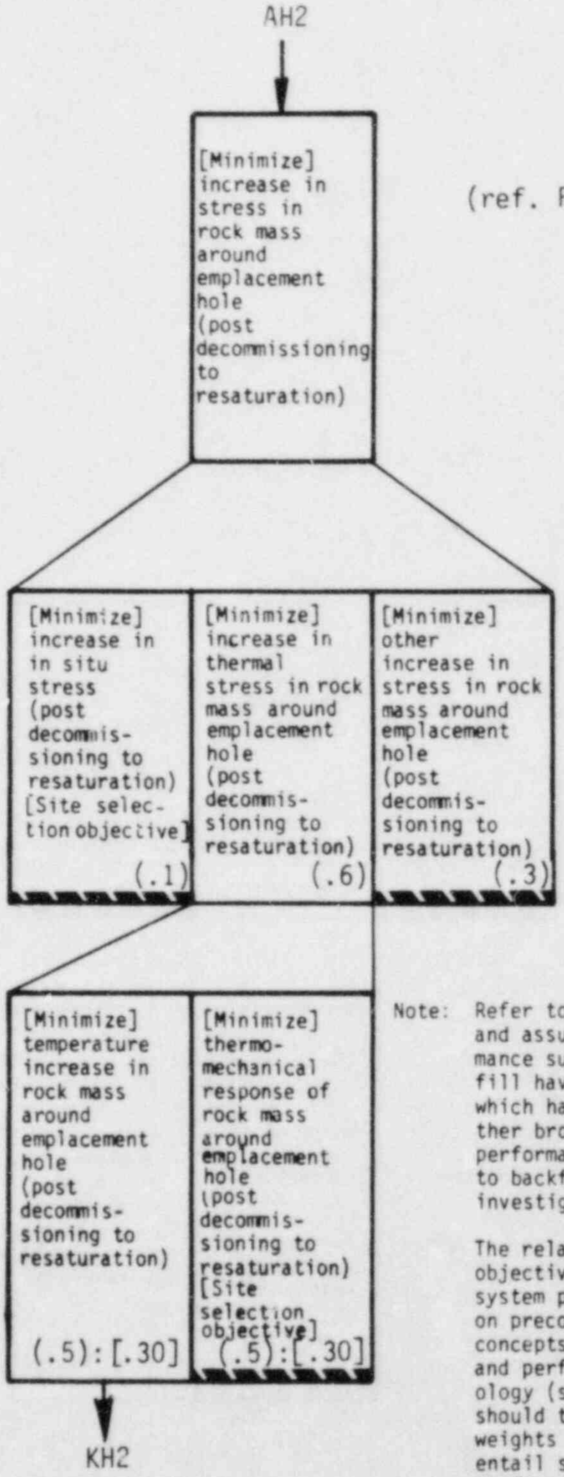
(ref. Figure A.22)

Note: Refer to Figure B.3 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down elsewhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▨.

The relative weight of each subobjective to achieving the repository system performance objective is based on preconceived repository design concepts, generic site conditions, and performance assessment methodology (see Section 2 of Main Text); should these premises change, the weights may change. Also, the weights entail significant subjectivity in their assessment, and should thus be considered only as approximate indicators of relative significance.

WEIGHTS OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES WITH RESPECT TO REFERENCED COMMON PERFORMANCE SUBOBJECTIVE AH2

Figure B.24

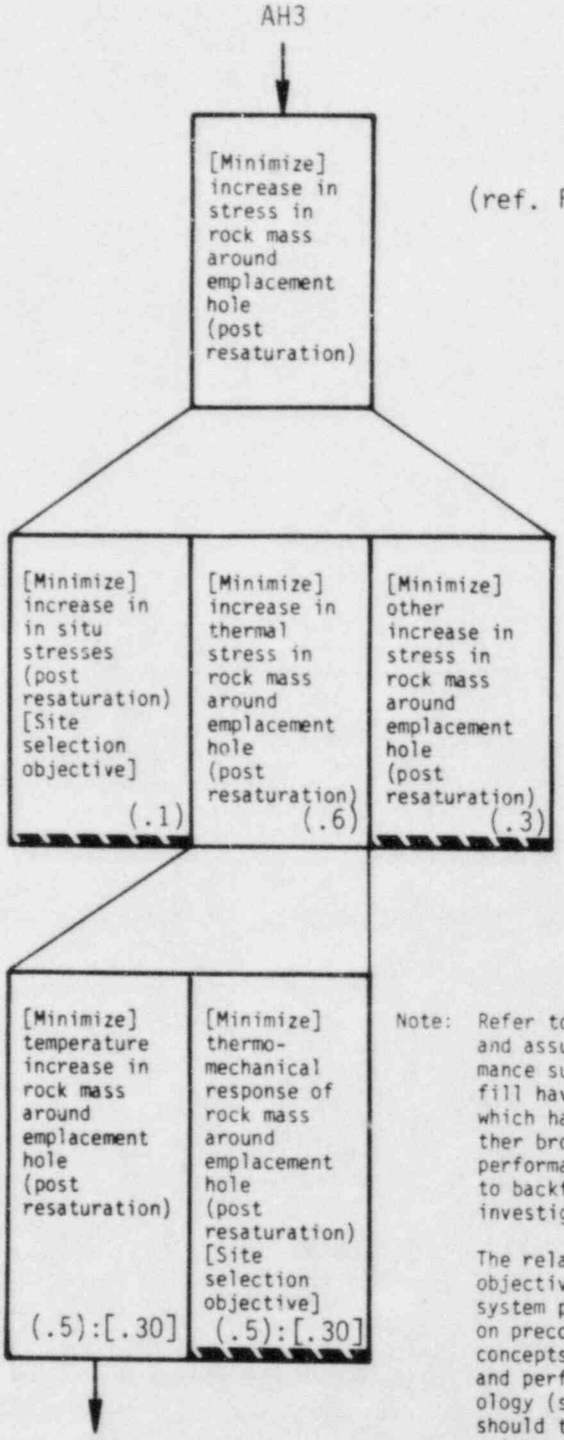


(ref. Figure A.23)

Note: Refer to Figure B.3 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down elsewhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▨.

The relative weight of each subobjective to achieving the repository system performance objective is based on preconceived repository design concepts, generic site conditions, and performance assessment methodology (see Section 2 of Main Text); should these premises change, the weights may change. Also, the weights entail significant subjectivity in their assessment, and should thus be considered only as approximate indicators of relative significance.

WEIGHTS OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES WITH RESPECT TO REFERENCED COMMON PERFORMANCE SUBOBJECTIVE AH3 **Figure B.25**



(ref. Figure A.24)

Note: Refer to Figure B.3 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down elsewhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▨.

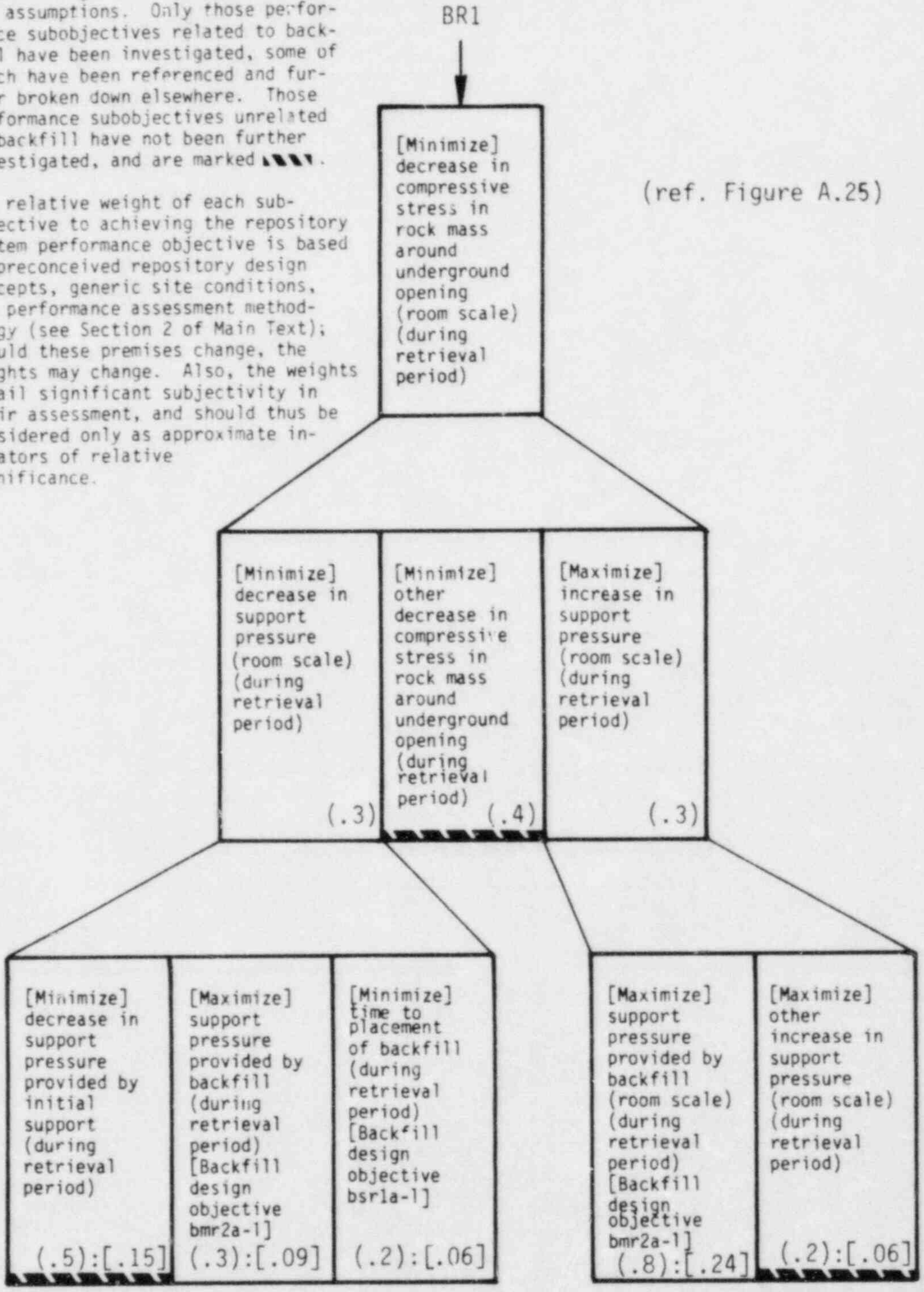
The relative weight of each subobjective to achieving the repository system performance objective is based on preconceived repository design concepts, generic site conditions, and performance assessment methodology (see Section 2 of Main Text); should these premises change, the weights may change. Also, the weights entail significant subjectivity in their assessment, and should thus be considered only as approximate indicators of relative significance.

WEIGHTS OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES WITH RESPECT TO REFERENCED COMMON PERFORMANCE SUBOBJECTIVE BR1

Figure B.26

Note: Refer to Figure B.3 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down elsewhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▨.

The relative weight of each subobjective to achieving the repository system performance objective is based on preconceived repository design concepts, generic site conditions, and performance assessment methodology (see Section 2 of Main Text); should these premises change, the weights may change. Also, the weights entail significant subjectivity in their assessment, and should thus be considered only as approximate indicators of relative significance.

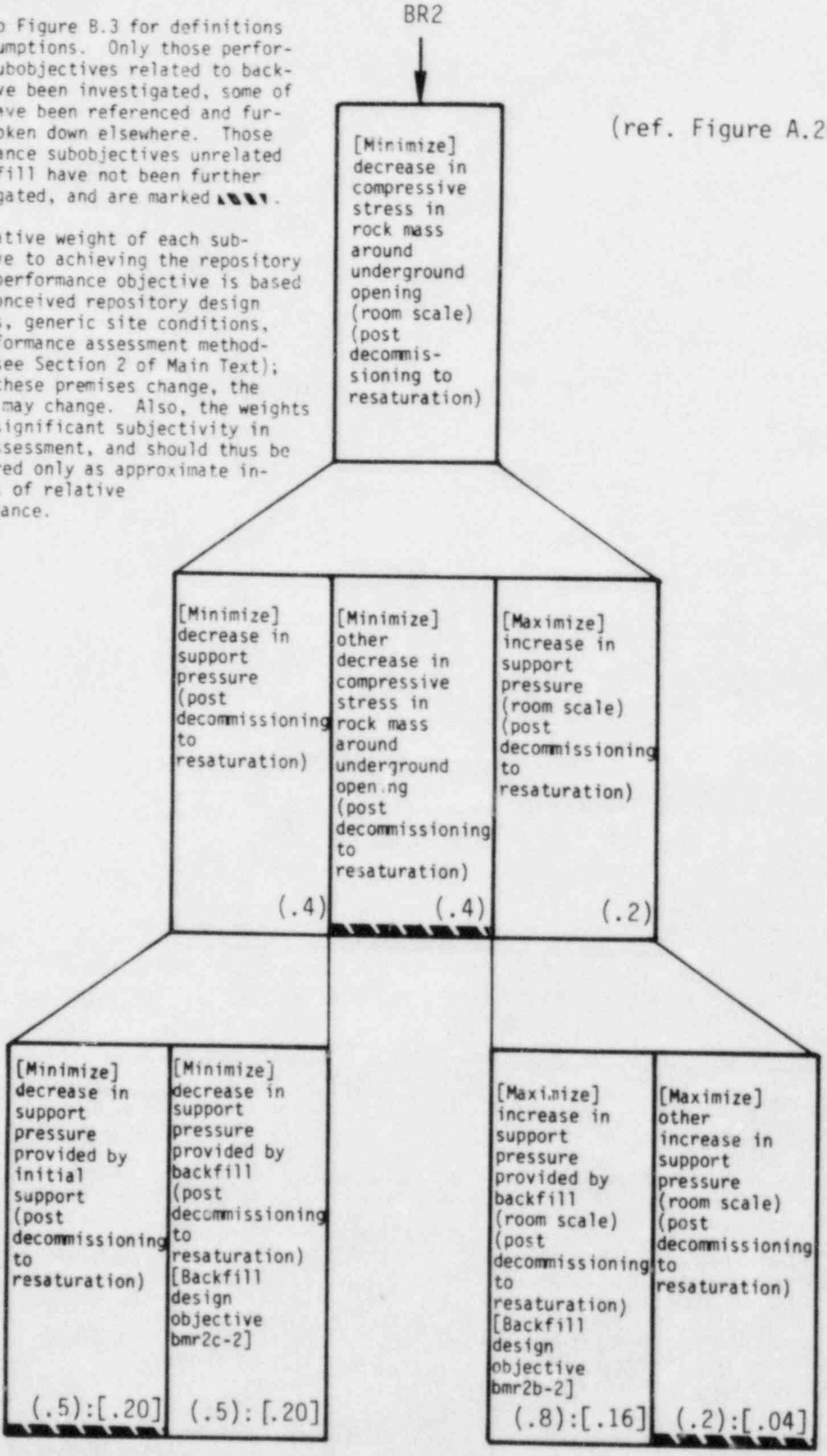


WEIGHTS OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES WITH RESPECT TO REFERENCED COMMON PERFORMANCE SUBOBJECTIVE BR2

Figure B.27

Note: Refer to Figure B.3 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down elsewhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▨.

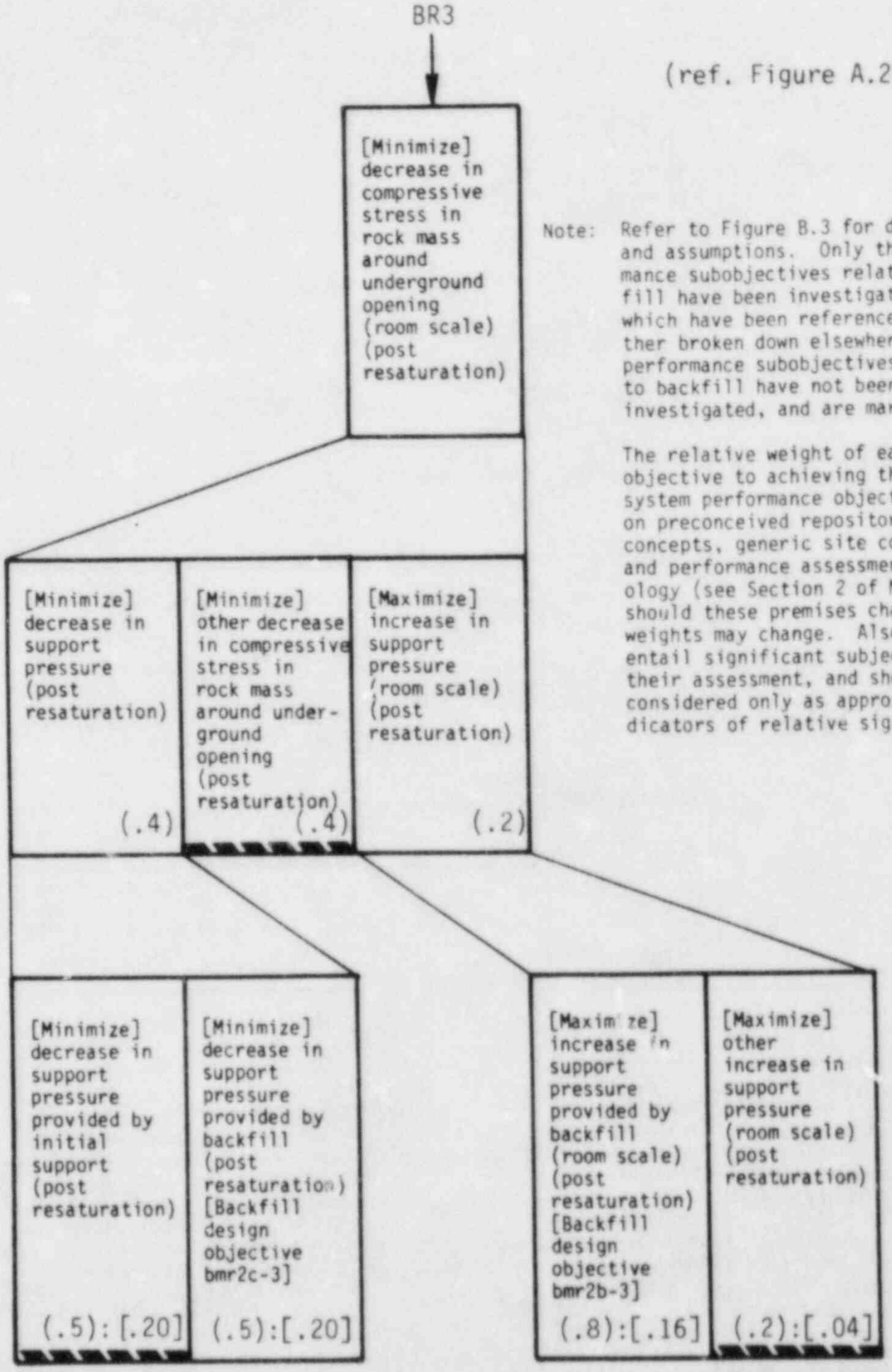
The relative weight of each subobjective to achieving the repository system performance objective is based on preconceived repository design concepts, generic site conditions, and performance assessment methodology (see Section 2 of Main Text); should these premises change, the weights may change. Also, the weights entail significant subjectivity in their assessment, and should thus be considered only as approximate indicators of relative significance.



(ref. Figure A.26)

WEIGHTS OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES WITH RESPECT TO REFERENCED COMMON PERFORMANCE SUBOBJECTIVE BR3

Figure B.28



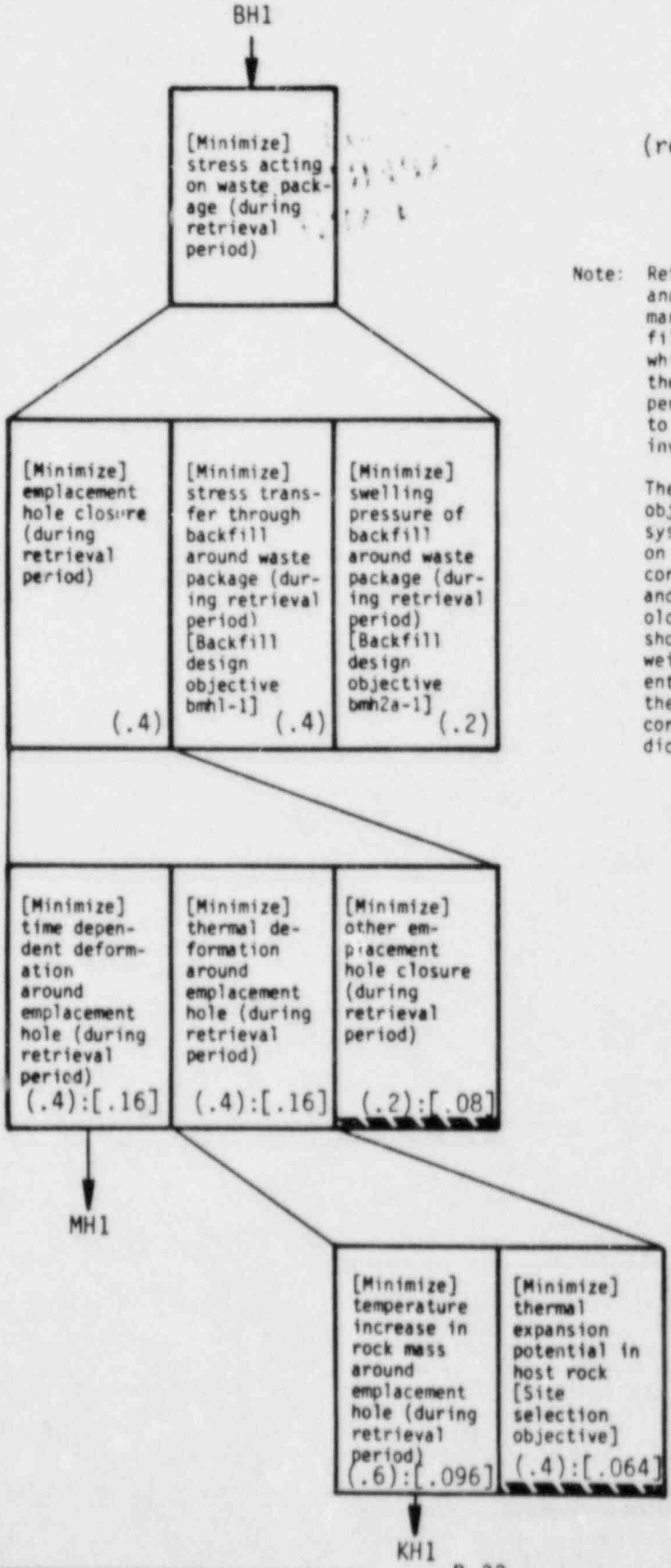
(ref. Figure A.27)

Note: Refer to Figure B.3 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down elsewhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▨.

The relative weight of each subobjective to achieving the repository system performance objective is based on preconceived repository design concepts, generic site conditions, and performance assessment methodology (see Section 2 of Main Text); should these premises change, the weights may change. Also, the weights entail significant subjectivity in their assessment, and should thus be considered only as approximate indicators of relative significance.

WEIGHTS OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES WITH RESPECT TO REFERENCED COMMON PERFORMANCE SUBOBJECTIVE BH1

Figure B.29



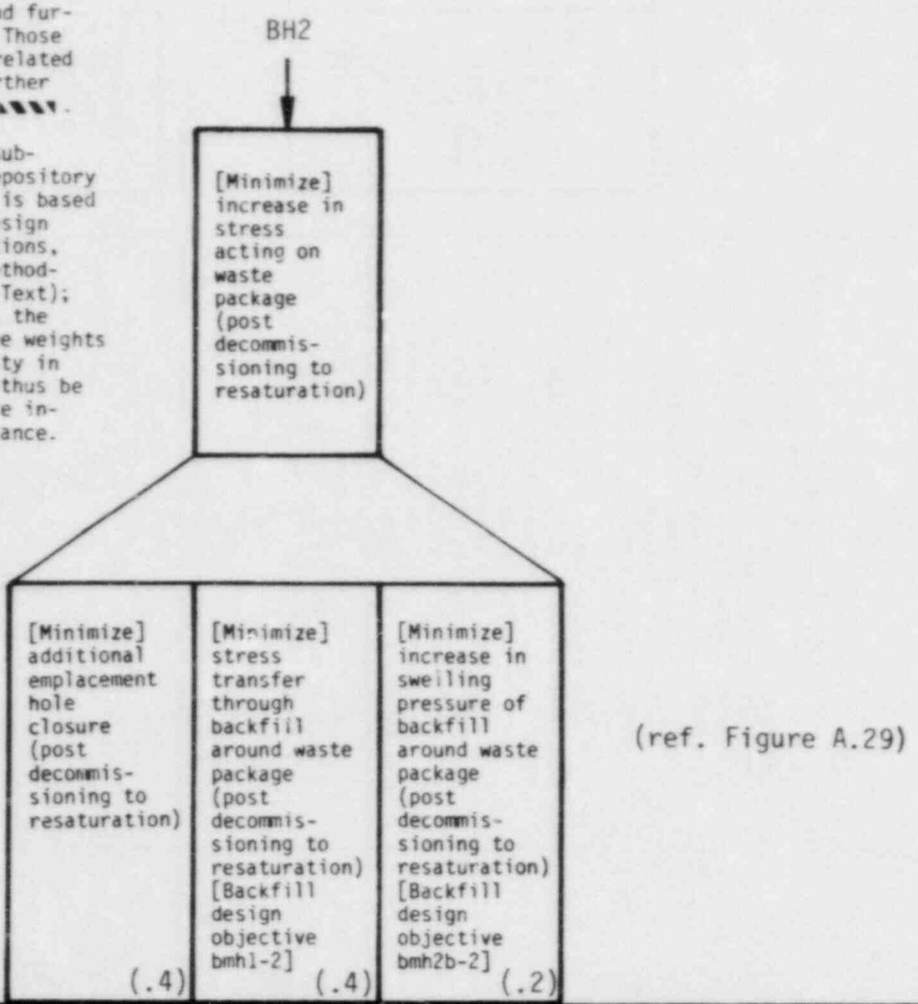
(ref. Figure A.28)

Note: Refer to Figure B.3 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down elsewhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▨.

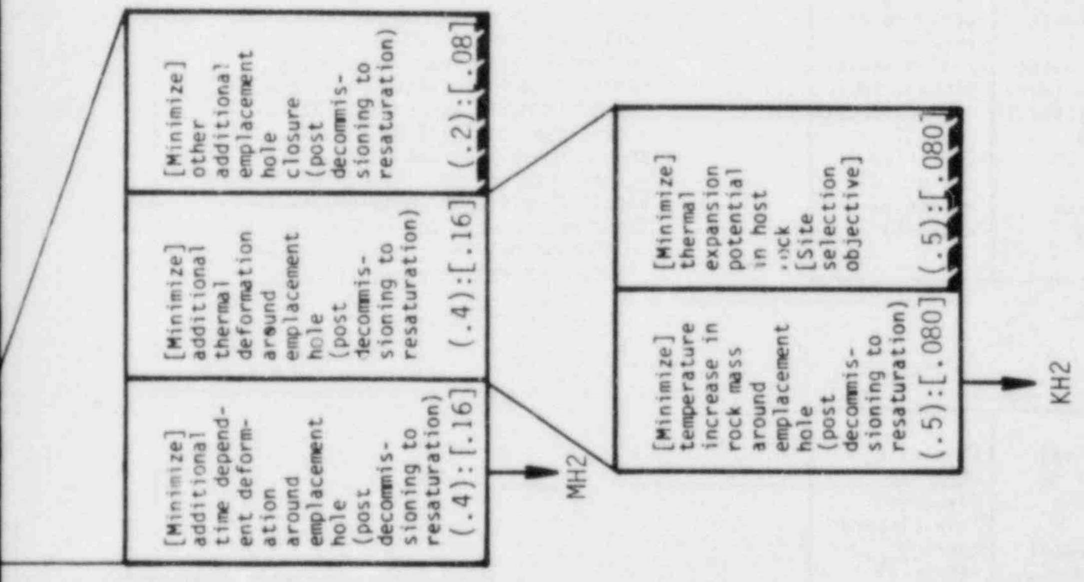
The relative weight of each subobjective to achieving the repository system performance objective is based on preconceived repository design concepts, generic site conditions, and performance assessment methodology (see Section 2 of Main Text); should these premises change, the weights may change. Also, the weights entail significant subjectivity in their assessment, and should thus be considered only as approximate indicators of relative significance.

Note: Refer to Figure B.3 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down elsewhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▨.

The relative weight of each subobjective to achieving the repository system performance objective is based on preconceived repository design concepts, generic site conditions, and performance assessment methodology (see Section 2 of Main Text); should these premises change, the weights may change. Also, the weights entail significant subjectivity in their assessment, and should thus be considered only as approximate indicators of relative significance.

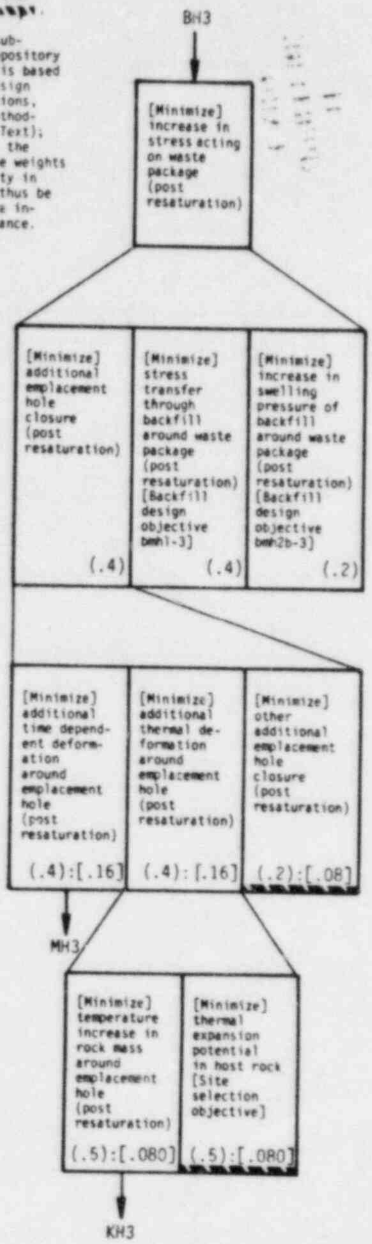


WEIGHTS OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES WITH RESPECT TO REFERENCED COMMON PERFORMANCE SUBOBJECTIVE BH2 Figure B.30



Note: Refer to Figure B.3 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down elsewhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▨.

The relative weight of each subobjective to achieving the repository system performance objective is based on preconceived repository design concepts, generic site conditions, and performance assessment methodology (see Section 2 of Main Text); should these premises change, the weights may change. Also, the weights entail significant subjectivity in their assessment, and should thus be considered only as approximate indicators of relative significance.



(ref. Figure A.30)

WEIGHTS OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES WITH RESPECT TO REFERENCED COMMON PERFORMANCE SUBOBJECTIVE BH3

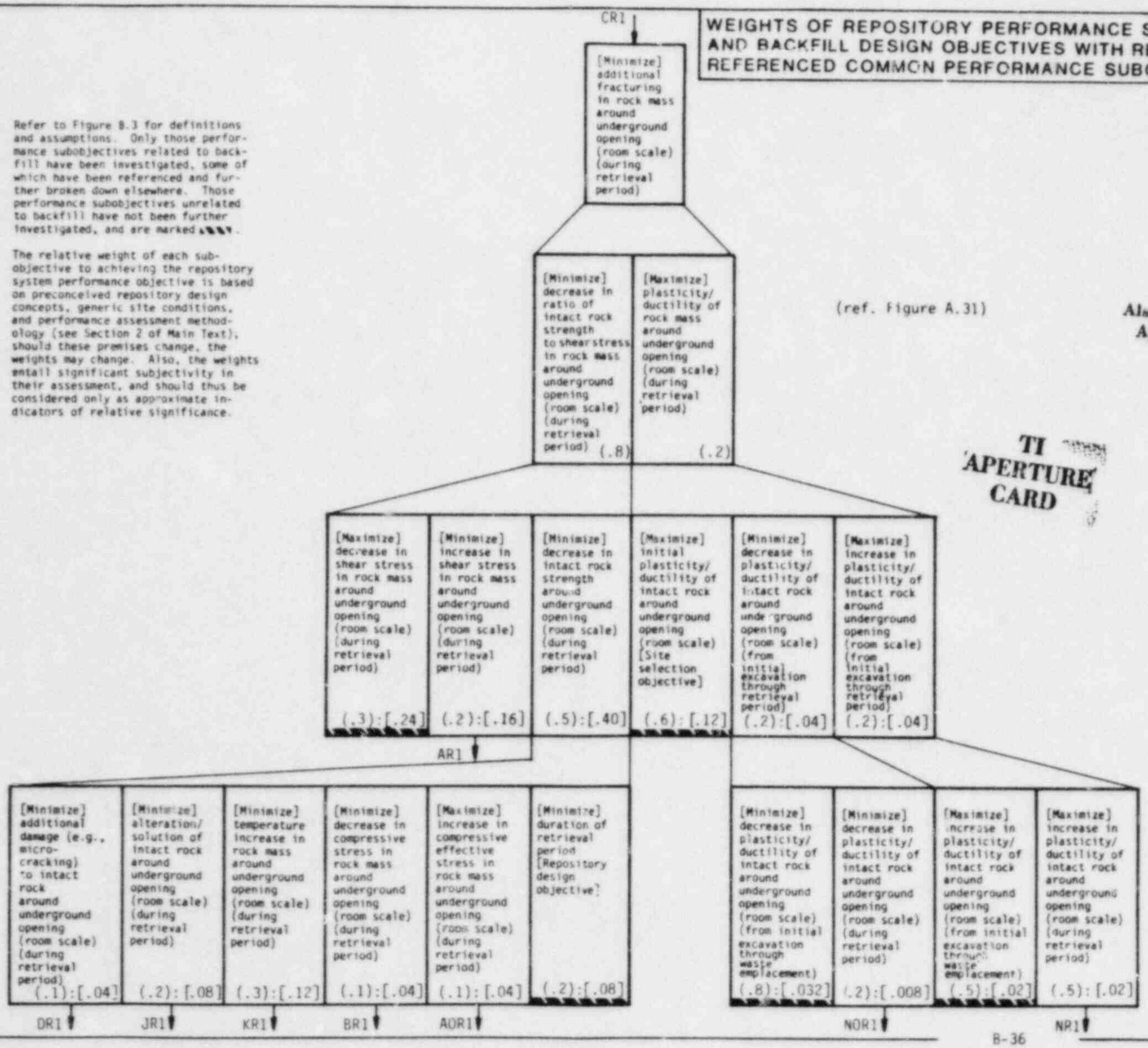
Figure B.31

WEIGHTS OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES WITH RESPECT TO REFERENCED COMMON PERFORMANCE SUBOBJECTIVE CR1

Figure B.32

Note: Refer to Figure B.3 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down elsewhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▨.

The relative weight of each subobjective to achieving the repository system performance objective is based on preconceived repository design concepts, generic site conditions, and performance assessment methodology (see Section 2 of Main Text); should these premises change, the weights may change. Also, the weights entail significant subjectivity in their assessment, and should thus be considered only as approximate indicators of relative significance.



(ref. Figure A.31)

WEIGHTS OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES WITH RESPECT TO REFERENCED COMMON PERFORMANCE SUBOBJECTIVE CR2

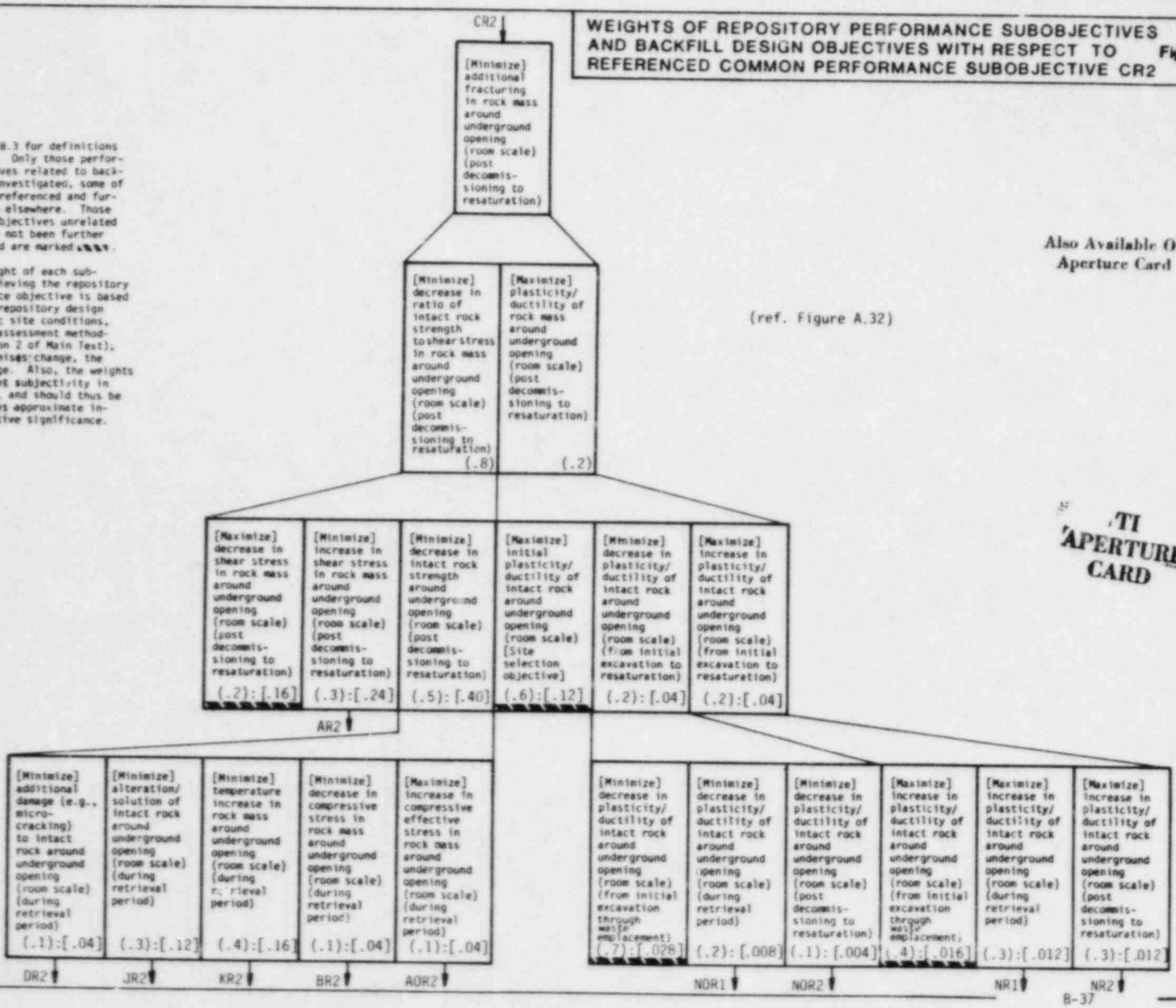
Figure B.33

Note: Refer to Figure B.3 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down elsewhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▨▨▨.

The relative weight of each subobjective to achieving the repository system performance objective is based on preconceived repository design concepts, generic site conditions, and performance assessment methodology (see Section 2 of Main Text); should these premises change, the weights may change. Also, the weights entail significant subjectivity in their assessment, and should thus be considered only as approximate indicators of relative significance.

(ref. Figure A.32)

Also Available On Aperture Card



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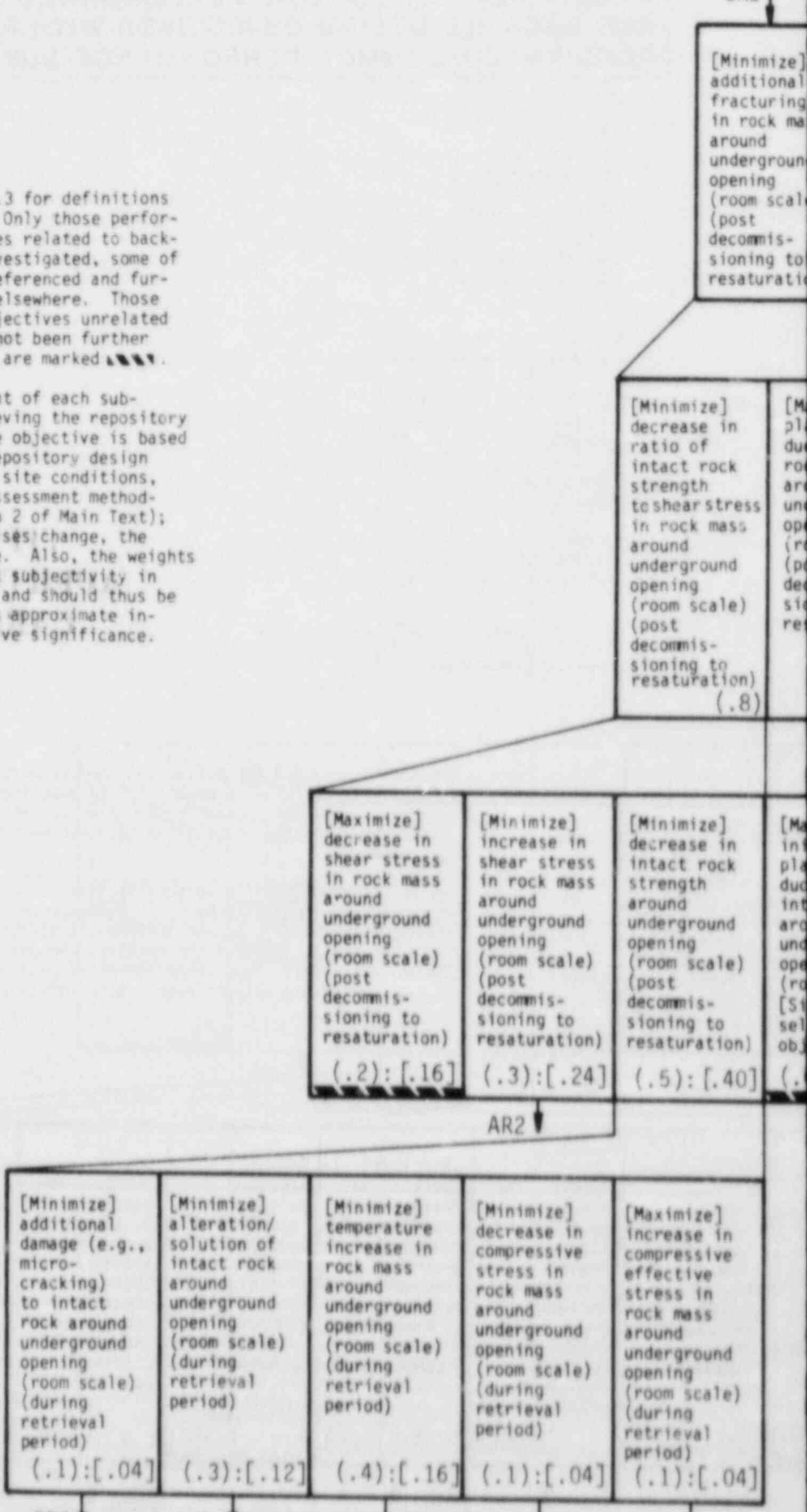
Note: Refer to Figure B.3 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down elsewhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▨.

The relative weight of each subobjective to achieving the repository system performance objective is based on preconceived repository design concepts, generic site conditions, and performance assessment methodology (see Section 2 of Main Text); should these premises change, the weights may change. Also, the weights entail significant subjectivity in their assessment, and should thus be considered only as approximate indicators of relative significance.

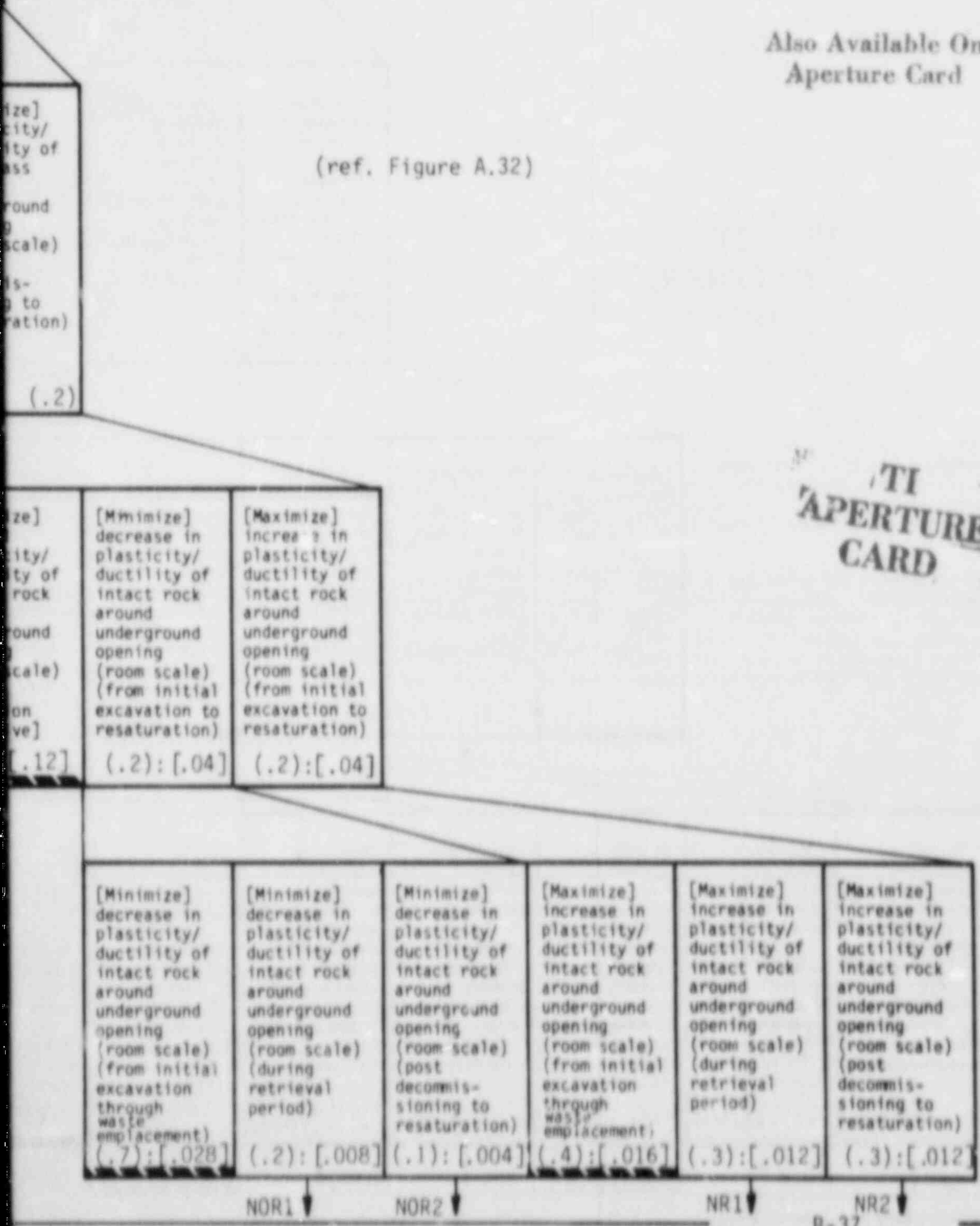


WEIGHTS OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES WITH RESPECT TO REFERENCED COMMON PERFORMANCE SUBOBJECTIVE CR2

Figure B.33

Also Available On
Aperture Card

(ref. Figure A.32)



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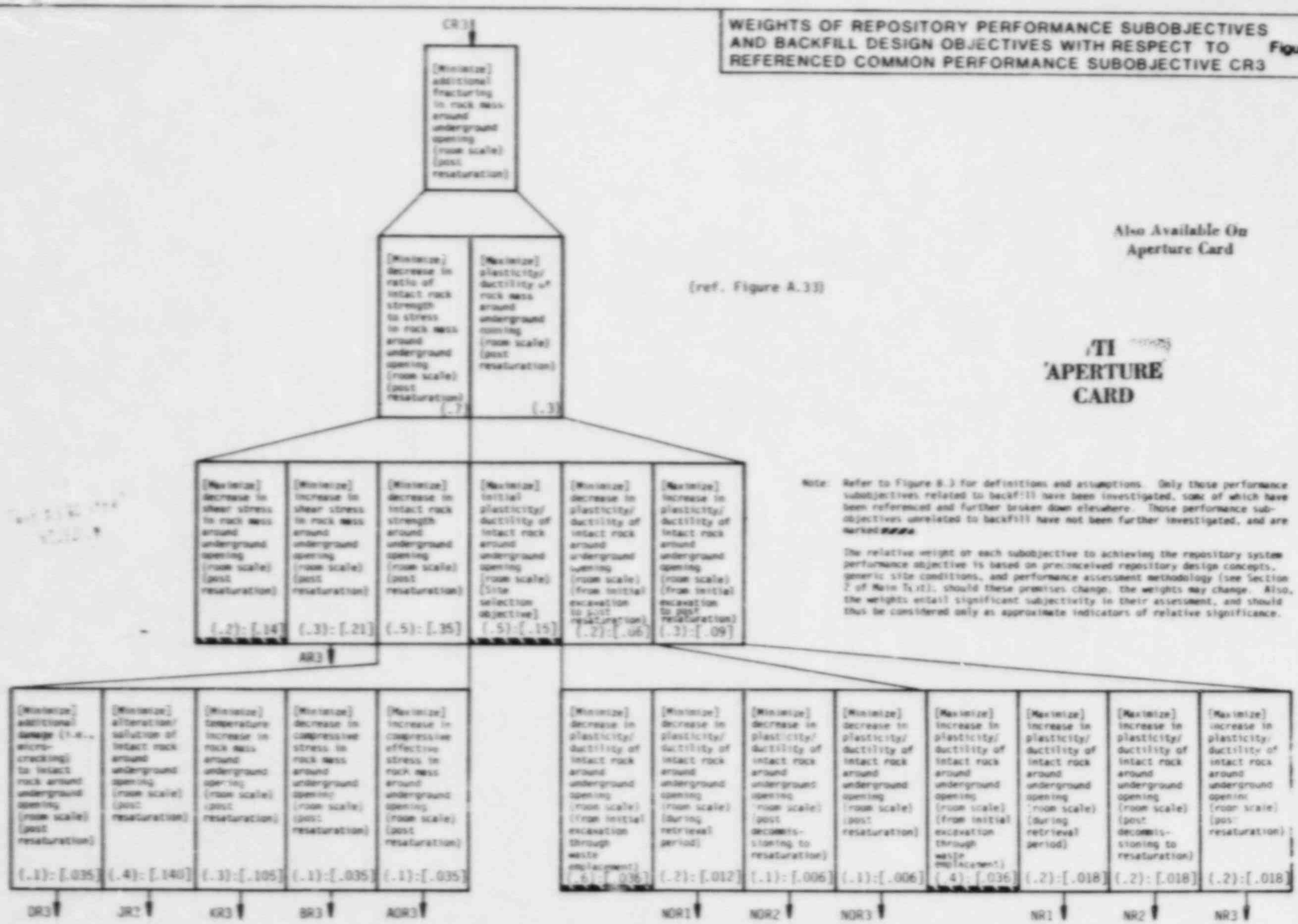
WEIGHTS OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES WITH RESPECT TO REFERENCED COMMON PERFORMANCE SUBOBJECTIVE CR3

Figure B.34



(ref. Figure A.33)

Also Available On
Aperture Card

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Note: Refer to Figure B.3 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down elsewhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▬▬.

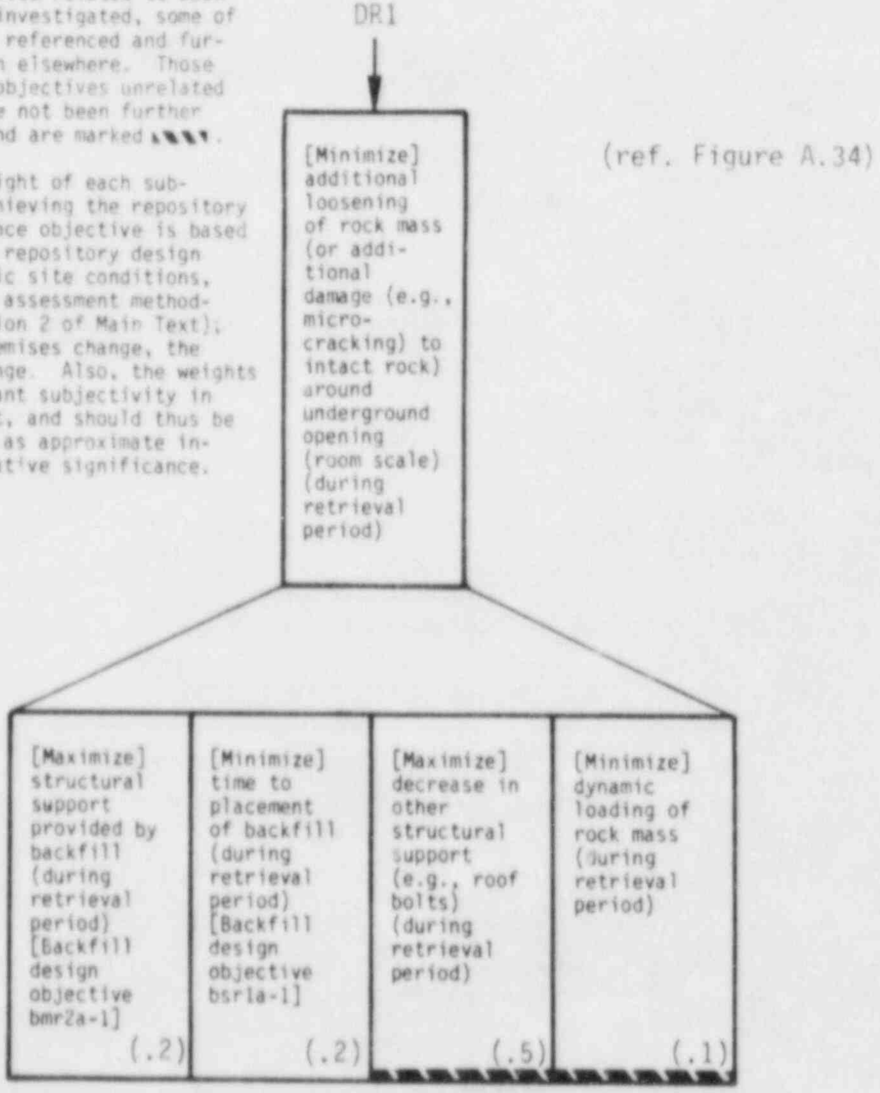
The relative weight of each subobjective to achieving the repository system performance objective is based on preconceived repository design concepts, generic site conditions, and performance assessment methodology (see Section 2 of Main Text); should these premises change, the weights may change. Also, the weights entail significant subjectivity in their assessment, and should thus be considered only as approximate indicators of relative significance.

WEIGHTS OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES WITH RESPECT TO REFERENCED COMMON PERFORMANCE SUBOBJECTIVE DR1

Figure B.35

Note: Refer to Figure B.3 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down elsewhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▨.

The relative weight of each subobjective to achieving the repository system performance objective is based on preconceived repository design concepts, generic site conditions, and performance assessment methodology (see Section 2 of Main Text); should these premises change, the weights may change. Also, the weights entail significant subjectivity in their assessment, and should thus be considered only as approximate indicators of relative significance.

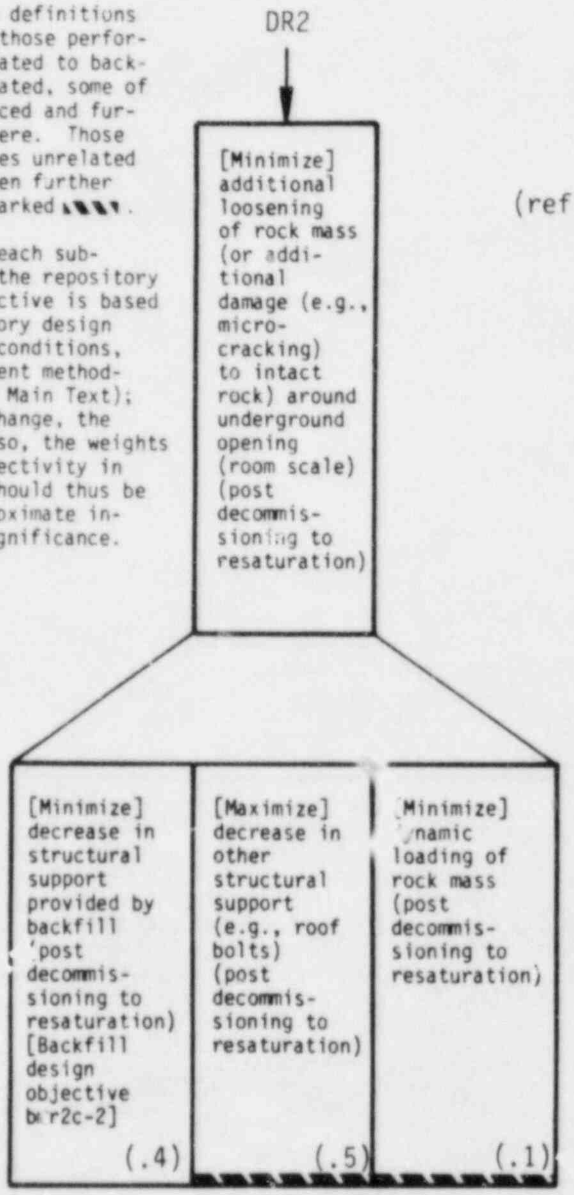


WEIGHTS OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES WITH RESPECT TO REFERENCED COMMON PERFORMANCE SUBOBJECTIVE DR2

Figure B.36

Note: Refer to Figure B.3 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down elsewhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▨.

The relative weight of each subobjective to achieving the repository system performance objective is based on preconceived repository design concepts, generic site conditions, and performance assessment methodology (see Section 2 of Main Text); should these premises change, the weights may change. Also, the weights entail significant subjectivity in their assessment, and should thus be considered only as approximate indicators of relative significance.



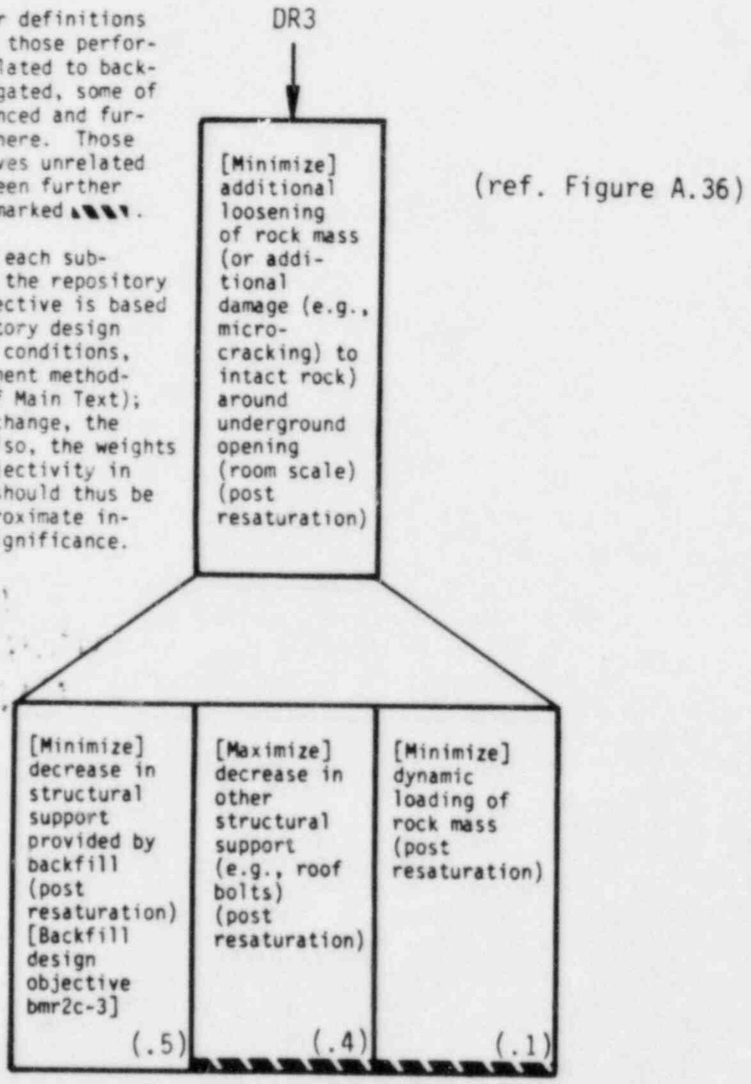
(ref. Figure A.35)

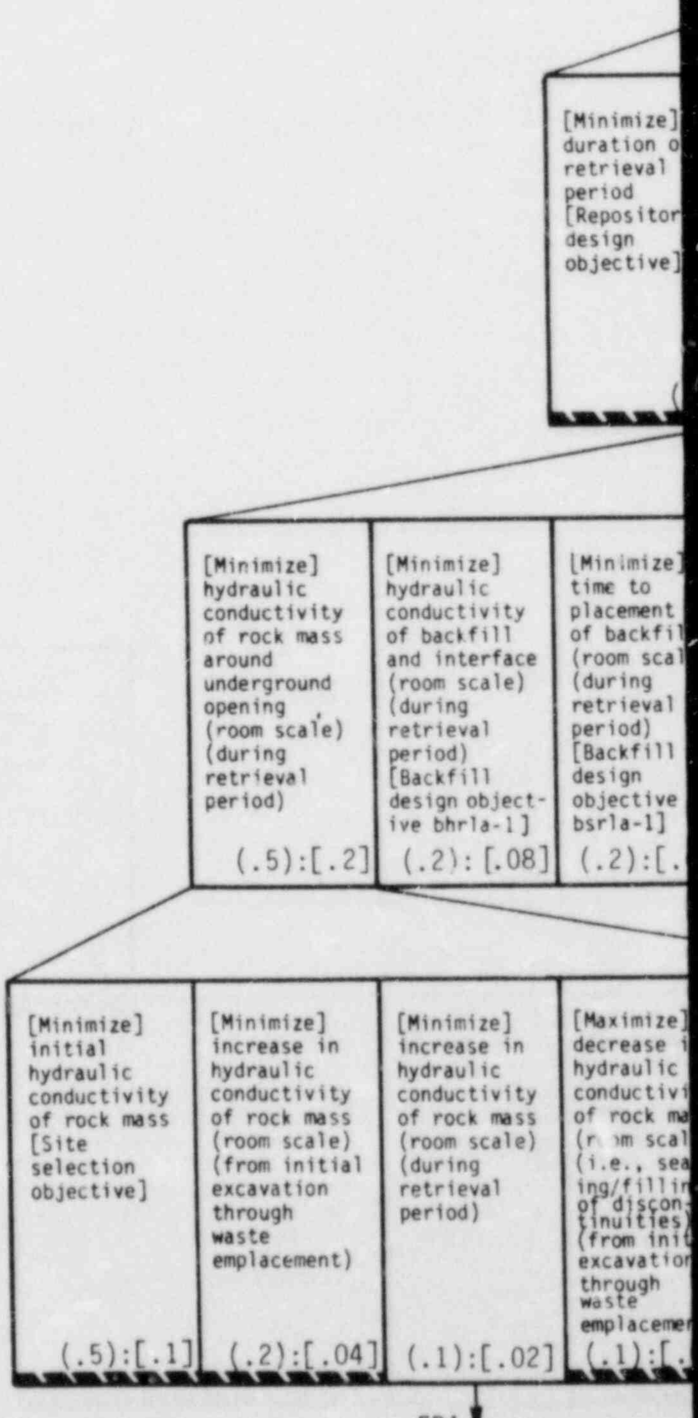
WEIGHTS OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES WITH RESPECT TO REFERENCED COMMON PERFORMANCE SUBOBJECTIVE DR3

Figure B.37

Note: Refer to Figure B.3 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down elsewhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▨.

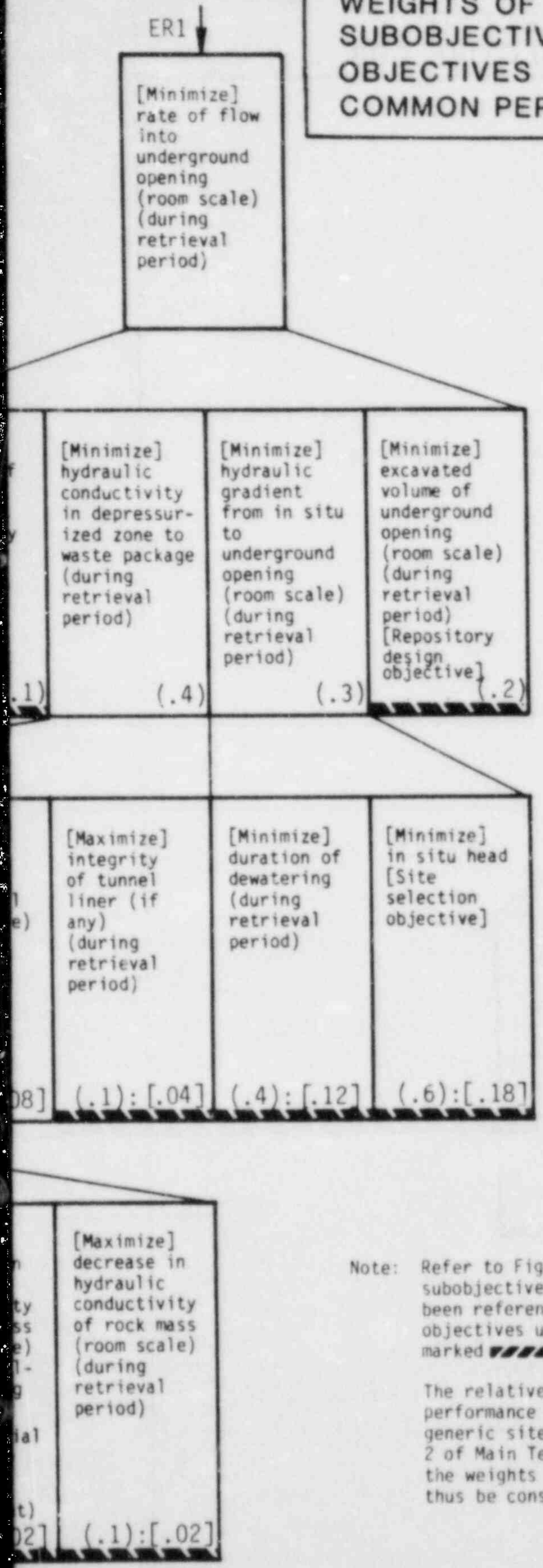
The relative weight of each subobjective to achieving the repository system performance objective is based on preconceived repository design concepts, generic site conditions, and performance assessment methodology (see Section 2 of Main Text); should these premises change, the weights may change. Also, the weights entail significant subjectivity in their assessment, and should thus be considered only as approximate indicators of relative significance.




[Minimize] duration o retrieval period [Repositor design objective]
(
[Minimize] hydraulic conductivity of rock mass around underground opening (room scale) (during retrieval period)
(.5):[.2]
[Minimize] hydraulic conductivity of backfill and interface (room scale) (during retrieval period) [Backfill design objective bhrla-1]
(.2):[.08]
[Minimize] time to placement of backfil (room scal (during retrieval period) [Backfill design objective bsrla-1]
(.2):[.
[Minimize] initial hydraulic conductivity of rock mass [Site selection objective]
(.5):[.1]
[Minimize] increase in hydraulic conductivity of rock mass (room scale) (from initial excavation through waste emplacement)
(.2):[.04]
[Minimize] increase in hydraulic conductivity of rock mass (room scale) (during retrieval period)
(.1):[.02]
[Maximize] decrease i hydraulic conductivi of rock ma (room scal (i.e., sea ing/fillin of discon-tinuities) (from init excavation through waste emplacemen
(.1):[.
FR1

WEIGHTS OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES WITH RESPECT TO REFERENCED COMMON PERFORMANCE SUBOBJECTIVE ER1

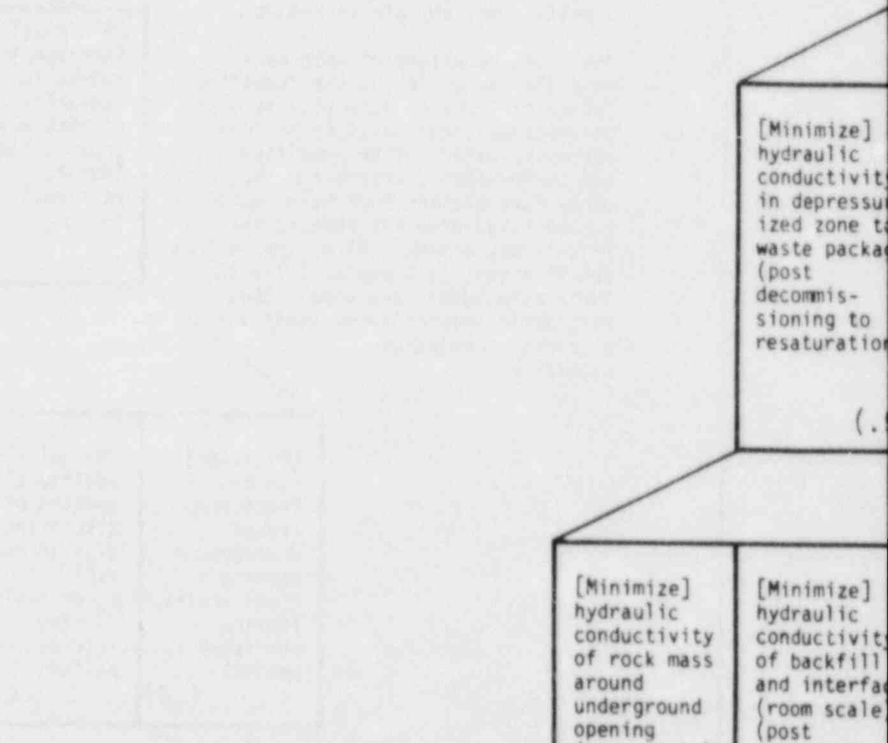
Figure B.38



(ref. Figure A.37)

Note: Refer to Figure B.3 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down eleswhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▨.

The relative weight of each subobjective to achieving the repository system performance objective is based on preconceived repository design concepts, generic site conditions, and performance assessment methodology (see Section 2 of Main Text); should these premises change, the weights may change. Also, the weights entail significant subjectivity in their assessment, and should thus be considered only as approximate indicators of relative significance.


[Minimize] hydraulic conductivit in depressu ized zone t waste packa (post decommis- sioning to resaturatio
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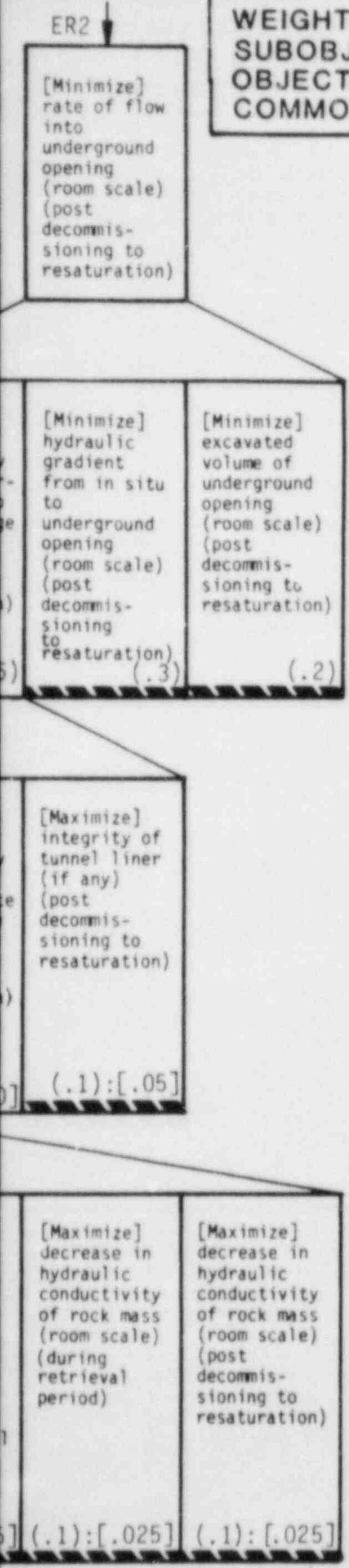
[Minimize] hydraulic conductivity of rock mass around underground opening (room scale) (post decommis- sioning to resaturation)
(.5):[.25]
[Minimize] hydraulic conductivit of backfill and interfa (room scale (post decommis- sioning to resaturatio [Backfill design objective bhrla-2]
(.4):[.2
[Minimize] initial hydraulic conductivity of rock mass [Site selection objective]
(.4):[.10]
[Minimize] increase in hydraulic conductivity of rock mass (room scale) (from initial excavation through waste emplacement)
(.1):[.025]
[Minimize] increase in hydraulic conductivity of rock mass (room scale) (during retrieval period)
(.1):[.025]
[Minimize] increase in hydraulic conductivity of rock mass (room scale) (post decommis- sioning to resaturation)
(.1):[.025]
[Maximize] decrease in hydraulic conductivity of rock mas (room scale) (i.e., seal- ing/filling of discont- inuities) (from initia excavation through waste emplacement
(.1):[.02
FR1
FR2

WEIGHTS OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES WITH RESPECT TO REFERENCED COMMON PERFORMANCE SUBOBJECTIVE ER2

Figure B.39



(ref. Figure A.38)

Note: Refer to Figure B.3 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down elsewhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▰▰▰▰.

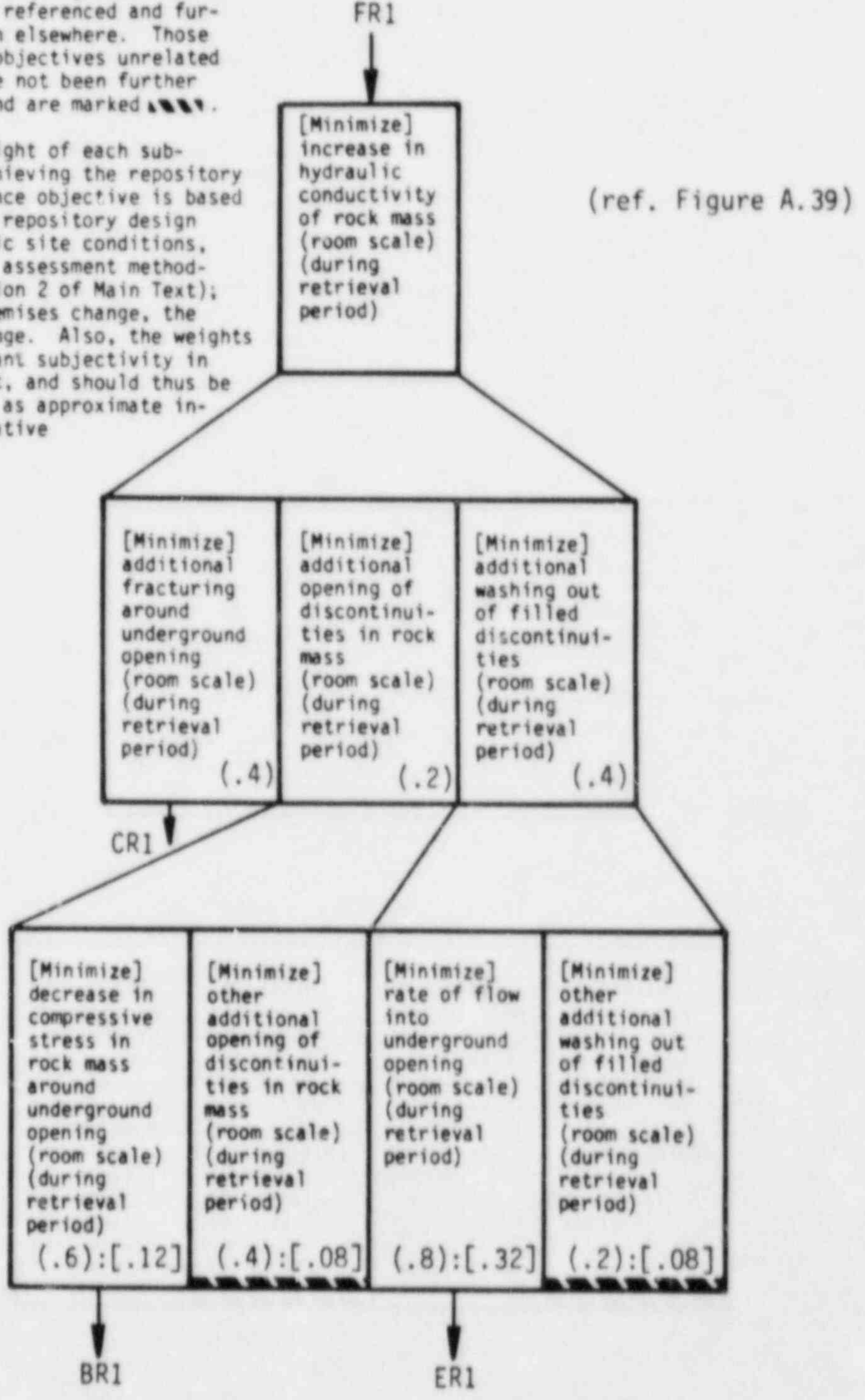
The relative weight of each subobjective to achieving the repository system performance objective is based on preconceived repository design concepts, generic site conditions, and performance assessment methodology (see Section 2 of Main Text); should these premises change, the weights may change. Also, the weights entail significant subjectivity in their assessment, and should thus be considered only as approximate indicators of relative significance.

WEIGHTS OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES WITH RESPECT TO REFERENCED COMMON PERFORMANCE SUBOBJECTIVE FR1

Figure B.40

Note: Refer to Figure B.3 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down elsewhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▨.

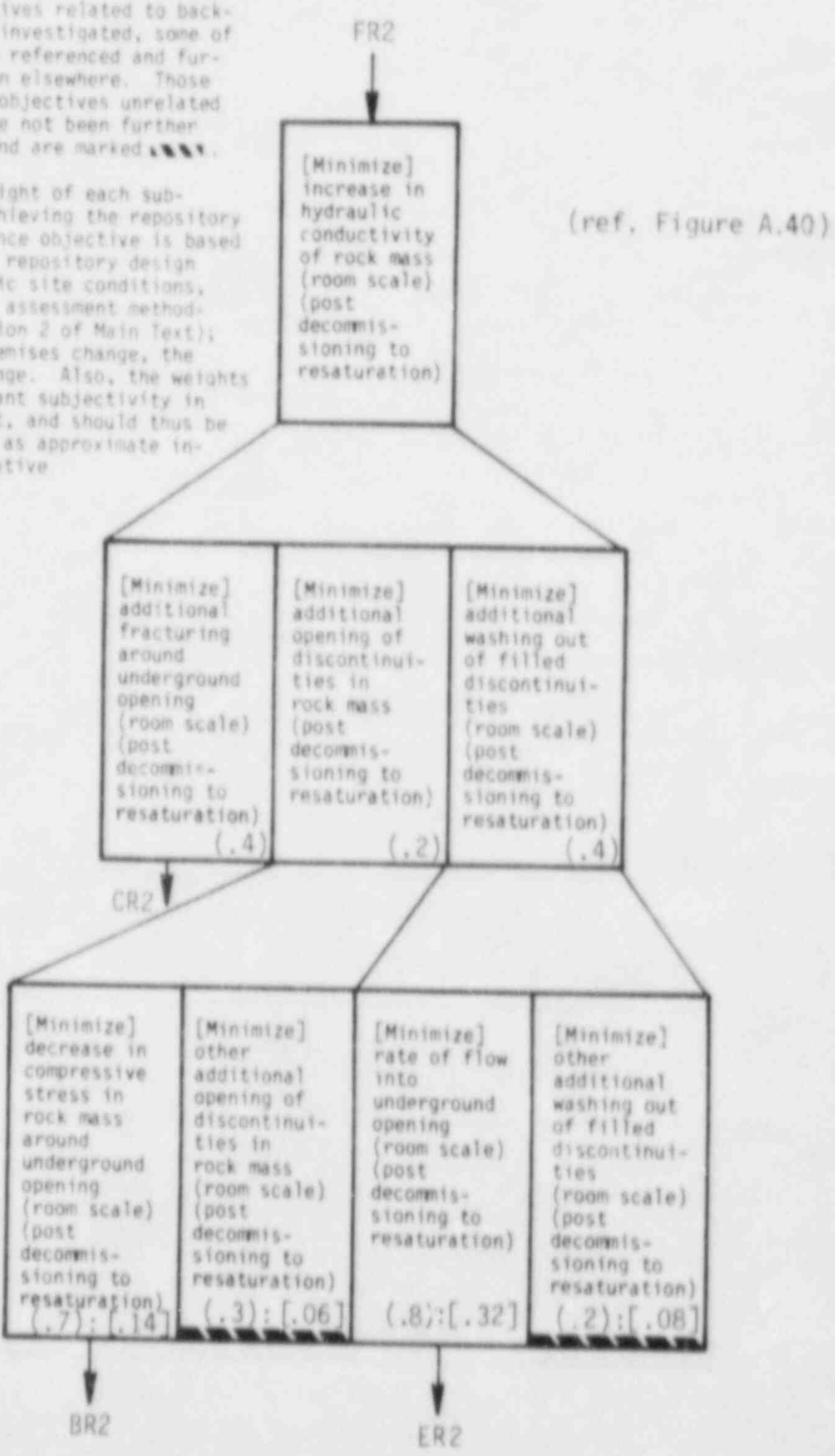
The relative weight of each subobjective to achieving the repository system performance objective is based on preconceived repository design concepts, generic site conditions, and performance assessment methodology (see Section 2 of Main Text); should these premises change, the weights may change. Also, the weights entail significant subjectivity in their assessment, and should thus be considered only as approximate indicators of relative significance.



WEIGHTS OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES WITH RESPECT TO REFERENCED COMMON PERFORMANCE SUBOBJECTIVE FR2 Figure B.41

Note: Refer to Figure B.3 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down elsewhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▨.

The relative weight of each subobjective to achieving the repository system performance objective is based on preconceived repository design concepts, generic site conditions, and performance assessment methodology (see Section 2 of Main Text); should these premises change, the weights may change. Also, the weights entail significant subjectivity in their assessment, and should thus be considered only as approximate indicators of relative significance.

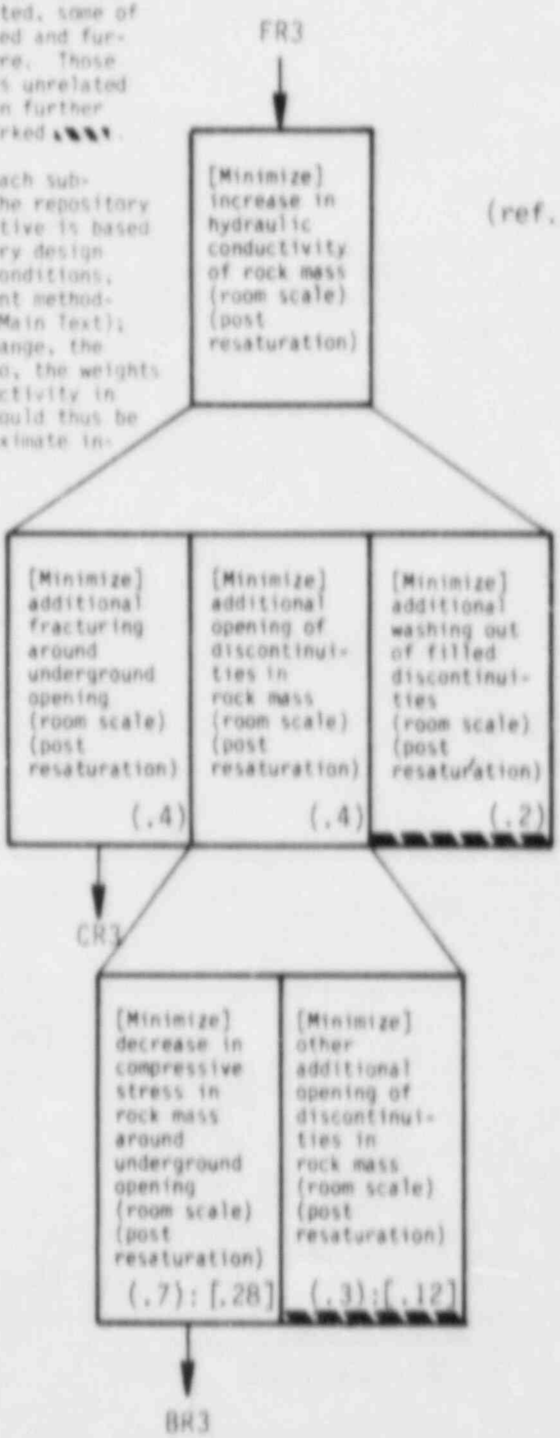


WEIGHTS OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES WITH RESPECT TO REFERENCED COMMON PERFORMANCE SUBOBJECTIVE FR3

Figure B.42

Note: Refer to Figure B.3 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down elsewhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▨▨▨.

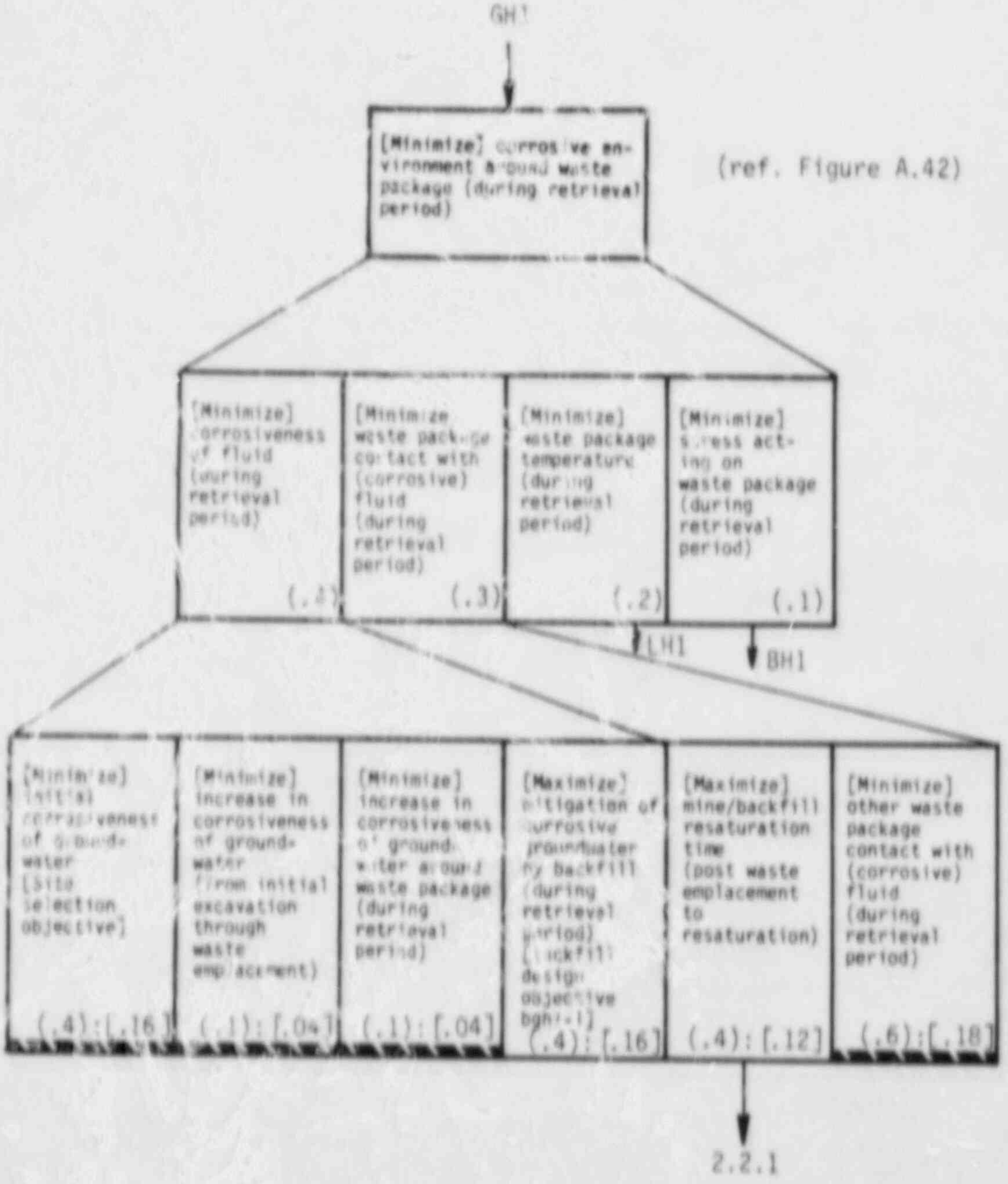
The relative weight of each subobjective to achieving the repository system performance objective is based on preconceived repository design concepts, generic site conditions, and performance assessment methodology (see Section 2 of Main Text); should these premises change, the weights may change. Also, the weights entail significant subjectivity in their assessment, and should thus be considered only as approximate indicators of relative significance.



(ref. Figure A.41)

WEIGHTS OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES WITH RESPECT TO REFERENCED COMMON PERFORMANCE SUBOBJECTIVE GH1

Figure B.43

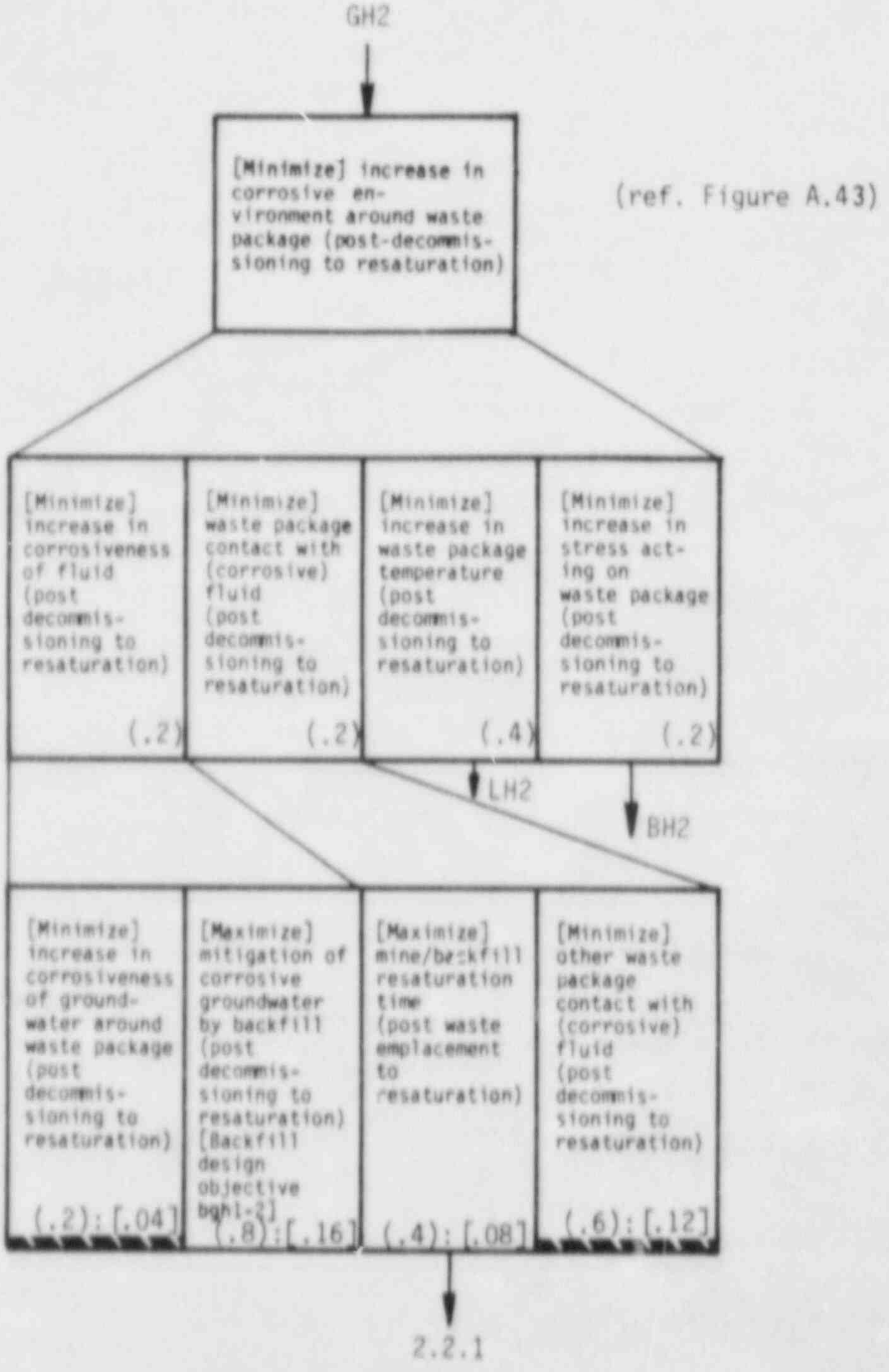


Note: Refer to Figure B.1 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down elsewhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▨▨▨▨.

The relative weight of each subobjective to achieving the repository system performance objective is based on preconceived repository design concepts, generic site conditions, and performance assessment methodology (see Section 2 of Main Text); should these premises change, the weights may change. Also, the weights entail significant subjectivity in their assessment, and should thus be considered only as approximate indicators of relative significance.

WEIGHTS OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES WITH RESPECT TO REFERENCED COMMON PERFORMANCE SUBOBJECTIVE GH2

Figure B.44

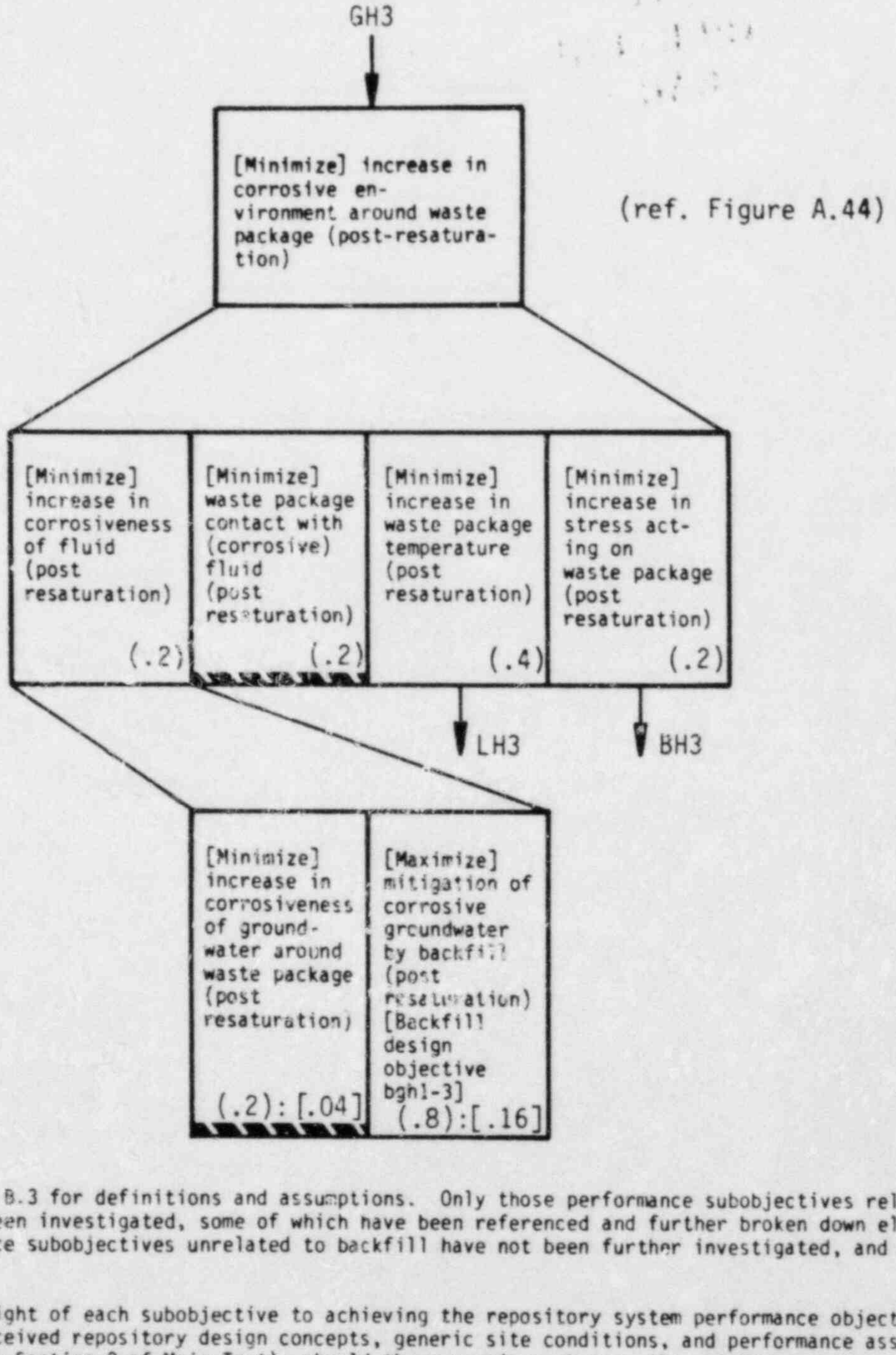


Note: Refer to Figure B.3 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down elsewhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▨▨▨▨.

The relative weight of each subobjective to achieving the repository system performance objective is based on preconceived repository design concepts, generic site conditions, and performance assessment methodology (see Section 2 of Main Text); should these premises change, the weights may change. Also, the weights entail significant subjectivity in their assessment, and should thus be considered only as approximate indicators of relative significance.

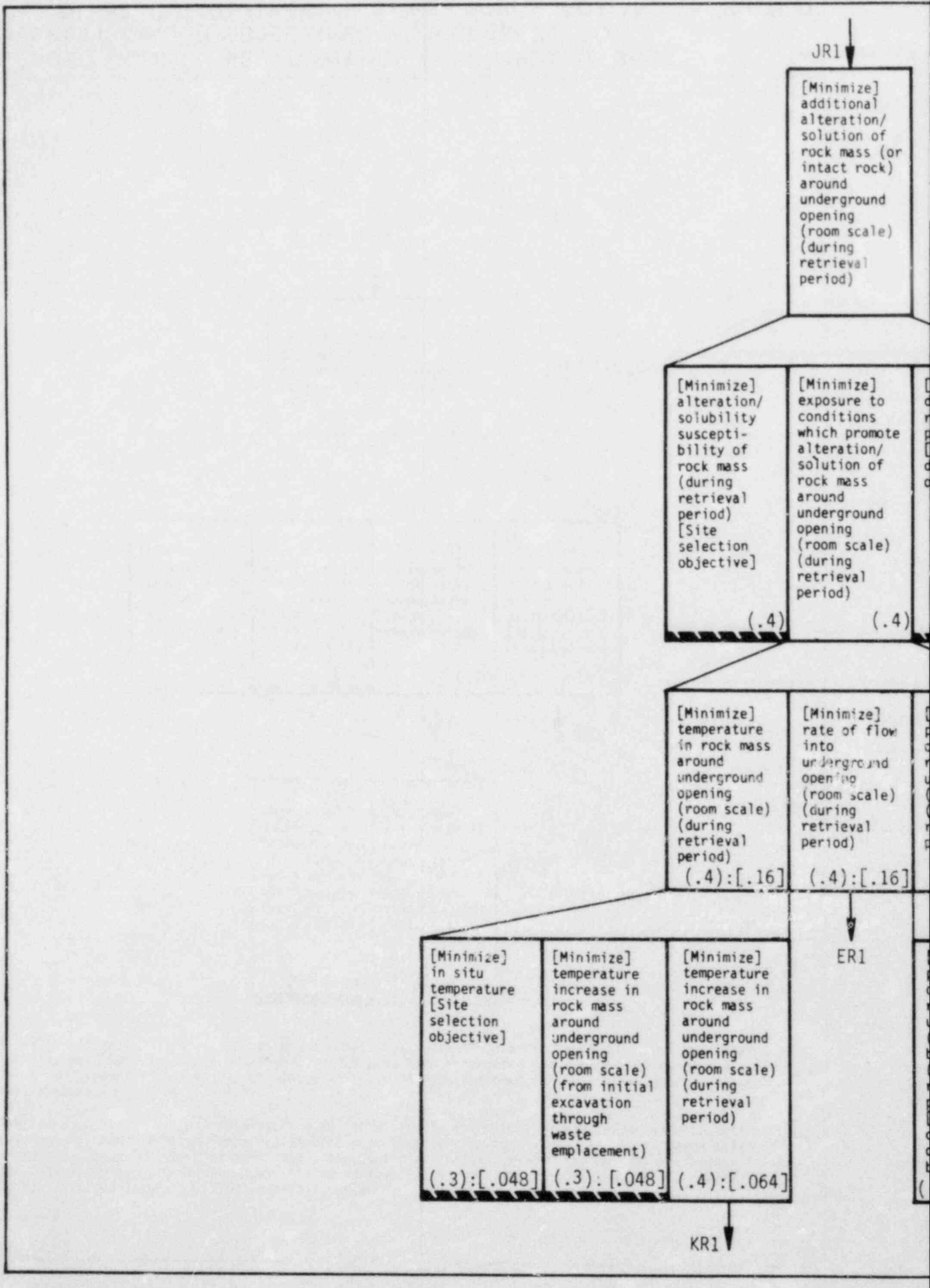
WEIGHTS OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES WITH RESPECT TO REFERENCED COMMON PERFORMANCE SUBOBJECTIVE GH3

Figure B.45



Note: Refer to Figure B.3 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down elsewhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▨▨▨▨.

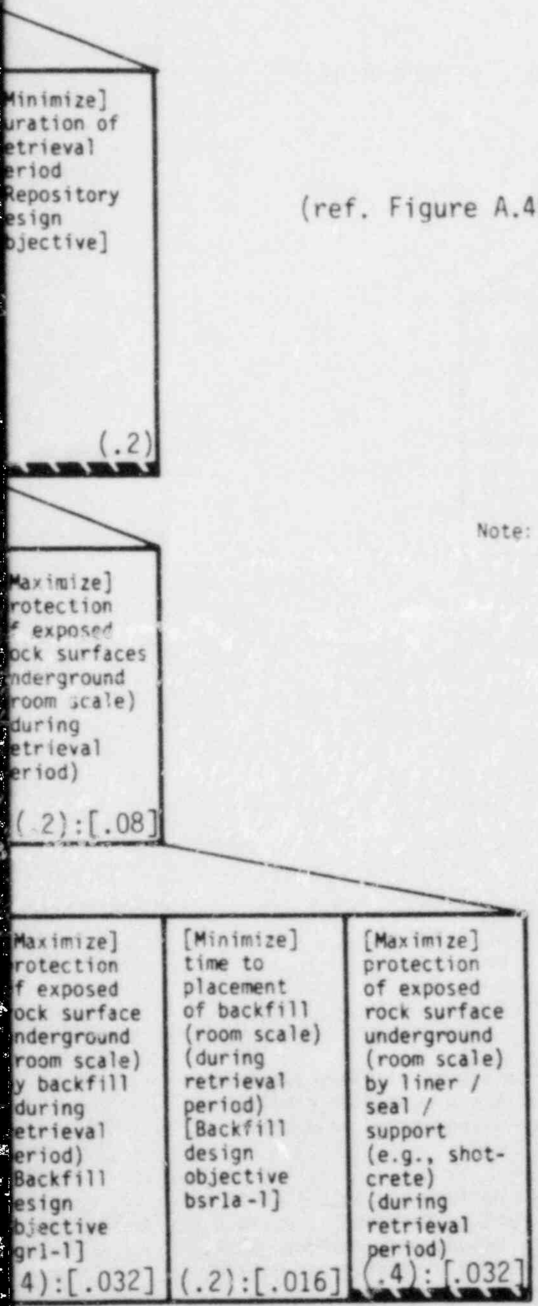
The relative weight of each subobjective to achieving the repository system performance objective is based on preconceived repository design concepts, generic site conditions, and performance assessment methodology (see Section 2 of Main Text), should these premises change, the weights may change. Also, the weights entail significant subjectivity in their assessment, and should thus be considered only as approximate indicators of relative significance


JR1
[Minimize] additional alteration/ solution of rock mass (or intact rock) around underground opening (room scale) (during retrieval period)
[Minimize] alteration/ solubility suscepti-bility of rock mass (during retrieval period) [Site selection objective] (.4)
[Minimize] exposure to conditions which promote alteration/ solution of rock mass around underground opening (room scale) (during retrieval period) (.4)
[Minimize] temperature in rock mass around underground opening (room scale) (during retrieval period) (.4):[.16]
[Minimize] rate of flow into underground opening (room scale) (during retrieval period) (.4):[.16]
ER1
[Minimize] in situ temperature [Site selection objective] (.3):[.048]
[Minimize] temperature increase in rock mass around underground opening (room scale) (from initial excavation through waste emplacement) (.3):[.048]
[Minimize] temperature increase in rock mass around underground opening (room scale) (during retrieval period) (.4):[.064]
KR1

WEIGHTS OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES WITH RESPECT TO REFERENCED COMMON PERFORMANCE SUBOBJECTIVE JR1

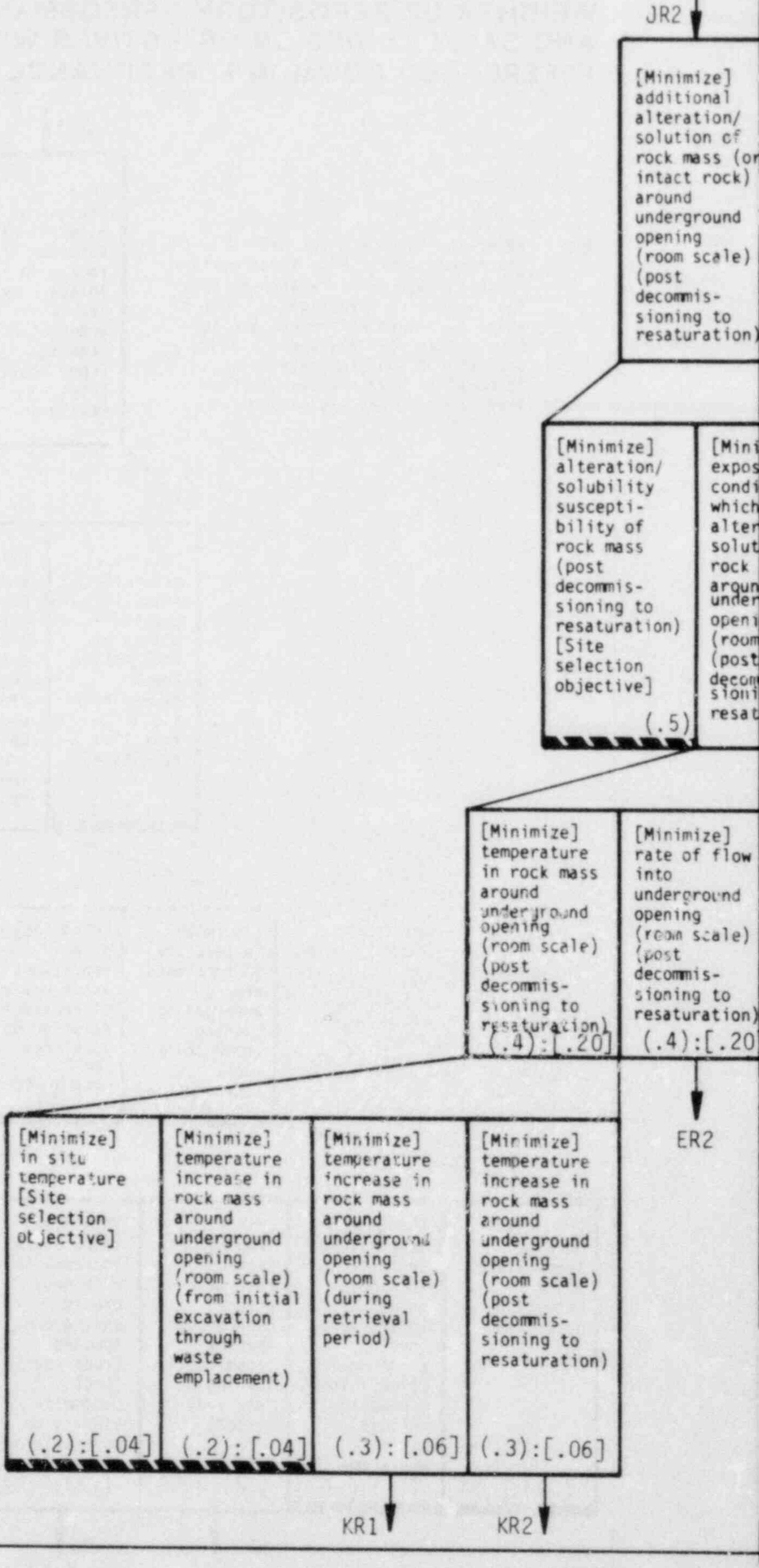
Figure B.46

(ref. Figure A.45)



Note: Refer to Figure B.3 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down eleswhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▨.

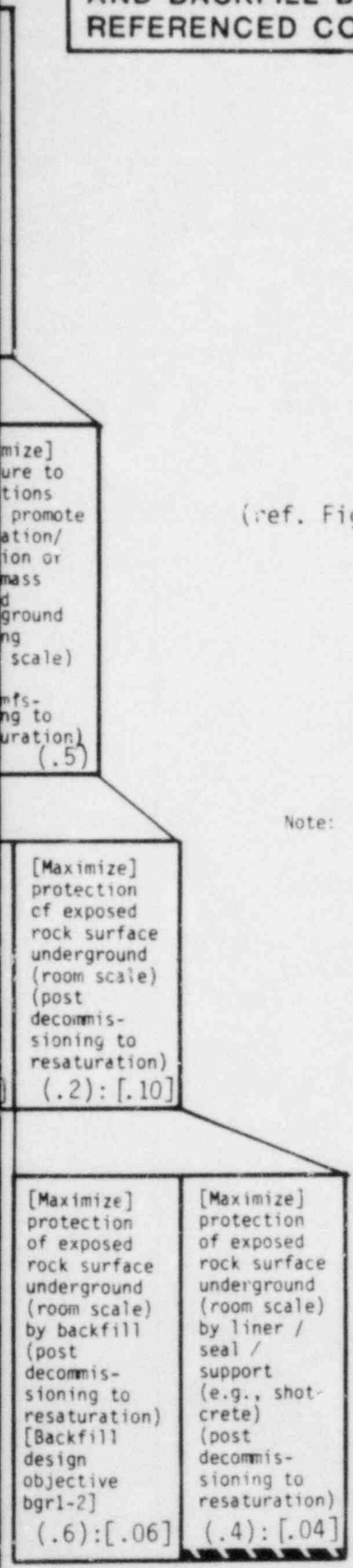
The relative weight of each subobjective to achieving the repository system performance objective is based on preconceived repository design concepts, generic site conditions, and performance assessment methodology (see Section 2 of Main Text); should these premises change, the weights may change. Also, the weights entail significant subjectivity in their assessment, and should thus be considered only as approximate indicators of relative significance.


JR2
[Minimize] additional alteration/ solution of rock mass (or intact rock) around underground opening (room scale) (post decommis-sioning to resaturation)
[Minimize] alteration/ solubility suscepti-bility of rock mass (post decommis-sioning to resaturation) [Site selection objective]
(.5)
[Mini expos condi which alter solut rock around under openi (room (post decom sioni resat
[Minimize] temperature in rock mass around underground opening (room scale) (post decommis-sioning to resaturation)
(.4):[.20]
[Minimize] rate of flow into underground opening (room scale) (post decommis-sioning to resaturation)
(.4):[.20
ER2
[Minimize] in situ temperature [Site selection objective]
(.2):[.04]
[Minimize] temperature increase in rock mass around underground opening (room scale) (from initial excavation through waste emplacement)
(.2):[.04]
[Minimize] temperature increase in rock mass around underground opening (room scale) (during retrieval period)
(.3):[.06]
[Minimize] temperature increase in rock mass around underground opening (room scale) (post decommis-sioning to resaturation)
(.3):[.06]
KR1
KR2

WEIGHTS OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES WITH RESPECT TO REFERENCED COMMON PERFORMANCE SUBOBJECTIVE JR2

Figure B.47

(ref. Figure A.46)



Note: Refer to Figure B.3 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down elsewhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▨.

The relative weight of each subobjective to achieving the repository system performance objective is based on preconceived repository design concepts, generic site conditions, and performance assessment methodology (see Section 2 of Main Text); should these premises change, the weights may change. Also, the weights entail significant subjectivity in their assessment, and should thus be considered only as approximate indicators of relative significance.

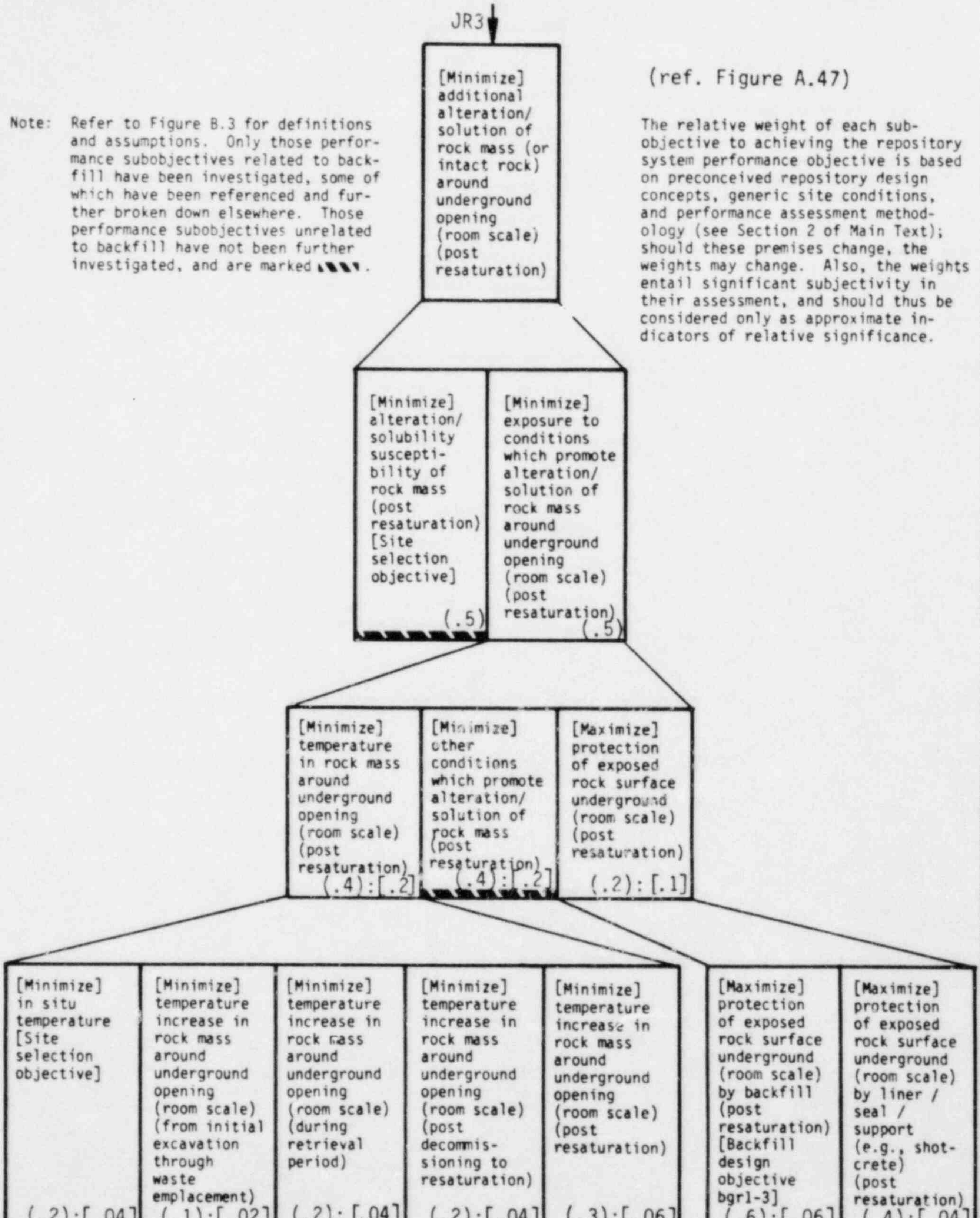
WEIGHTS OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES WITH RESPECT TO REFERENCED COMMON PERFORMANCE SUBOBJECTIVE JR3

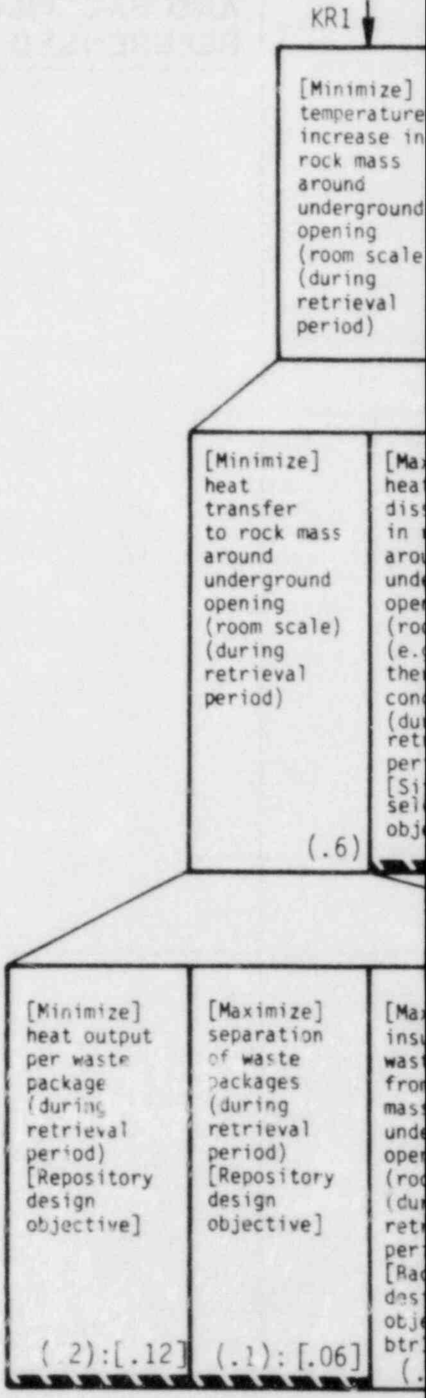
Figure B.48

Note: Refer to Figure B.3 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down elsewhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▨.

(ref. Figure A.47)

The relative weight of each subobjective to achieving the repository system performance objective is based on preconceived repository design concepts, generic site conditions, and performance assessment methodology (see Section 2 of Main Text); should these premises change, the weights may change. Also, the weights entail significant subjectivity in their assessment, and should thus be considered only as approximate indicators of relative significance.



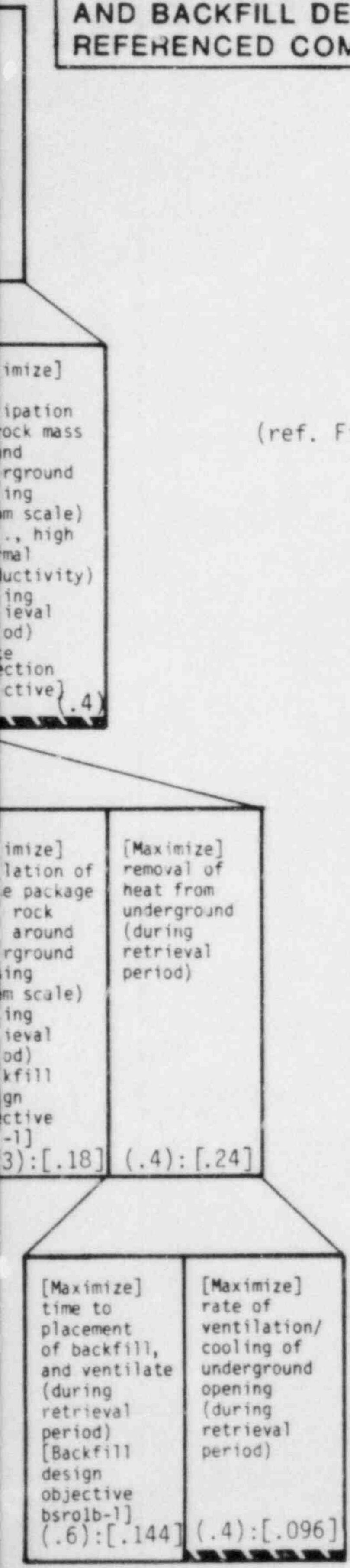


Note: Refer to Figure B.3 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down eleswhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▨▨▨▨.

The relative weight of each subobjective to achieving the repository system performance objective is based on preconceived repository design concepts, generic site conditions, and performance assessment methodology (see Section 2 of Main Text); should these premises change, the weights may change. Also, the weights entail significant subjectivity in their assessment, and should thus be considered only as approximate indicators of relative significance.

WEIGHTS OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES WITH RESPECT TO REFERENCED COMMON PERFORMANCE SUBOBJECTIVE KR1

Figure B.49



(ref. Figure A.48)

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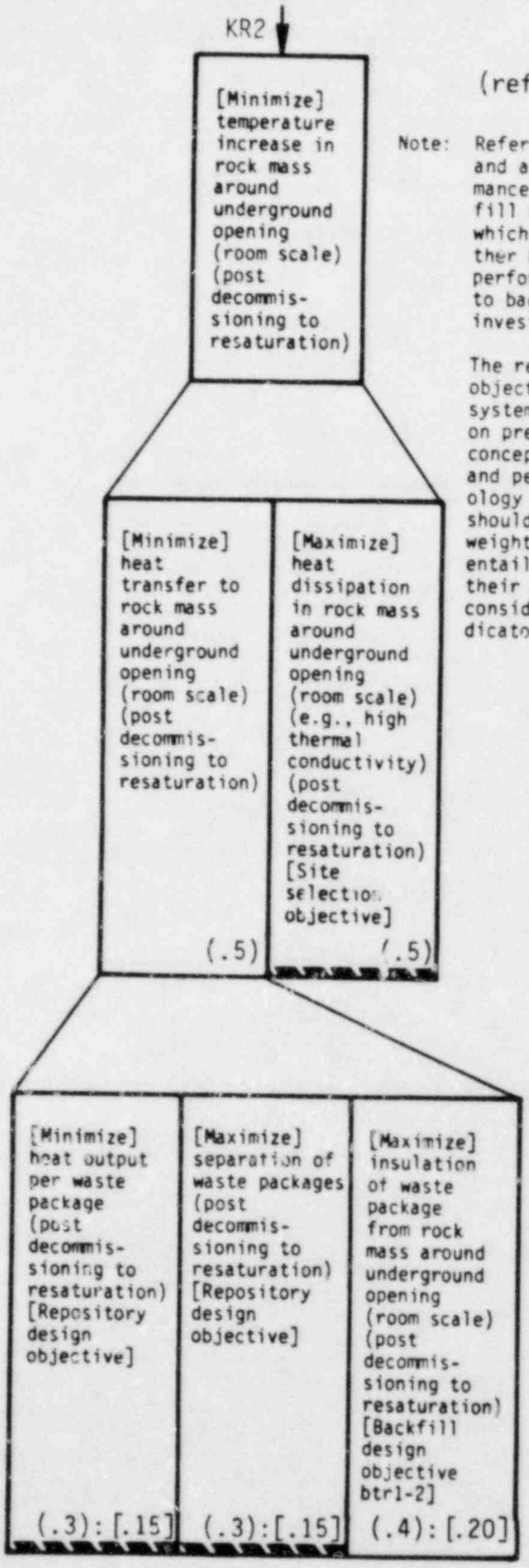
WEIGHTS OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES WITH RESPECT TO REFERENCED COMMON PERFORMANCE SUBOBJECTIVE KR2

Figure B.50



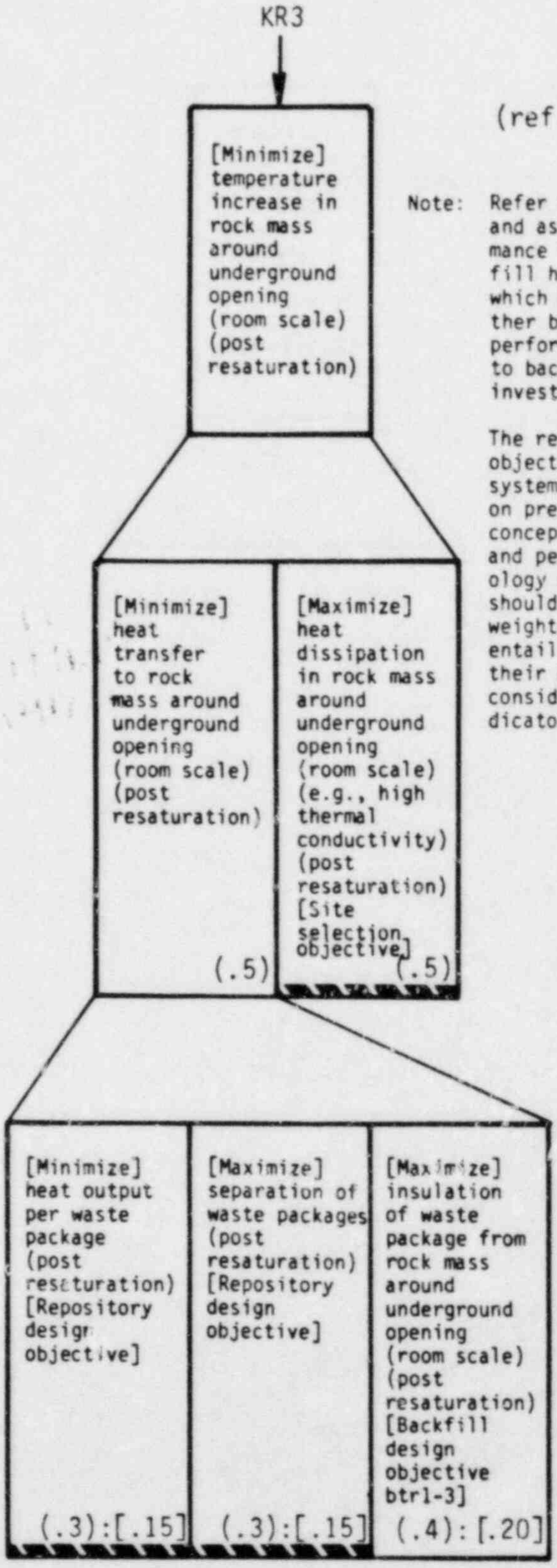
(ref. Figure A.49)

Note: Refer to Figure B.3 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down elsewhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▨.

The relative weight of each subobjective to achieving the repository system performance objective is based on preconceived repository design concepts, generic site conditions, and performance assessment methodology (see Section 2 of Main Text); should these premises change, the weights may change. Also, the weights entail significant subjectivity in their assessment, and should thus be considered only as approximate indicators of relative significance.

WEIGHTS OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES WITH RESPECT TO REFERENCED COMMON PERFORMANCE SUBOBJECTIVE KR3

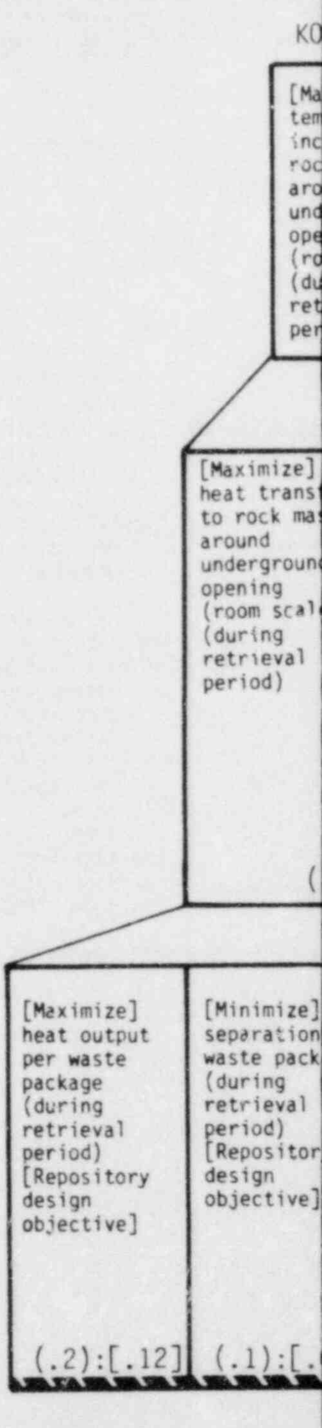
Figure B.51



(ref. Figure A.50)

Note: Refer to Figure B.3 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down elsewhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▨.

The relative weight of each subobjective to achieving the repository system performance objective is based on preconceived repository design concepts, generic site conditions, and performance assessment methodology (see Section 2 of Main Text); should these premises change, the weights may change. Also, the weights entail significant subjectivity in their assessment, and should thus be considered only as approximate indicators of relative significance.

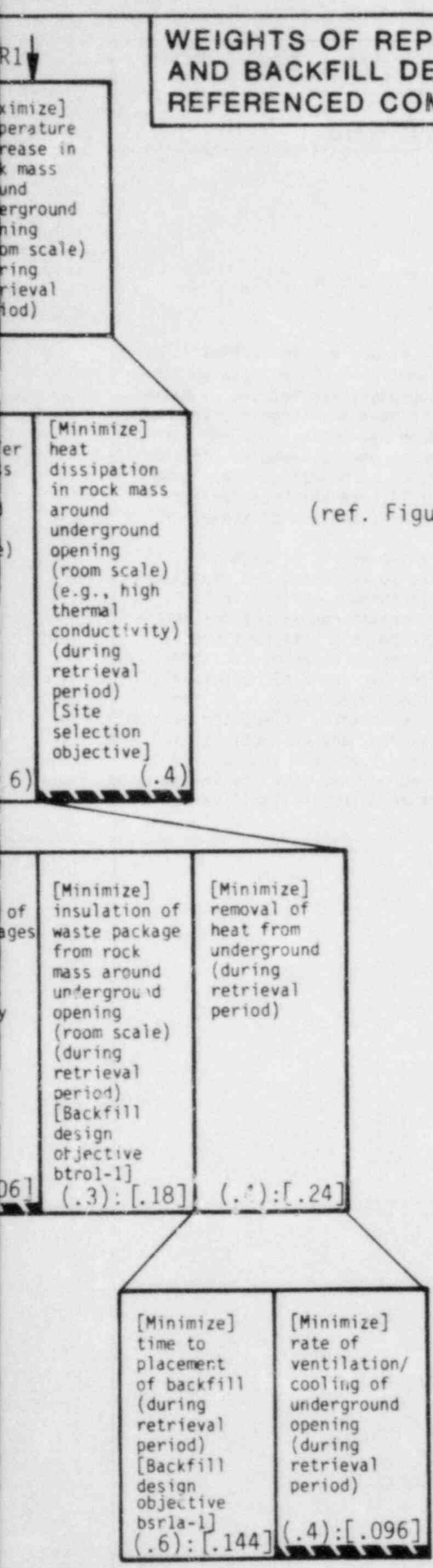


Note: Refer to Figure B.3 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down eleswhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▨▨▨.

The relative weight of each subobjective to achieving the repository system performance objective is based on preconceived repository design concepts, generic site conditions, and performance assessment methodology (see Section 2 of Main Text); should these premises change, the weights may change. Also, the weights entail significant subjectivity in their assessment, and should thus be considered only as approximate indicators of relative significance.

WEIGHTS OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES WITH RESPECT TO REFERENCED COMMON PERFORMANCE SUBOBJECTIVE KOR1

Figure B.52



(ref. Figure A.51)

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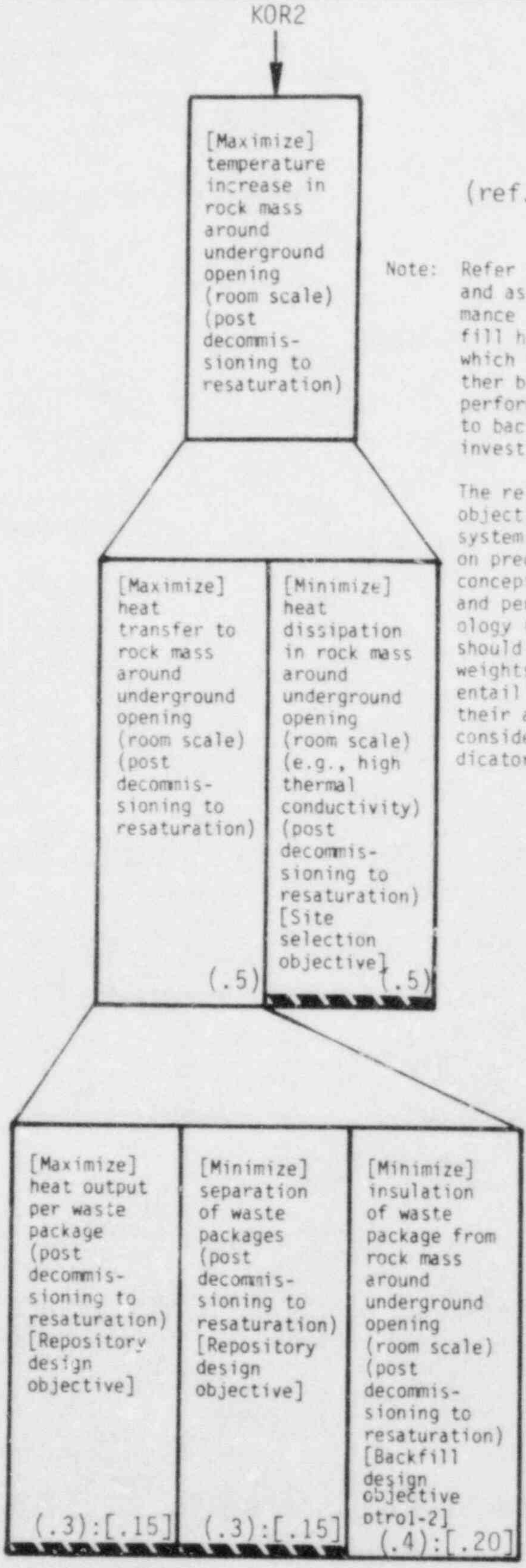
WEIGHTS OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES WITH RESPECT TO REFERENCED COMMON PERFORMANCE SUBOBJECTIVE KOR2

Figure B.53



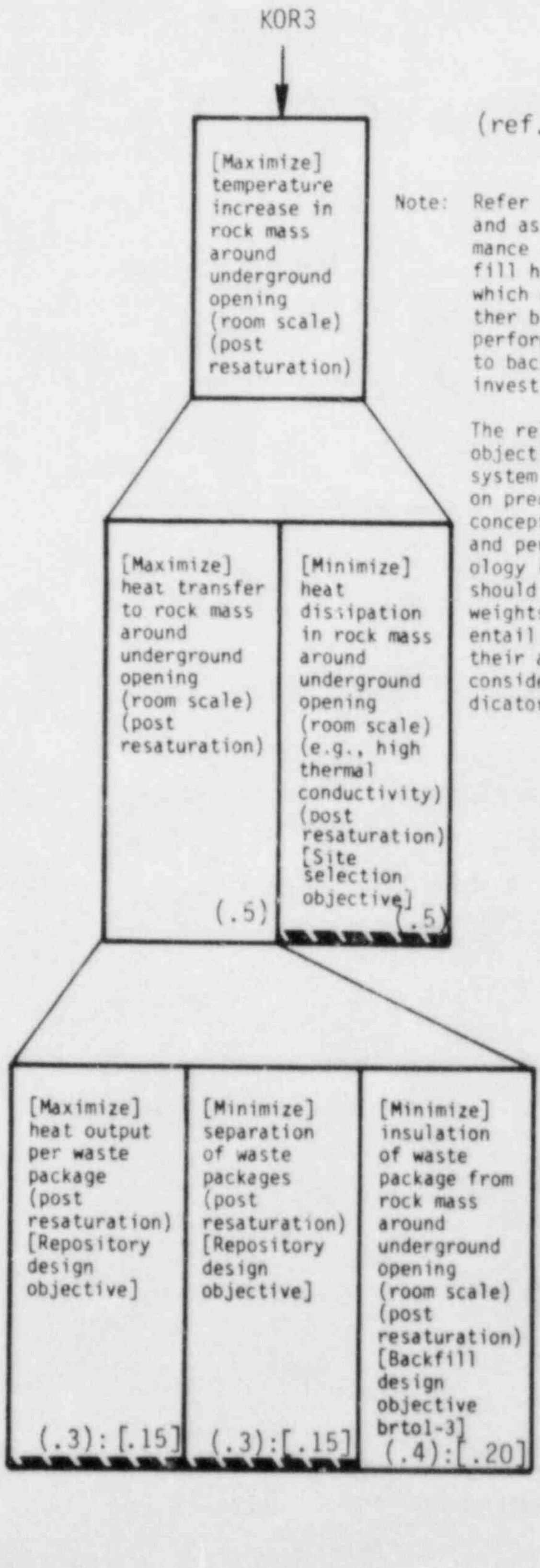
(ref. Figure A.52)

Note: Refer to Figure B.3 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down elsewhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▨.

The relative weight of each subobjective to achieving the repository system performance objective is based on preconceived repository design concepts, generic site conditions, and performance assessment methodology (see Section 2 of Main Text); should these premises change, the weights may change. Also, the weights entail significant subjectivity in their assessment, and should thus be considered only as approximate indicators of relative significance.

WEIGHTS OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES WITH RESPECT TO REFERENCED COMMON PERFORMANCE SUBOBJECTIVE KOR3

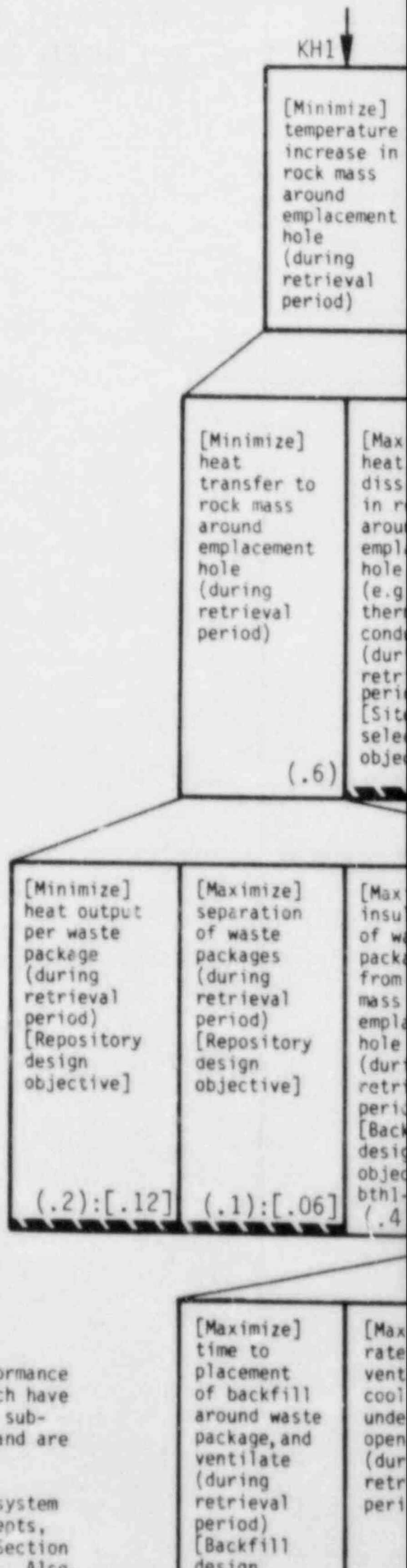
Figure B.54



(ref. Figure A.53)

Note: Refer to Figure B.3 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down elsewhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▨.

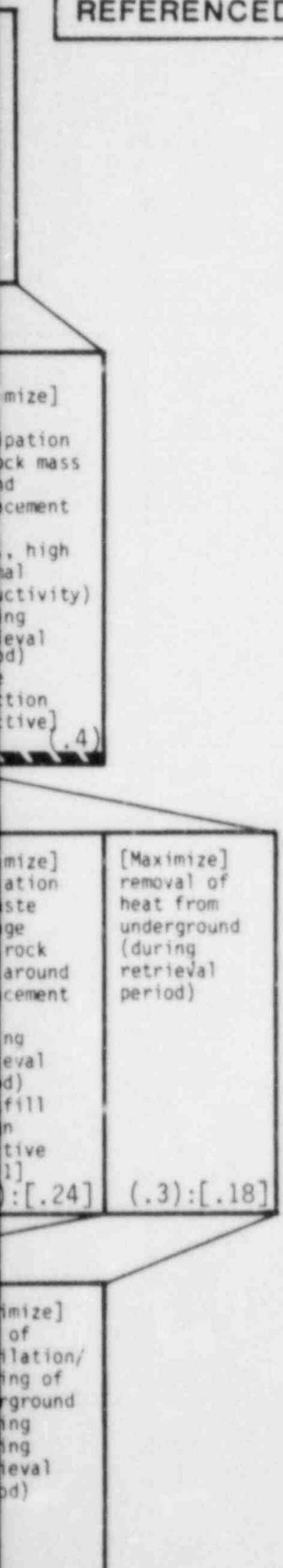
The relative weight of each subobjective to achieving the repository system performance objective is based on preconceived repository design concepts, generic site conditions, and performance assessment methodology (see Section 2 of Main Text); should these premises change, the weights may change. Also, the weights entail significant subjectivity in their assessment, and should thus be considered only as approximate indicators of relative significance.



Note: Refer to Figure B.3 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down eleswhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▨.

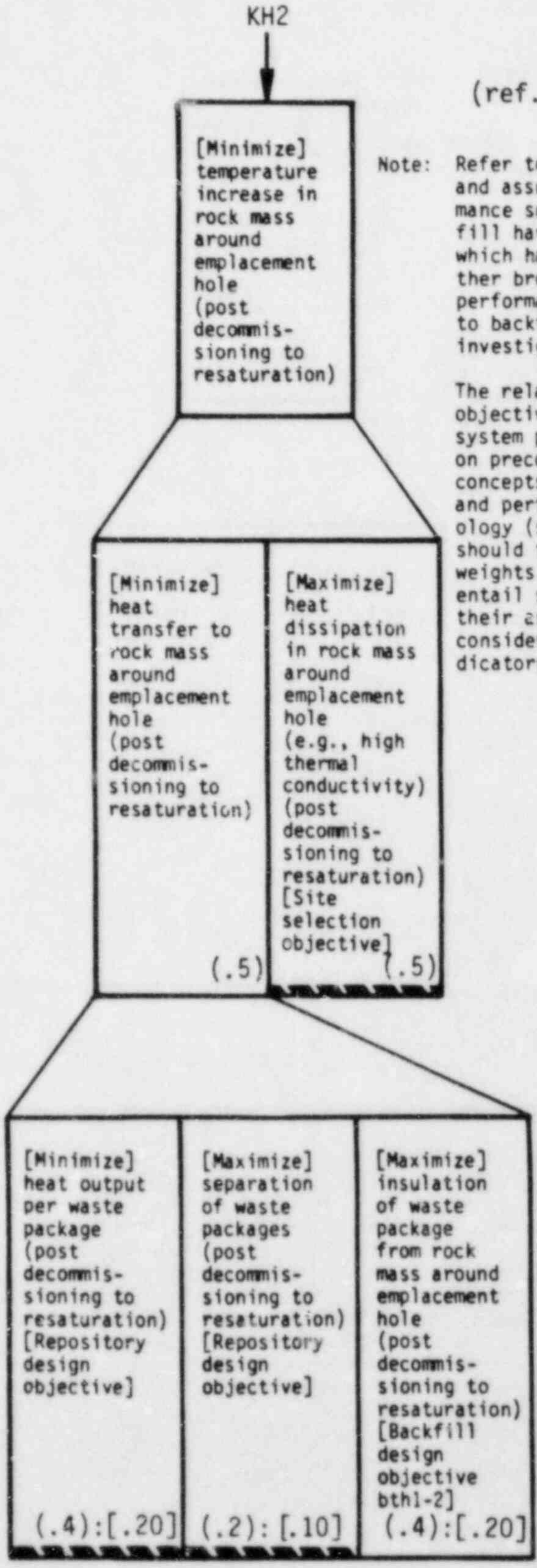
The relative weight of each subobjective to achieving the repository system performance objective is based on preconceived repository design concepts, generic site conditions, and performance assessment methodology (see Section 2 of Main Text); should these premises change, the weights may change. Also, the weights entail significant subjectivity in their assessment, and should thus be considered only as approximate indicators of relative significance.

WEIGHTS OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES WITH RESPECT TO REFERENCED COMMON PERFORMANCE SUBOBJECTIVE KH1 **Figure B.55**



(ref. Figure A.54)

WEIGHTS OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES WITH RESPECT TO REFERENCED COMMON PERFORMANCE SUBOBJECTIVE KH2 Figure B.56



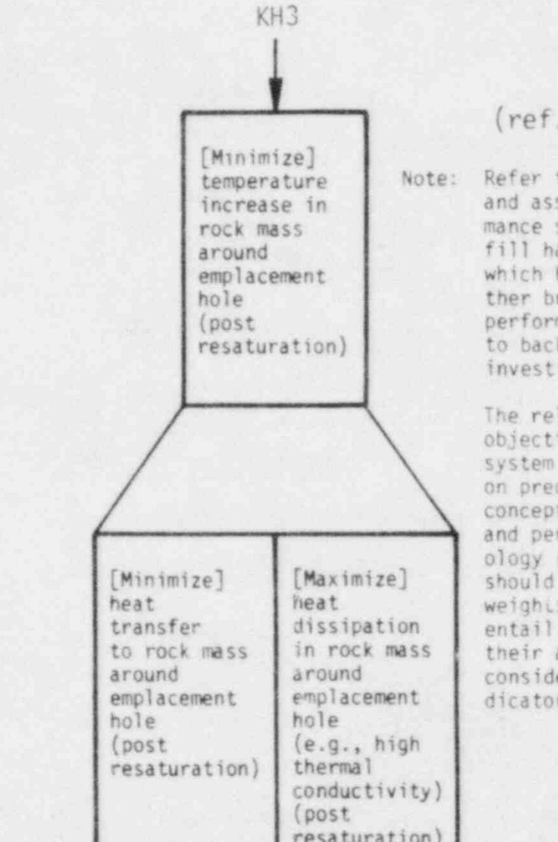
(ref. Figure A.55)

Note: Refer to Figure B.3 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down elsewhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▨.

The relative weight of each subobjective to achieving the repository system performance objective is based on preconceived repository design concepts, generic site conditions, and performance assessment methodology (see Section 2 of Main Text); should these premises change, the weights may change. Also, the weights entail significant subjectivity in their assessment, and should thus be considered only as approximate indicators of relative significance.

WEIGHTS OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES WITH RESPECT TO REFERENCED COMMON PERFORMANCE SUBOBJECTIVE KH3

Figure B.57



(ref. Figure A.56)

Note: Refer to Figure B.3 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down elsewhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▨.

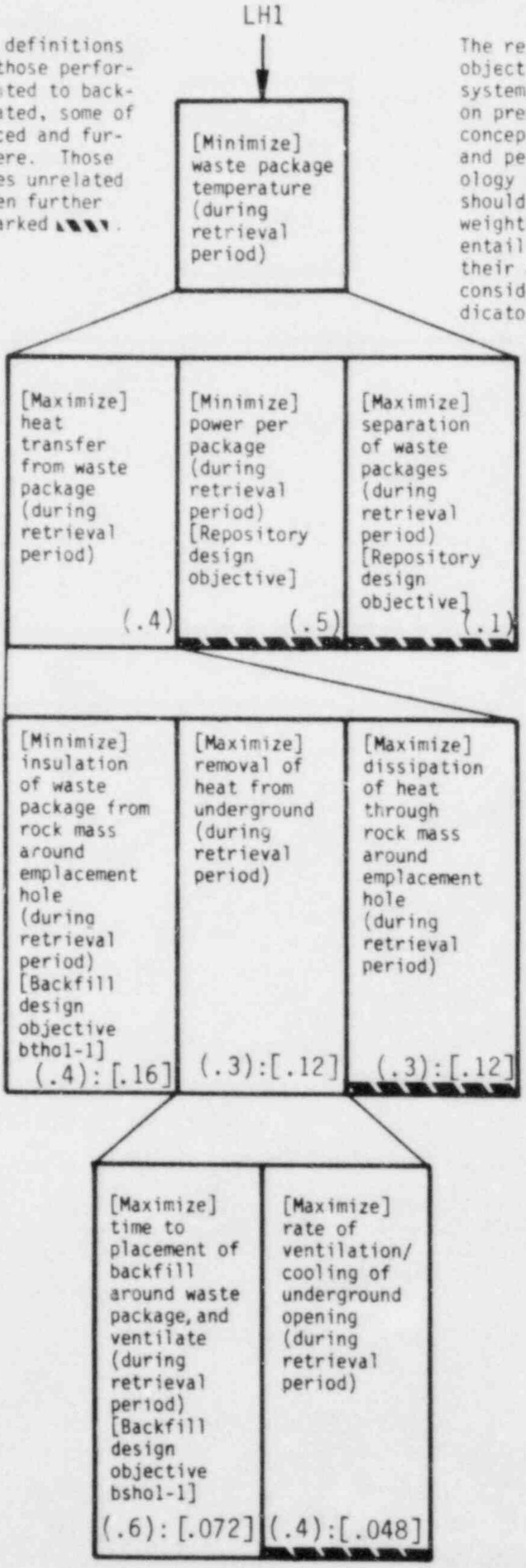
The relative weight of each subobjective to achieving the repository system performance objective is based on preconceived repository design concepts, generic site conditions, and performance assessment methodology (see Section 2 of Main Text); should these premises change, the weights may change. Also, the weights entail significant subjectivity in their assessment, and should thus be considered only as approximate indicators of relative significance.

WEIGHTS OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES WITH RESPECT TO REFERENCED COMMON PERFORMANCE SUBOBJECTIVE LH1

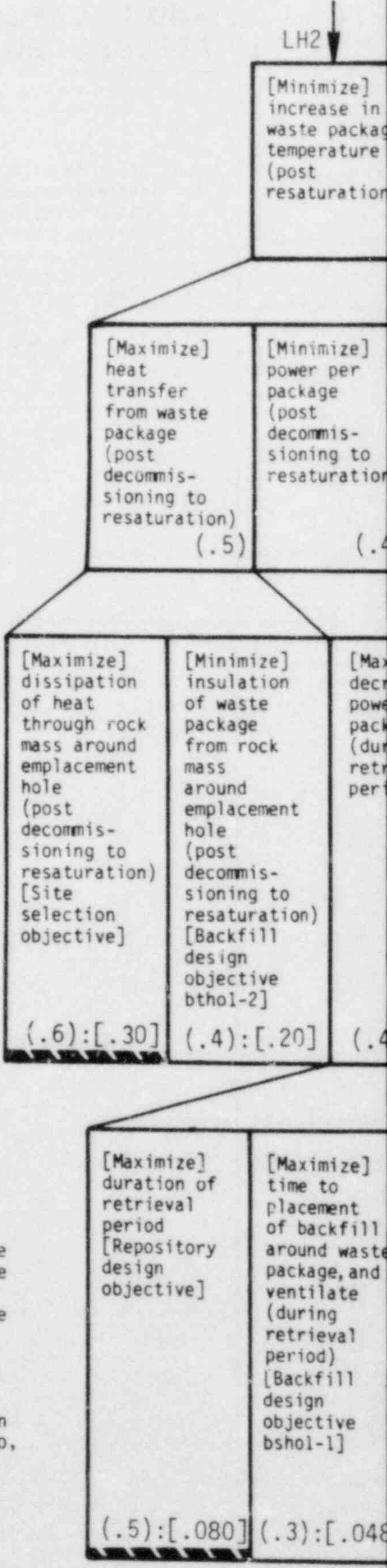
Figure B.58

Note: Refer to Figure B.3 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down elsewhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▨.

The relative weight of each subobjective to achieving the repository system performance objective is based on preconceived repository design concepts, generic site conditions, and performance assessment methodology (see Section 2 of Main Text); should these premises change, the weights may change. Also, the weights entail significant subjectivity in their assessment, and should thus be considered only as approximate indicators of relative significance.



(ref. Figure A.57)

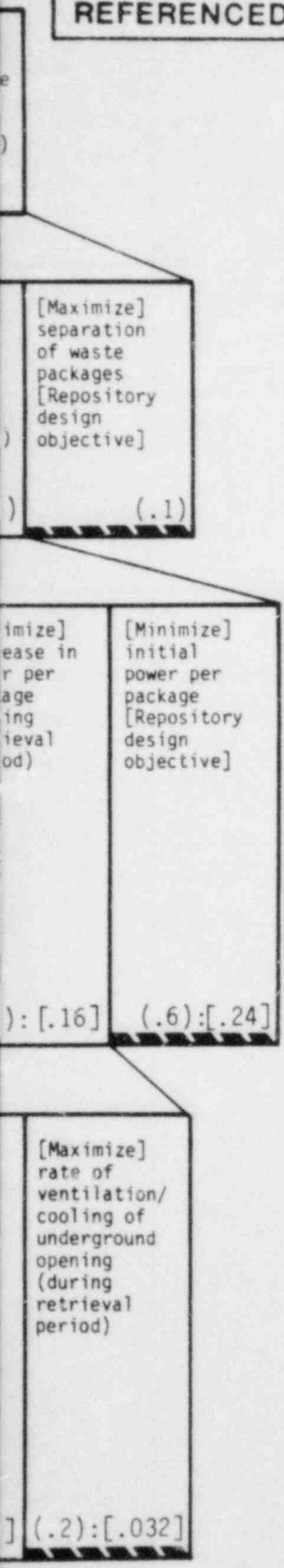


Note: Refer to Figure B.3 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down eleswhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▨.

The relative weight of each subobjective to achieving the repository system performance objective is based on preconceived repository design concepts, generic site conditions, and performance assessment methodology (see Section 2 of Main Text); should these premises change, the weights may change. Also, the weights entail significant subjectivity in their assessment, and should thus be considered only as approximate indicators of relative significance.

WEIGHTS OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES WITH RESPECT TO REFERENCED COMMON PERFORMANCE SUBOBJECTIVE LH2

Figure B.59



(ref. Figure A.58)

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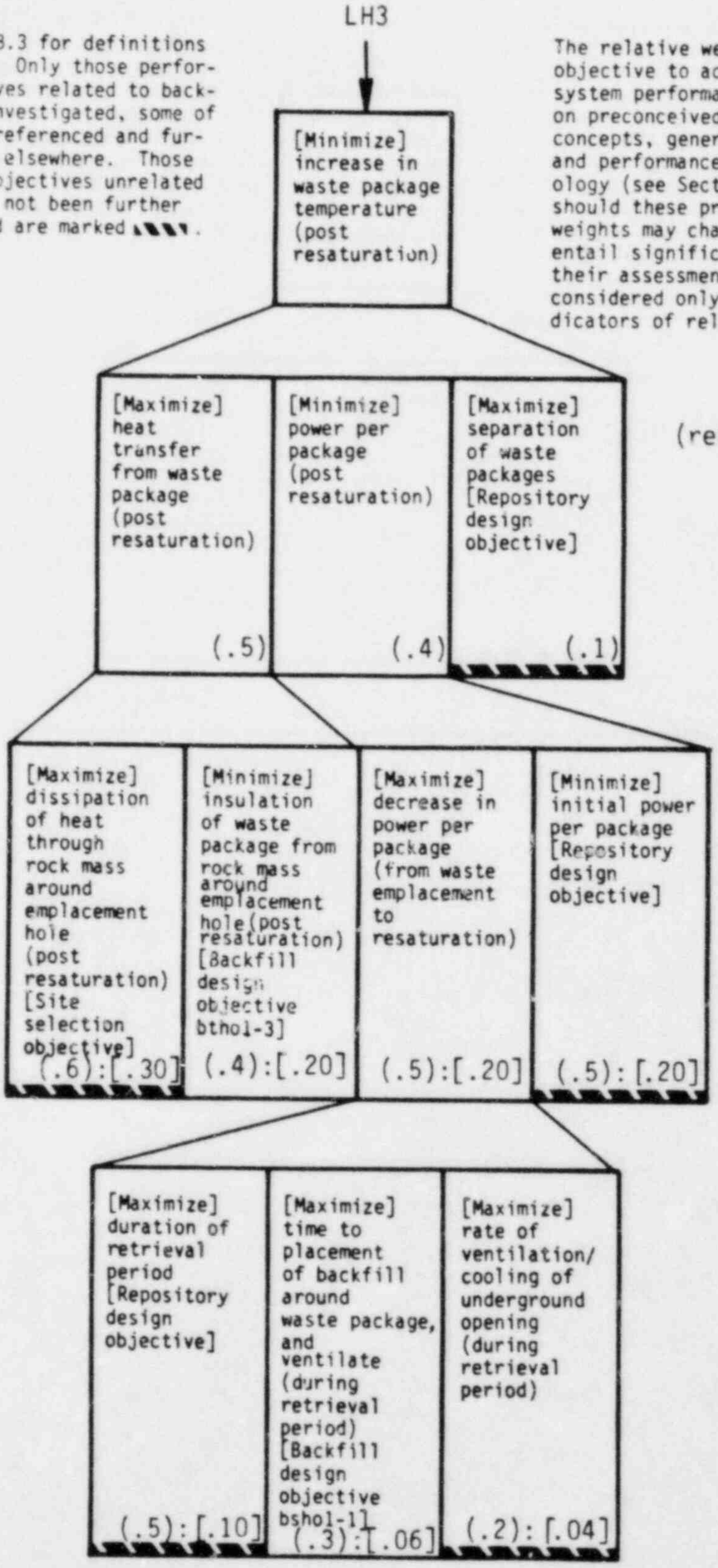
WEIGHTS OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES WITH RESPECT TO REFERENCED COMMON PERFORMANCE SUBOBJECTIVE LH3 Figure B.60

Note: Refer to Figure B.3 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down elsewhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▚▚▚.

The relative weight of each subobjective to achieving the repository system performance objective is based on preconceived repository design concepts, generic site conditions, and performance assessment methodology (see Section 2 of Main Text); should these premises change, the weights may change. Also, the weights entail significant subjectivity in their assessment, and should thus be considered only as approximate indicators of relative significance.



(ref. Figure A.59)

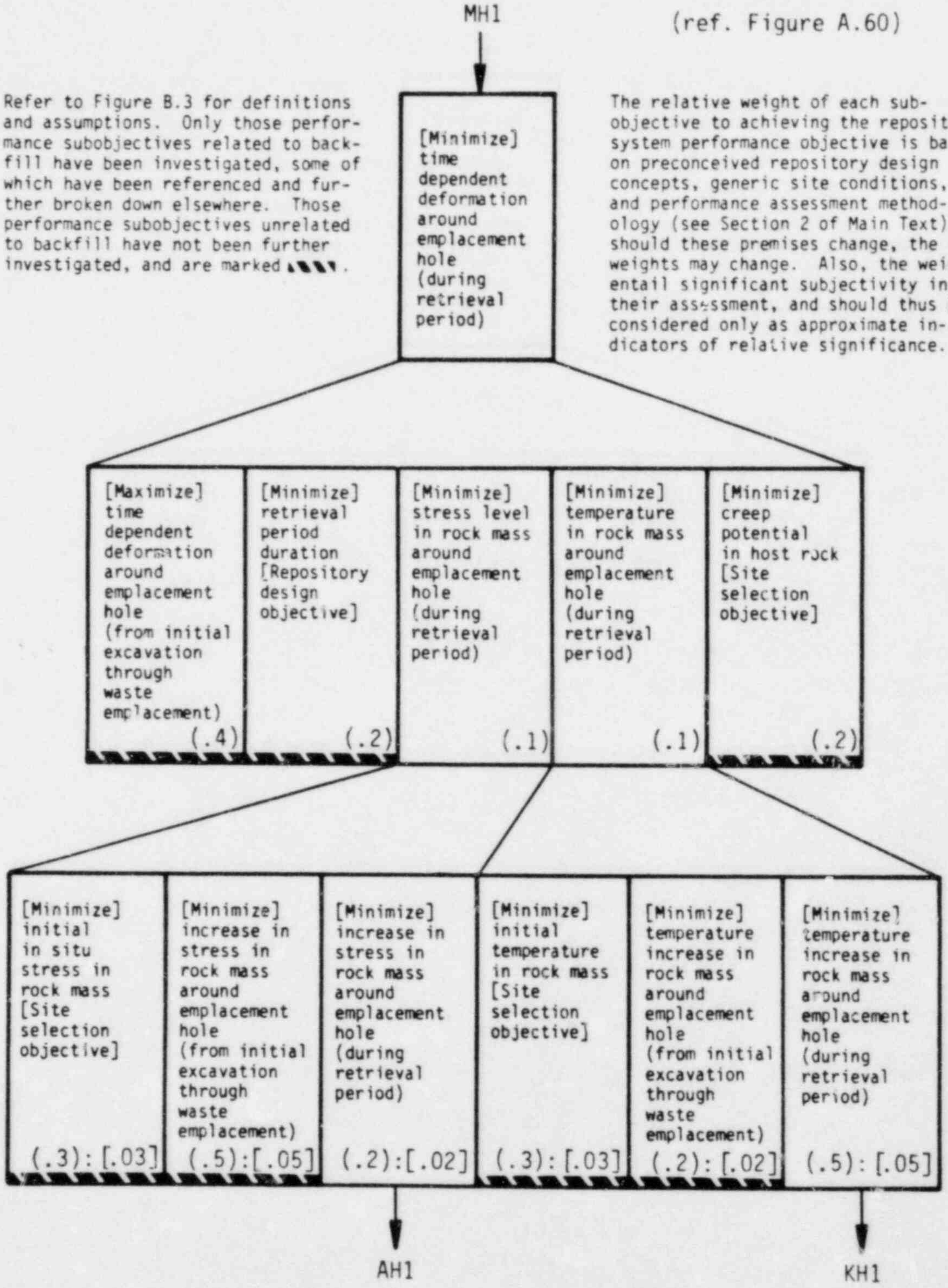
WEIGHTS OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES WITH RESPECT TO REFERENCED COMMON PERFORMANCE SUBOBJECTIVE MH1

Figure B.61

(ref. Figure A.60)

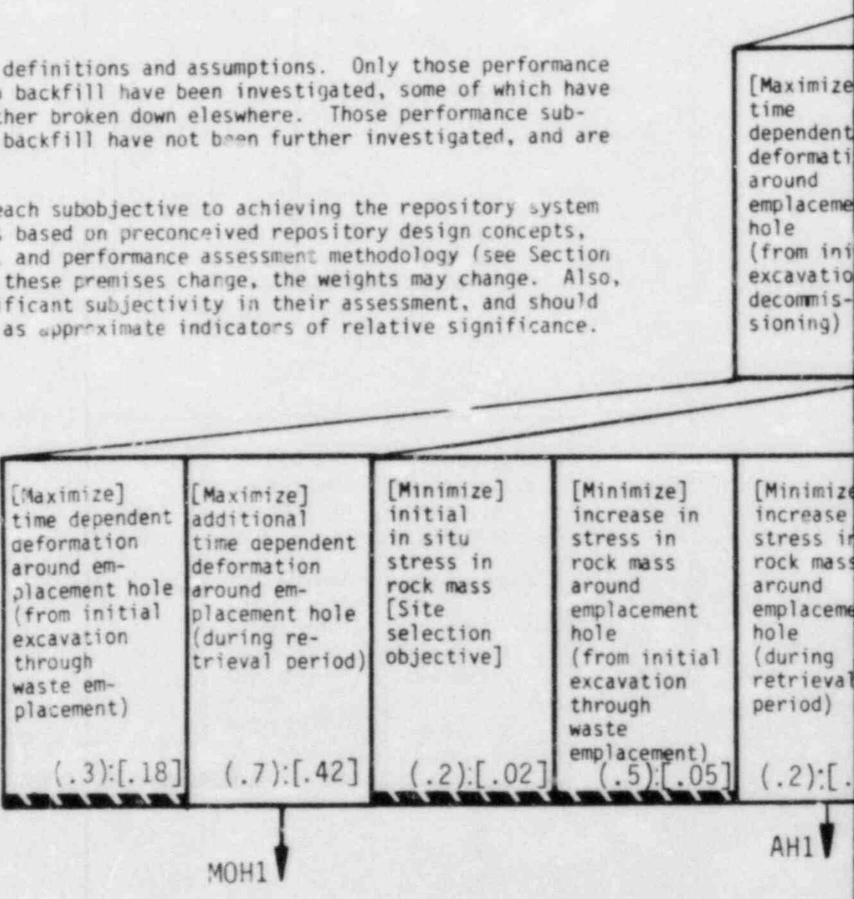
Note: Refer to Figure B.3 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down elsewhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▨.

The relative weight of each subobjective to achieving the repository system performance objective is based on preconceived repository design concepts, generic site conditions, and performance assessment methodology (see Section 2 of Main Text); should these premises change, the weights may change. Also, the weights entail significant subjectivity in their assessment, and should thus be considered only as approximate indicators of relative significance.



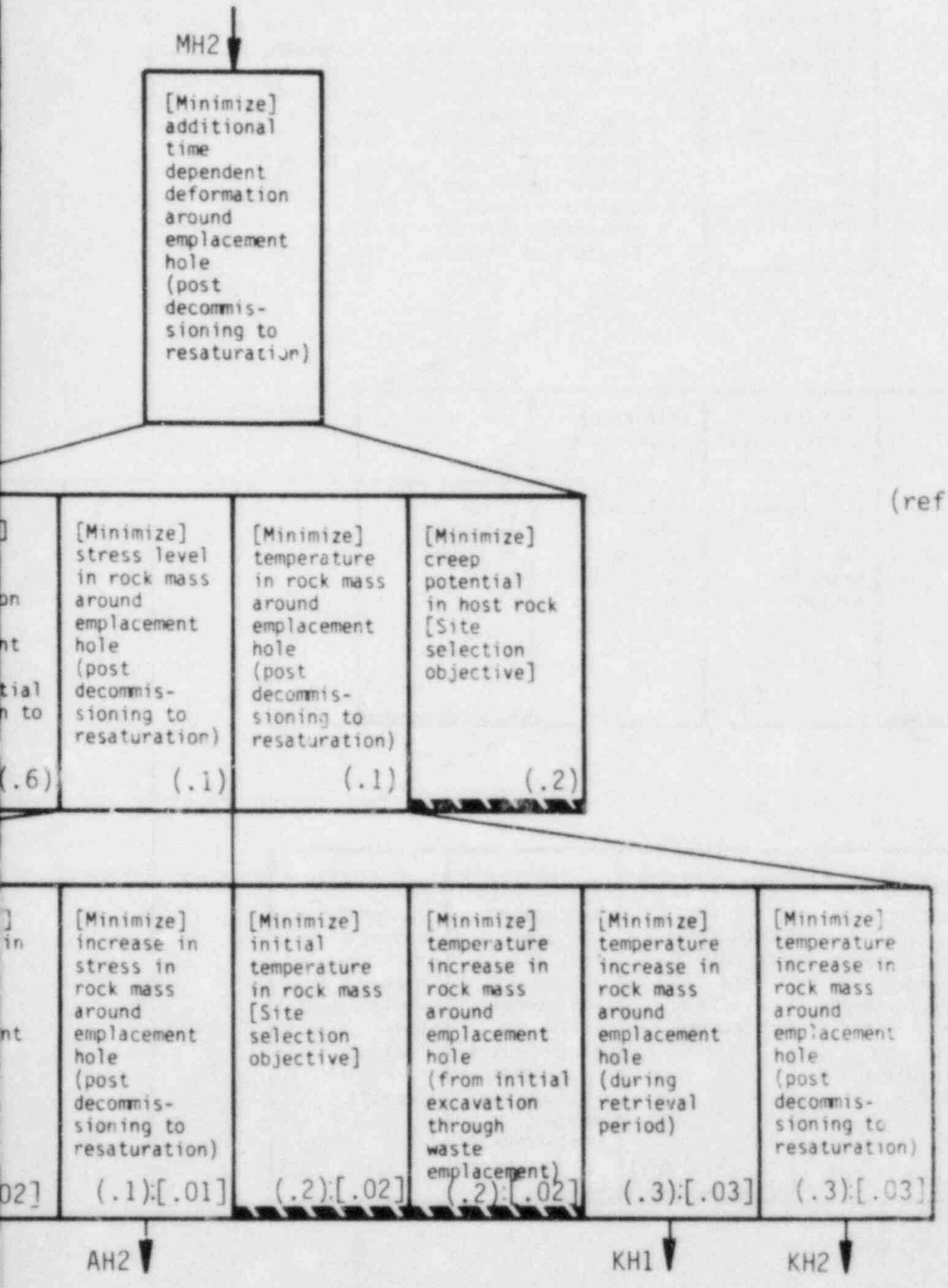
Note: Refer to Figure B.3 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down eleswhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▨.

The relative weight of each subobjective to achieving the repository system performance objective is based on preconceived repository design concepts, generic site conditions, and performance assessment methodology (see Section 2 of Main Text); should these premises change, the weights may change. Also, the weights entail significant subjectivity in their assessment, and should thus be considered only as approximate indicators of relative significance.



WEIGHTS OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES WITH RESPECT TO REFERENCED COMMON PERFORMANCE SUBOBJECTIVE MH2

Figure B.62



(ref. Figure A.61)

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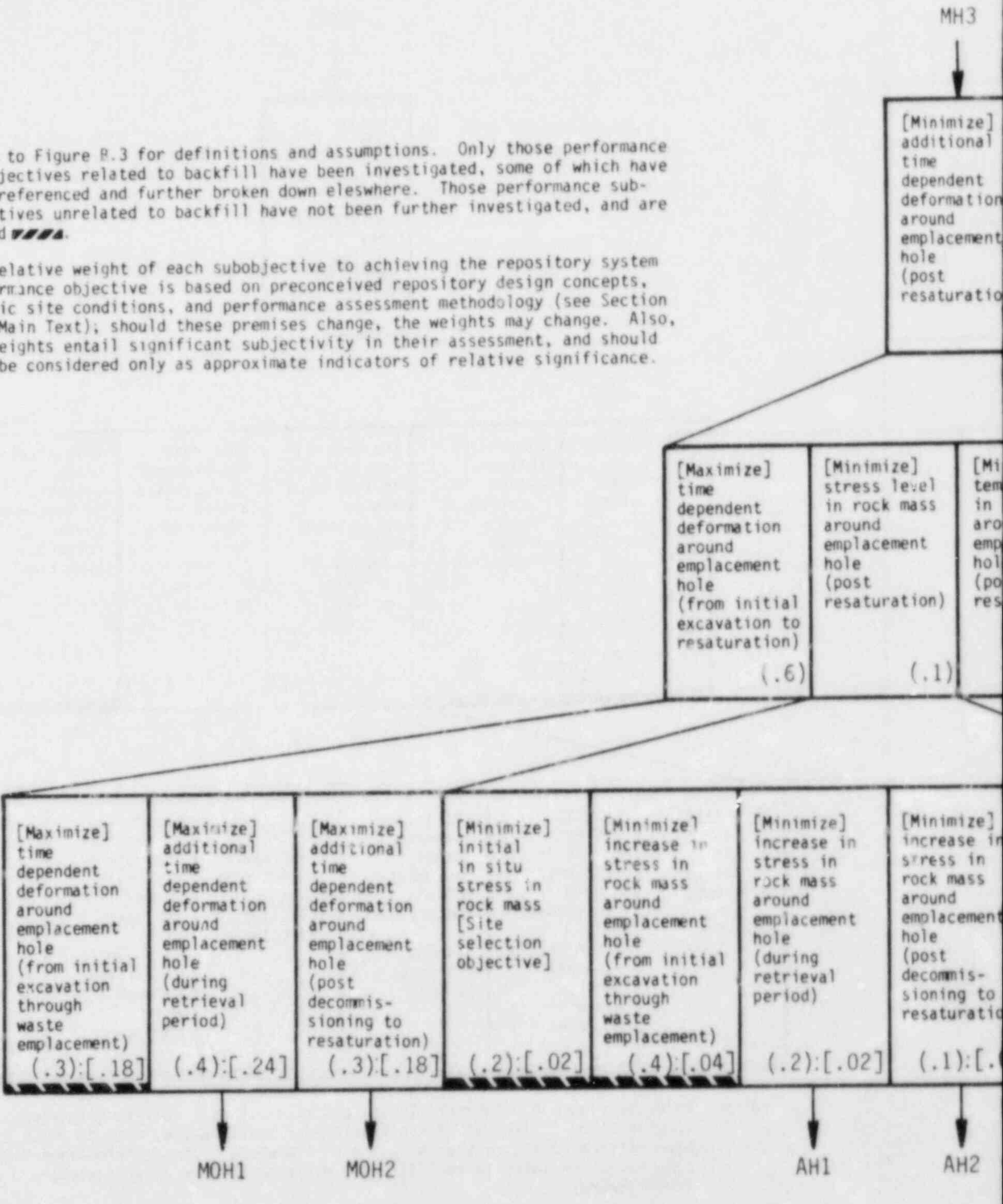
Note: Refer to Figure B.3 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down eleswhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▨.

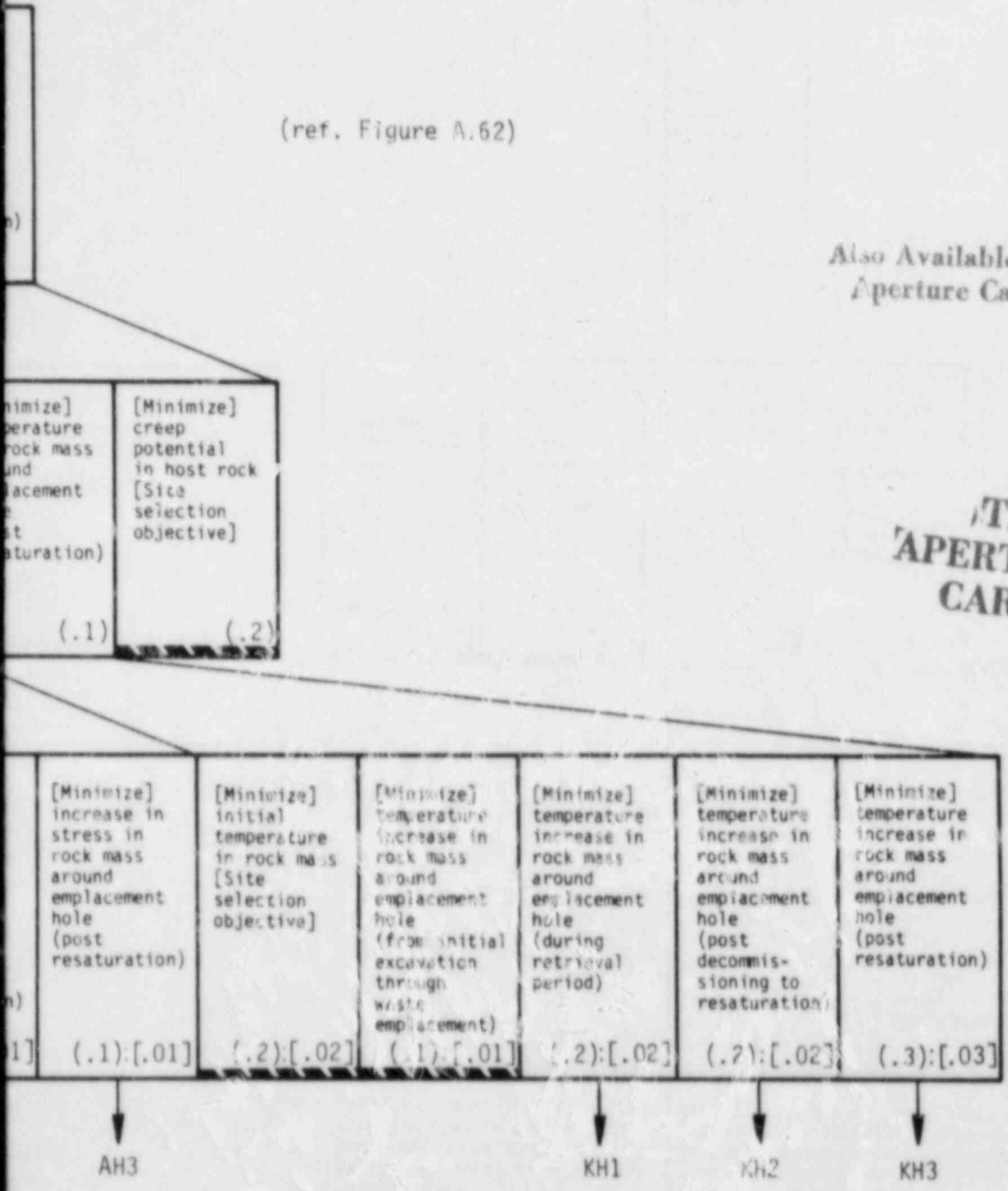
The relative weight of each subobjective to achieving the repository system performance objective is based on preconceived repository design concepts, generic site conditions, and performance assessment methodology (see Section 2 of Main Text); should these premises change, the weights may change. Also, the weights entail significant subjectivity in their assessment, and should thus be considered only as approximate indicators of relative significance.



WEIGHTS OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES WITH RESPECT TO REFERENCED COMMON PERFORMANCE SUBOBJECTIVE MH3

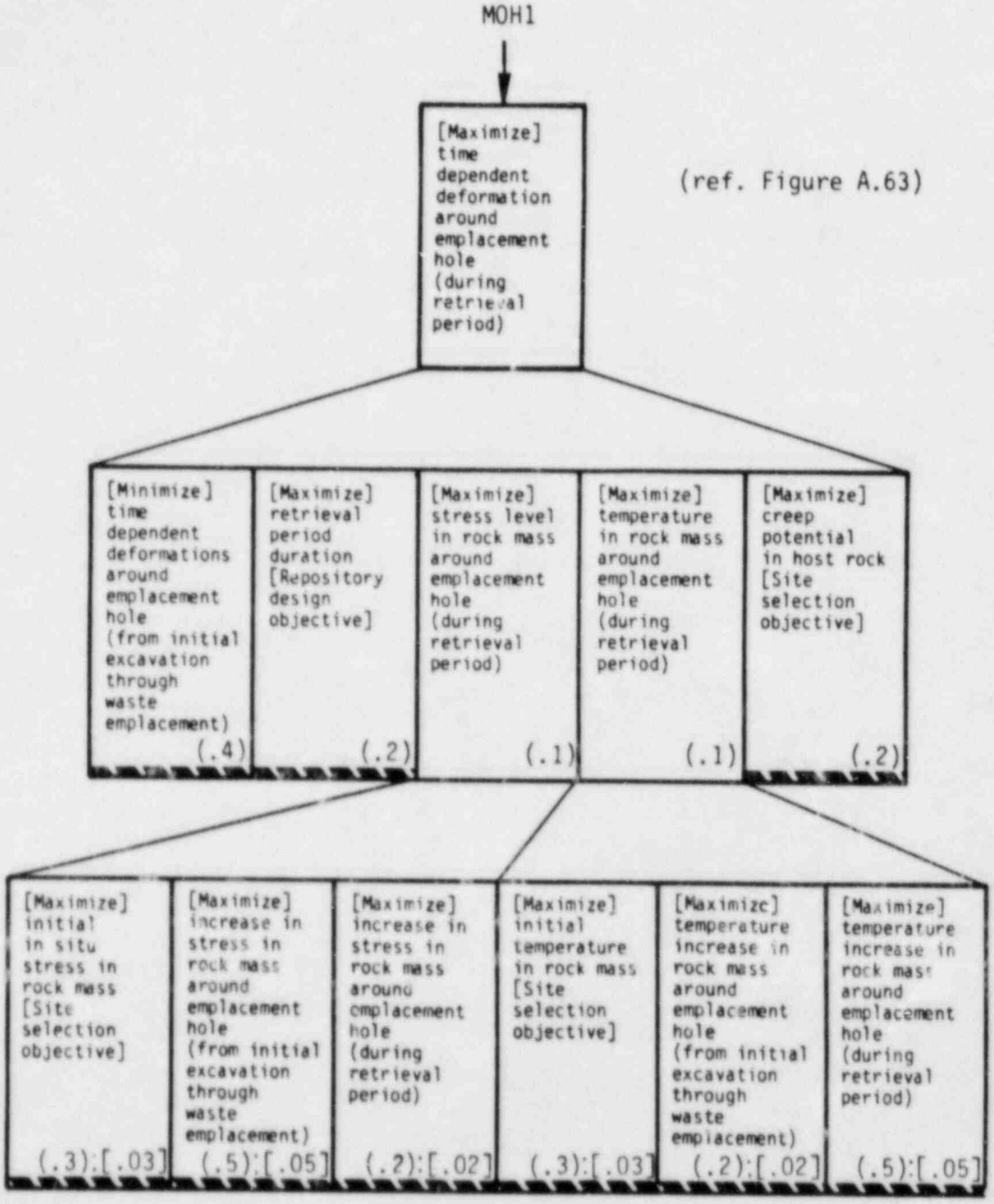
Figure B.63

(ref. Figure A.62)



WEIGHTS OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES WITH RESPECT TO REFERENCED COMMON PERFORMANCE SUBOBJECTIVE MOH1

Figure B.64



(ref. Figure A.63)

Note: Refer to Figure B.3 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down eleswhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▨.

The relative weight of each subobjective to achieving the repository system performance objective is based on preconceived repository design concepts, generic site conditions, and performance assessment methodology (see Section 2 of Main Text); should these premises change, the weights may change. Also, the weights entail significant subjectivity in their assessment, and should thus be considered only as approximate indicators of relative significance.

Note: Refer to Figure B.3 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down eleswhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▨.

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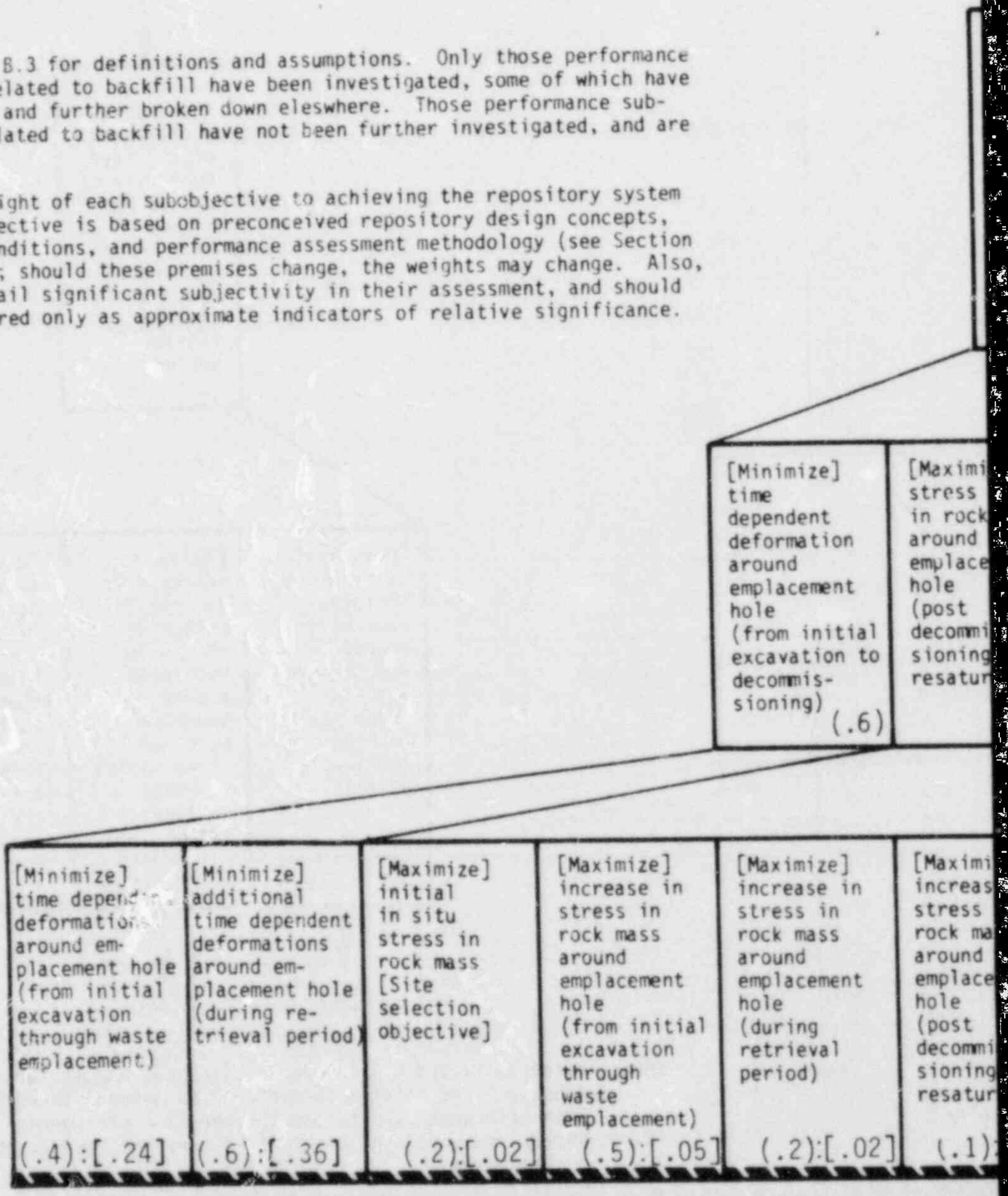
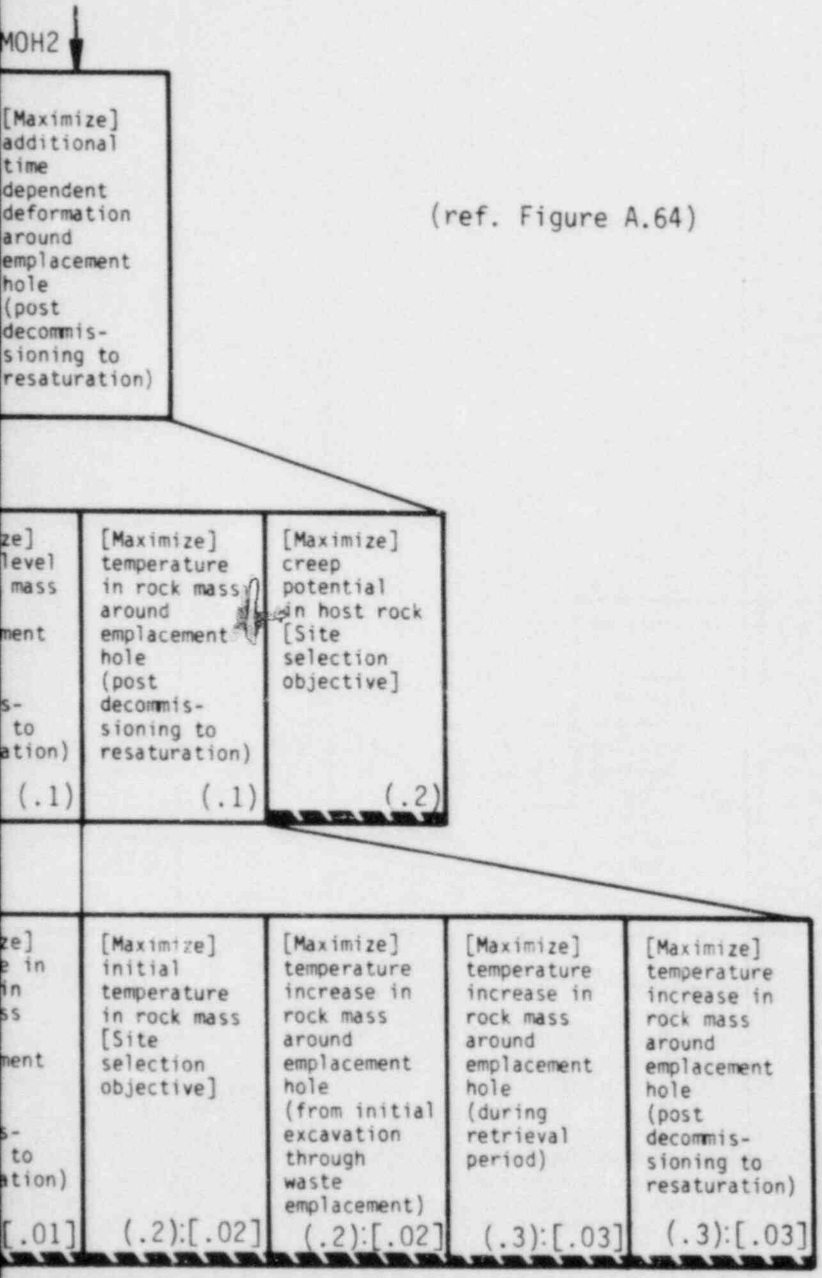


WEIGHTS OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES WITH RESPECT TO REFERENCED COMMON PERFORMANCE SUBOBJECTIVE MOH2

Figure B.65



(ref. Figure A.64)

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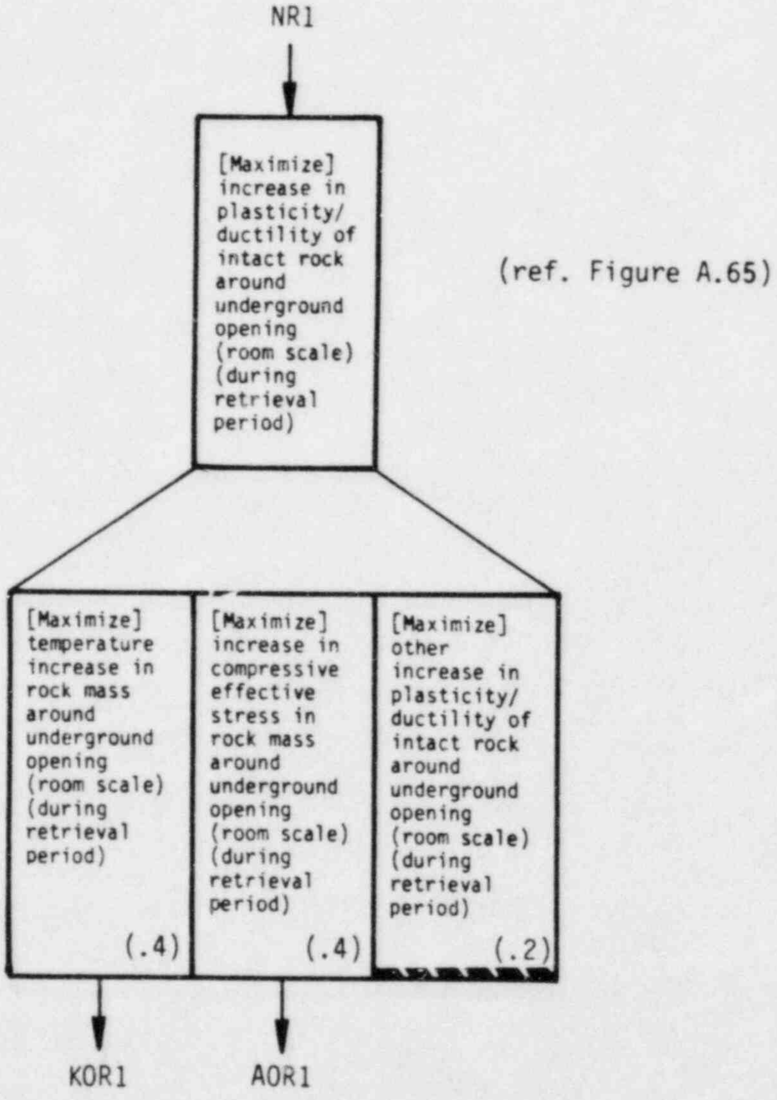
WEIGHTS OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES WITH RESPECT TO REFERENCED COMMON PERFORMANCE SUBOBJECTIVE NR1

Figure B.66



Note: Refer to Figure B.3 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down elsewhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▨.

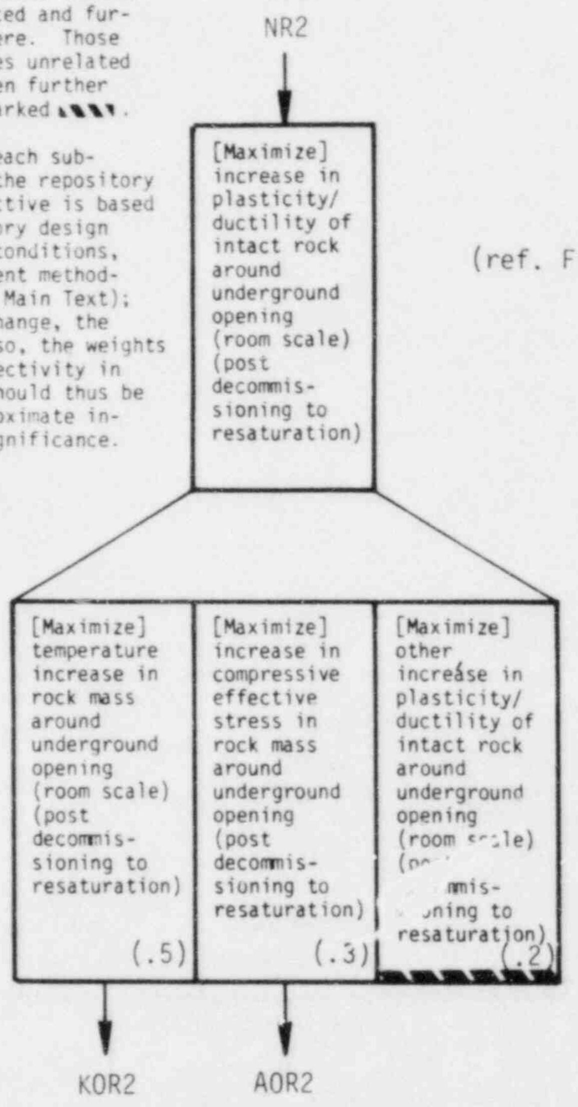
The relative weight of each subobjective to achieving the repository system performance objective is based on preconceived repository design concepts, generic site conditions, and performance assessment methodology (see Section 2 of Main Text); should these premises change, the weights may change. Also, the weights entail significant subjectivity in their assessment, and should thus be considered only as approximate indicators of relative significance.

WEIGHTS OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES WITH RESPECT TO REFERENCED COMMON PERFORMANCE SUBOBJECTIVE NR2

Figure B.67

Note: Refer to Figure B.3 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down elsewhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▨.

The relative weight of each subobjective to achieving the repository system performance objective is based on preconceived repository design concepts, generic site conditions, and performance assessment methodology (see Section 2 of Main Text); should these premises change, the weights may change. Also, the weights entail significant subjectivity in their assessment, and should thus be considered only as approximate indicators of relative significance.



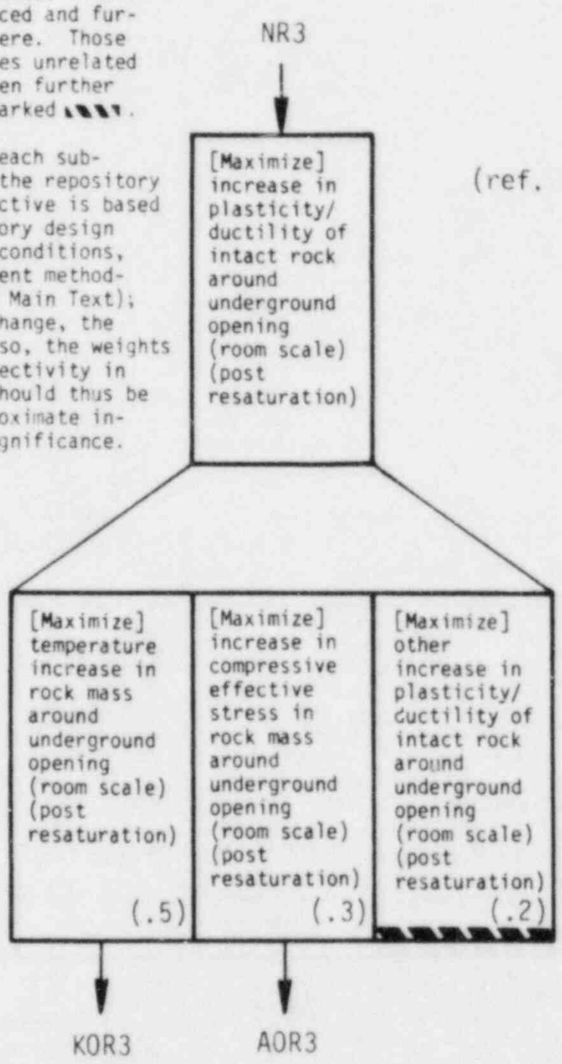
(ref. Figure A.66)

WEIGHTS OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES WITH RESPECT TO REFERENCED COMMON PERFORMANCE SUBOBJECTIVE NR3

Figure B.68

Note: Refer to Figure B.3 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down elsewhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▨.

The relative weight of each subobjective to achieving the repository system performance objective is based on preconceived repository design concepts, generic site conditions, and performance assessment methodology (see Section 2 of Main Text); should these premises change, the weights may change. Also, the weights entail significant subjectivity in their assessment, and should thus be considered only as approximate indicators of relative significance.



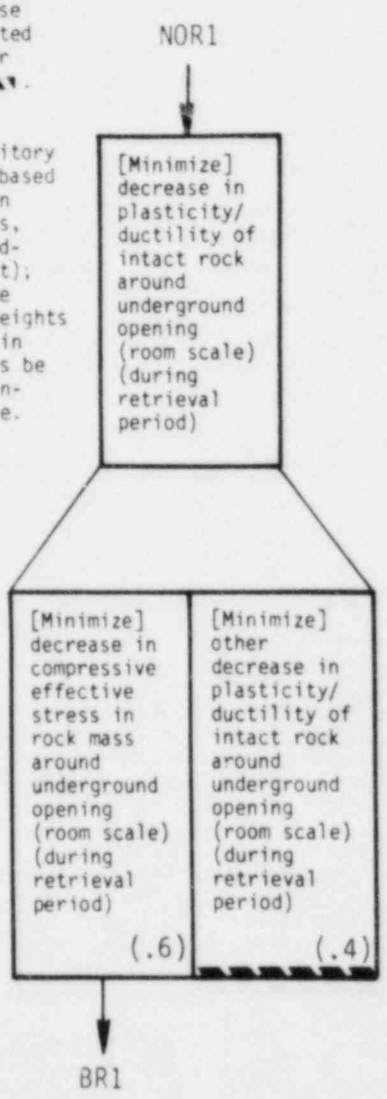
(ref. Figure A.67)

WEIGHTS OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES WITH RESPECT TO REFERENCED COMMON PERFORMANCE SUBOBJECTIVE NOR1

Figure B.69

Note: Refer to Figure B.3 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down elsewhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▨.

The relative weight of each subobjective to achieving the repository system performance objective is based on preconceived repository design concepts, generic site conditions, and performance assessment methodology (see Section 2 of Main Text); should these premises change, the weights may change. Also, the weights entail significant subjectivity in their assessment, and should thus be considered only as approximate indicators of relative significance.



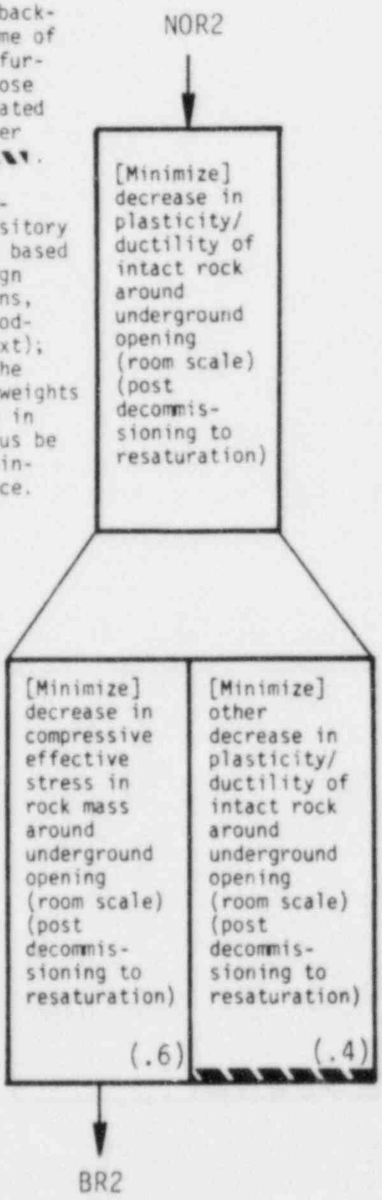
(ref. Figure A.68)

WEIGHTS OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES WITH RESPECT TO REFERENCED COMMON PERFORMANCE SUBOBJECTIVE NOR2

Figure B. 70

Note: Refer to Figure B.3 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down elsewhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▨.

The relative weight of each subobjective to achieving the repository system performance objective is based on preconceived repository design concepts, generic site conditions, and performance assessment methodology (see Section 2 of Main Text); should these premises change, the weights may change. Also, the weights entail significant subjectivity in their assessment, and should thus be considered only as approximate indicators of relative significance.



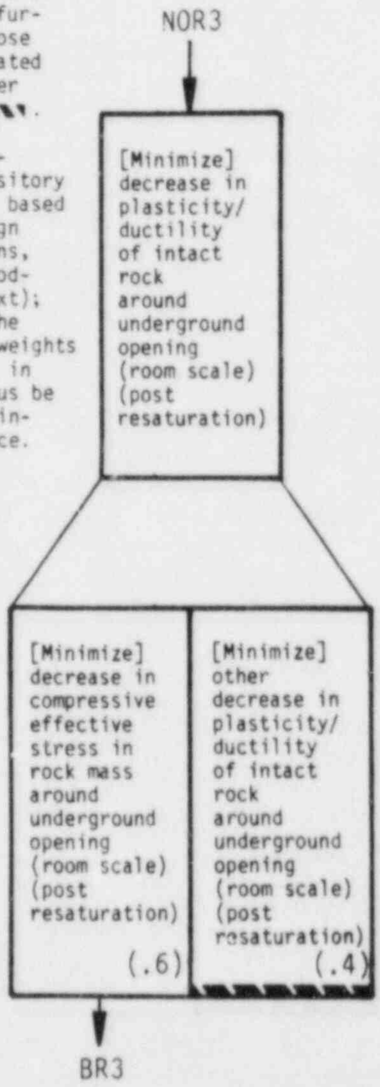
(ref. Figure A.69)

WEIGHTS OF REPOSITORY PERFORMANCE SUBOBJECTIVES AND BACKFILL DESIGN OBJECTIVES WITH RESPECT TO REFERENCED COMMON PERFORMANCE SUBOBJECTIVE NOR3

Figure B.71

Note: Refer to Figure B.3 for definitions and assumptions. Only those performance subobjectives related to backfill have been investigated, some of which have been referenced and further broken down elsewhere. Those performance subobjectives unrelated to backfill have not been further investigated, and are marked ▨.

The relative weight of each subobjective to achieving the repository system performance objective is based on preconceived repository design concepts, generic site conditions, and performance assessment methodology (see Section 2 of Main Text); should these premises change, the weights may change. Also, the weights entail significant subjectivity in their assessment, and should thus be considered only as approximate indicators of relative significance.



(ref. Figure A.70)

WEIGHTS OF AN ANNOTATED HIERARCHY OF REPOSITORY PERFORMANCE SUBOBJECTIVES & BACKFILL DESIGN OBJECTIVES WITH RESPECT TO THE TWO SUMMARY REPOSITORY SYSTEM PERFORMANCE OBJECTIVES

Table B.1
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1. [.3]	1.1 (.3):[.09]			
	1.2 (.1):[.03]			
	1.3 (.4):[.12]	1.3.1 (.2):[.024]		
		1.3.2 (.2):[.024]	bpl-1 [.0036]	
		1.3.3 (.3):[.036]	AR1 [.00216]	bsrla-1 (.04):[.0000864] bsrolb-1 (.02592):[.000055987] bmr2a-1 (.22):[.0004752] btrl-1 (.0324):[.000069984]
			AOR1 [.002304]	bsrla-1 (.02592):[.00005972] bsrolb-1 (.08):[.00018432] bmro2a-1 (.12):[.00027648] btrol-1 (.0324):[.00007465]
			BR1 [.000216]	bsrla-1 (.06):[.00001296] bmr2a-1 (.33):[.00007128]

WEIGHTS OF AN ANNOTATED HIERARCHY OF REPOSITORY PERFORMANCE SUBOBJECTIVES & BACKFILL DESIGN OBJECTIVES WITH RESPECT TO THE TWO SUMMARY REPOSITORY SYSTEM PERFORMANCE OBJECTIVES

Table B.1
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1. (cont.) [.3]	1.3 (cont.) (.4):[.12]	1.3.3 (cont.) (.3):[.036]	CR1 [.001296]	bsrla-1 (.021798611):[.000028251] bsrolb-1 (.026007179):[.000033705] bmr2a-1 (.058000181):[.000075168] bmr02a-1 (.005760594):[.000007466] btrl-1 (.027708441):[.00003591] btrol-1 (.002995509):[.000003882] bhrla-1 (.001030708):[.000001336] bgrl-1 (.002560264):[.000003318]
			DR1 [.000432]	bsrla-1 (.2):[.0000864] bmr2a-1 (.2):[.0000864]
			JR1 [.000216]	bsrla-1 (.028933718):[.000006250] bsrolb-1 (.00924974):[.000001998] bmr2a-1 (.000202255):[.000000044] bmr02a-1 (.000007421):[.000000002] btrl-1 (.011555516):[.000002496] btrol-1 (.000003859):[.000000001] bhrla-1 (.012883769):[.000002733] bgrl-1 (.032003298):[.000006913]

WEIGHTS OF AN ANNOTATED HIERARCHY OF REPOSITORY PERFORMANCE SUBOBJECTIVES & BACKFILL DESIGN OBJECTIVES WITH RESPECT TO THE TWO SUMMARY REPOSITORY SYSTEM PERFORMANCE OBJECTIVES

Table B.1
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1. (cont.) [.3]	1.3 (cont.) (.4):[.12]	1.3.3 (cont.) (.3):[.036]	KR1 [.000216]	bsrolb-1 (.144):[.000031104] btrl-1 (.18):[.00003888]
			bsrla-1 [.000144] bmr2a-1 [.000144]	
		1.3.4 (.3):[.036]	BH1 [.001512]	bshol-1 (.01135641):[.000017171] bmhl-1 (.4):[.0006048] bmh2a-1 (.2):[.0003024] bthl-1 (.02523648):[.000038158]
			LH1 [.000648]	bshol-1 (.072):[.000046656] bthol-1 (.16):[.00010368]
			bsrla-1 [.00108] bshl-1 [.000648] bgr2-1 [.00108]	

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WEIGHTS OF AN ANNOTATED HIERARCHY OF REPOSITORY PERFORMANCE SUBOBJECTIVES & BACKFILL DESIGN OBJECTIVES WITH RESPECT TO THE TWO SUMMARY REPOSITORY SYSTEM PERFORMANCE OBJECTIVES

1. (cont.) [.3]	1.3 (cont.) (.4):[.12]	1.3.4 (cont.) (.3):[.036]	bgh2-1 [.000972]		
	1.4 (.2):[.06]	1.4.1 (.3):[.018]	bp2-1 [.00432]		
		1.4.2 (.3):[.018]	bp3-1 [.00432]		
		1.4.3 (.1):[.006]	bsrlb-1 [.0003024]		
		1.4.4 (.3):[.018]	bsrla-1 [.000432] bp4-1 [.002268] bp5-1 [.000972]		
2. [.7]	2.1 (.2):[.14]	2.1.1 (.1):[.014]			
		2.1.2 (.3):[.042]	1.3.3 [.001008]	AR1 (.06):[.00006048]	bsrla-1 (.04):[.000002419] bsrolb-1 (.02592):[.000001568] bmr2a-1 (.22):[.000013306] btrl-1 (.0324):[.000001960]

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WEIGHTS OF AN ANNOTATED HIERARCHY OF REPOSITORY PERFORMANCE SUBOBJECTIVES & BACKFILL DESIGN OBJECTIVES WITH RESPECT TO THE TWO SUMMARY REPOSITORY SYSTEM PERFORMANCE OBJECTIVES

2. (cont.) [.7]	2.1 (cont.) (.2):[.14]	2.1.2 (cont.) (.3):[.042]	1.3.3 (cont.) [.001008]	AOR1 (.064):[.000064512]	bsrla-1 (.02592):[.000001672] bsrolb-1 (.08):[.000005161] bmro2a-1 (.12):[.000007741] btrol-1 (.0324):[.000002090]
				BR1 (.006):[.000006048]	bsrla-1 (.06):[.000000363] bmr2a-1 (.33):[.000001996]
				CR1 (.036):[.000036288]	bsrla-1 (.021798208):[.000000791] bsrolb-1 (.026007179):[.000000944] bmr2a-1 (.058000181):[.000002105] bmro2a-1 (.005760594):[.000000209] btrl-1 (.027708441):[.000001005] btrol-1 (.002995509):[.000000109] bhrla-1 (.001030708):[.000000037] bgrl-1 (.002560264):[.000000093]
				DR1 (.012):[.000012096]	bsrla-1 (.2):[.000002419] bmr2a-1 (.2):[.000002419]

WEIGHTS OF AN ANNOTATED HIERARCHY OF REPOSITORY PERFORMANCE SUBOBJECTIVES & BACKFILL DESIGN OBJECTIVES WITH RESPECT TO THE TWO SUMMARY REPOSITORY SYSTEM PERFORMANCE OBJECTIVES

Table B.1
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2. (cont.) [.7]	2.1 (cont.) (.2):[.14]	2.1.2 (cont.) (.3):[.042]	1.3.3 (cont.) [.001008]	JR1 (.006):[.000006048]	bsrla-1 (.028946982):[.000000175] bsrolb-1 (.00924974):[.000000056] bmr2a-1 (.000197134):[.000000001] bmr02a-1 (.000007421):[-] btrl-1 (.011555516):[.00000007] btrol-1 (.000003859):[-] bhrla-1 (.012883769):[.000000078] bgrl-1 (.032003298):[.000000194]
				KR1 (.006):[.000006048]	bsrolb-1 (.144):[.000000871] btrl-1 (.18):[.000001089]
				bsrla-1 (.004):[.000004032] bmr2a-1 (.004):[.000004032]	
			AR1 [.00002688]	bsrla-1 (.04):[.000001075] bsrolb-1 (.02592):[.000000697] bmr2a-1 (.22):[.000005914] btrl-1 (.0324):[.000000871]	

WEIGHTS OF AN ANNOTATED HIERARCHY OF REPOSITORY PERFORMANCE SUBOBJECTIVES & BACKFILL DESIGN OBJECTIVES WITH RESPECT TO THE TWO SUMMARY REPOSITORY SYSTEM PERFORMANCE OBJECTIVES

2. (cont.) [.7]	2.1 (cont.) (.2):[.14]	2.1.2 (cont.) (.3):[.042]	GH1 [.0002688]	bsrla-1 (.000043600):[.000000012] bsrolb-1 (.000011081):[.000000003] bsrolc-1 (.036):[.000009677] bshol-1 (.015535642):[.000004176] bmr2a-1 (.000065931):[.000000018] bmr2b-2 (.000011427):[.000000003] bmr2c-2 (.000016448):[.000000004] bmr02a-1 (.00000249):[.000000001] bmr02c-2 (.000001216):[-] bmhl-1 (.04):[.000010752] bmh2a-1 (.02):[.000005376] btrl-1 (.000011777):[.000000003] btrl-2 (.000005999):[.000000002] btrol-1 (.00000139):[-] btrol-2 (.000000350):[-] bthl-1 (.002523648):[.000000678] bthol-1 (.032):[.000008602]

WEIGHTS OF AN ANNOTATED HIERARCHY OF REPOSITORY PERFORMANCE SUBOBJECTIVES & BACKFILL DESIGN OBJECTIVES WITH RESPECT TO THE TWO SUMMARY REPOSITORY SYSTEM PERFORMANCE OBJECTIVES

Table B.1
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2. (cont.) [.7]	2.1 (cont.) (.2):[.14]	2.1.2 (cont.) (.3):[.042]	GH1 (cont.) [.0002688]	bhrla-1 (.000027218):[.00000007] bhrla-2 (.008662972):[.000002329] bhr2-1 (.0054):[.000001452] bhr2-2 (.0054):[.000001452] bgrl-1 (.000001072):[-] bgrl-2 (.000001003):[-] bghl-1 (.16):[.000043008]
			KR1 [.00049728]	bsrolb-1 (.144):[.000071608] btrl-1 (.18):[.00008951]
			bsrla-1 [.0009408] bsrola-1 [.000504] bprl-1 [.00084] bmrl-1 [.000336] bmr2a-1 [.0014112]	
		2.1.3 (.6):[.084]	GH1 [.00672]	bsrla-1 (.000043600):[.000000293] bsrolb-1 (.000011081):[.000000074] bsrolc-1 (.036):[.00024192] bshol-1 (.015535642):[.000104400]

WEIGHTS OF AN ANNOTATED HIERARCHY OF REPOSITORY PERFORMANCE SUBOBJECTIVES & BACKFILL DESIGN OBJECTIVES WITH RESPECT TO THE TWO SUMMARY REPOSITORY SYSTEM PERFORMANCE OBJECTIVES

Table B.1
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2. (cont.) [.7]	2.1 (cont.) (.2):[.14]	2.1.3 (cont.) (.6):[.084]	GH1 (cont.) [.00672]	bmr2a-1 (.000065931):[.000000443] bmr2b-2 (.000011427):[.000000077] bmr2c-2 (.000016448):[.000000111] bmr02a-1 (.00000249):[.000000017] bmr02c-2 (.000001216):[.000000008] bmh1-1 (.04):[.0002688] bmh2a-1 (.02):[.0001344] btr1-1 (.000011777):[.000000079] btr1-2 (.000005999):[.000000004] btro1-1 (.00000139):[.000000009] btro1-2 (.000000350):[.000000002] bth1-1 (.002523648):[.000016959] btho1-1 (.032):[.00021504] bhr1a-1 (.000027218):[.000000183] bhr1a-2 (.008662972):[.000058215] bhr2-1 (.0054):[.000036288] bhr2-2 (.0054):[.000036288] bgr1-1 (.000001072):[.000000007] bgr1-2 (.000001003):[.000000007] bgh1-1 (.16):[.0010752]

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WEIGHTS OF AN ANNOTATED HIERARCHY OF REPOSITORY PERFORMANCE SUBOBJECTIVES & BACKFILL DESIGN OBJECTIVES WITH RESPECT TO THE TWO SUMMARY REPOSITORY SYSTEM PERFORMANCE OBJECTIVES

2. (cont.) [.7]	2.1 (cont.) (.2):[.14]	2.1.3 (cont.) (.6):[.084]	GH2 [.00672]	bsrla-1 (.000029067):[.000000195] bsrolb-1 (.000007389):[.00000005] bsrolc-1 (.024):[.00016128] bshol-1 (.019328563):[.000129888] bmr2a-1 (.000043956):[.000000295] bmr2b-2 (.000007618):[.000000051] bmr2c-2 (.000010964):[.000000074] bmro2a-1 (.000001660):[.000000011] bmro2c-2 (.000000810):[.00000005] bmh1-2 (.08):[.0005376] bmh2b-2 (.04):[.0002688] btr1-1 (.000007851):[.000000053] btr1-2 (.000003995):[.000000027] btrol-1 (.000000930):[.000000006] btrol-2 (.000000234):[.000000002] bth1-1 (.000285696):[.00000192] bth1-2 (.003411200):[.000022923] bthol-2 (.08):[.0005376]

WEIGHTS OF AN ANNOTATED HIERARCHY OF REPOSITORY PERFORMANCE SUBOBJECTIVES & BACKFILL DESIGN OBJECTIVES WITH RESPECT TO THE TWO SUMMARY REPOSITORY SYSTEM PERFORMANCE OBJECTIVES

Table B.1
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2. (cont.) [.7]	2.1 (cont.) (.2):[.14]	2.1.3 (cont.) (.6):[.084]	GH2 (cont.) [.00672]	bhrla-1 (.000018095):[.000000122] bhrla-2 (.005775314):[.00003881] bhr2-1 (.0054):[.000024192] bhr2-2 (.0054):[.000024192] bgrl-1 (.000000737):[.000000005] bgrl-2 (.000000669):[.000000004] bghl-2 (.16):[.0010752]
			GH3 [.02016]	bshol-1 (.024094):[.000485735] bmhl-3 (.08):[.0016128] bmh2b-3 (.04):[.0008064] bthl-1 (.000208896):[.000004211] bthl-2 (.0001472):[.000002968] bthl-3 (.0034112):[.00006877] bth0l-3 (.08):[.0016128] bghl-3 (.16):[.0032256]
	2.2 (.4): [.28]	2.2.1 (.2):[.056]	FR1 [.00048384]	bsrla-1 (.04178698):[.000020218] bsrolb-1 (.010469871):[.000005066] bmr2a-1 (.063204581):[.000030581] bmr02a-1 (.002318982):[.000001122]

WEIGHTS OF AN ANNOTATED HIERARCHY OF REPOSITORY PERFORMANCE SUBOBJECTIVES & BACKFILL DESIGN OBJECTIVES WITH RESPECT TO THE TWO SUMMARY REPOSITORY SYSTEM PERFORMANCE OBJECTIVES

Table B.1
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2. (cont.) [.7]	2.2 (cont.) (.4):[.28]	2.2.1 (cont.) (.2):[.056]	FR1 (cont.) [.00048384]	btrl-1 (.011154301):[.000005397] btrol-1 (.001205871):[.000000583] bhrla-1 (.026179832):[.000012667] bgrl-1 (.001030702):[.000000499]
			FR2 [.00016128]	bsrla-1 (.000792246):[.000000128] bsrolb-1 (.000659971):[.000000106] bmr2a-1 (.001163112):[.000000188] bmr2b-2 (.033063819):[.000005333] bmr2c-2 (.047785755):[.000007707] bmro2a-1 (.000251582):[.000000041] bmro2c-2 (.00351698):[.000000567] btrl-1 (.000615344):[.000000099] btrl-2 (.017359038):[.0000028] btrol-1 (.000421179):[.000000068] btrol-2 (.001011466):[.000000163] bhrla-1 (.000217499):[.000000035] bhrla-2 (.066467694):[00001072]

WEIGHTS OF AN ANNOTATED HIERARCHY OF REPOSITORY PERFORMANCE SUBOBJECTIVES & BACKFILL DESIGN OBJECTIVES WITH RESPECT TO THE TWO SUMMARY REPOSITORY SYSTEM PERFORMANCE OBJECTIVES

Table B.1
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2. (cont.) [.7]	2.2 (cont.) (.4):[.28]	2.2.1 (cont.) (.2):[.056]	FR2 (cont.) [.00016128]	bgrl-1 (.000008564):[.000000001] bgrl-2 (.002903731):[.000000468]
			bsrolc-1 [.0168] bhrla-2 [.004032] bhr2-1 [.00252] bhr2-2 [.00252]	
		2.2.2 (.8):[.224]	FR1 [.00258048]	bsrla-1 (.04178698):[.00010783] bsrolb-1 (.010469871):[.000027017] bmr2a-1 (.063204581):[.000163098] bmr02a-1 (.002318982):[.000005984] btrl-1 (.011154773):[.000028785] btrol-1 (.001205871):[.000003112] bhrla-1 (.026179832):[.000067557] bgrl-1 (.001030702):[.00000266]

WEIGHTS OF AN ANNOTATED HIERARCHY OF REPOSITORY PERFORMANCE SUBOBJECTIVES & BACKFILL DESIGN OBJECTIVES WITH RESPECT TO THE TWO SUMMARY REPOSITORY SYSTEM PERFORMANCE OBJECTIVES

Table B.1
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2. (cont.) [.7]	2.2 (cont.) (.4):[.28]	2.2.2 (cont.) (.8):[.224]	FR2 [.00129024]	bsrla-1 (.000792246):[.000001022] bsrolb-1 (.00066003):[.000000852] bmr2a-1 (.001163997):[.000001502] bmr2b-2 (.033066064):[.000042663] bmr2c-2 (.047785755):[.000061655] bmr02a-1 (.000251582):[.000000325] bmr02c-2 (.00351698):[.000004538] btrl-1 (.000615344):[.000000794] btrl-2 (.017359038):[.000022397] btrol-1 (.000421179):[.000000543] btrol-2 (.001011466):[.000001305] bhrla-1 (.000217499):[.000000281] bhrla-2 (.066467694):[.000085759] bgrl-1 (.000008564):[.000000011] bgrl-2 (.002903731):[.000003747]
			FR3 [.00129024]	bsrla-1 (.00066217):[.000000854] bsrolb-1 (.00055296):[.000000713]

WEIGHTS OF AN ANNOTATED HIERARCHY OF REPOSITORY PERFORMANCE SUBOBJECTIVES & BACKFILL DESIGN OBJECTIVES WITH RESPECT TO THE TWO SUMMARY REPOSITORY SYSTEM PERFORMANCE OBJECTIVES

Table B.1
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2. (cont.) [.7]	2.2 (cont.) (.4):[.28]	2.2.2 (cont.) (.8):[.224]	FR3 (cont.) [.00129024]	bmr2a-1 (.0009504):[.000001226] bmr2b-2 (.0002304):[.000000297] bmr2b-3 (.0539904):[.000069661] bmr2c-2 (.000288):[.000000372] bmr2c-3 (.074488):[.000096107] bmro2a-1 (.0003456):[.000000446] bmro2c-2 (.000432):[.000000557] bmr02c-3 (.003232):[.000004170] btr1-1 (.0004032):[.00000052] btr1-2 (.000448):[.000000578] btr1-3 (.012432):[.000016040] btro1-1 (.000611712):[.000000789] btro1-2 (.0007848):[.000001013] btro1-3 (.0012048):[.000001554] bgr1-3 (.00336):[.000004335]
			bhr1a-3 [.016128] bhr1b-3 [.002064384] bh1-3 [.016128]	

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WEIGHTS OF AN ANNOTATED HIERARCHY OF REPOSITORY PERFORMANCE SUBOBJECTIVES & BACKFILL DESIGN OBJECTIVES WITH RESPECT TO THE TWO SUMMARY REPOSITORY SYSTEM PERFORMANCE OBJECTIVES

2. (cont.) [.7]	2.3 (.3):[.21]	2.3.1 (.3):[.063]	bg1-3 [.00756] bg2-3 [.00756] bg3-3 [.00378]
		2.3.2 (.7):[.147]	bg4-3 [.0441]
	2.4 (.1):[.07]	2.4.1 (.7):[.049]	
		2.4.2 (.3):[.021]	

Notes: The weights of these performance subobjectives and backfill design objectives, with respect to their relative contribution to achieving the repository system performance objectives, have been explicitly derived (Figures B.3 to B.71). This development has been based on preconceived repository design concepts (specifically vertical waste emplacement), performance assessment methodology, and generic site conditions (see Section 2 - Main Text); should these premises change, the weights may change. Also, the weights entail significant subjectivity in their assessment, and should thus be considered only as approximate indicators of relative significance. In many cases, the breakdown of performance subobjectives down to backfill design objectives, and thus the determination of relative weights (Figures B.4 to B.71), has simply been summarized, as this breakdown sometimes proceeds through numerous levels and in some cases loops; where a loop has formed, enough iterations have been taken through the loop to achieve an accuracy of at least 10^{-8}.

SUMMARY OF WEIGHTS OF BACKFILL DESIGN OBJECTIVES

Table B.2
1 of 4

(REFERENCE TABLE A.2)

BACKFILL DESIGN OBJECTIVES				RELATIVE WEIGHT OF BACKFILL DESIGN OBJECTIVES WITH RESPECT TO ACHIEVING REPOSITORY SYSTEM PERFORMANCE OBJECTIVES (see Table B.1) — PERIOD OF CONCERN		
	Scale	Code	Objective	-1) During Retrieval Period	-2) Post Decommissioning To Resaturation	-3) Post Resaturation
SCHEDULE	Room Scale	bsrla	[Minimize] time to placement of backfill (room scale)	3.02×10^{-3}		
		bsrlb	[Delay and minimize] backfilling of tunnels along possible egress routes	3.02×10^{-4}		
		bsrola	[Maximize] time to placement of backfill (room scale)	5.04×10^{-4}		
		bsrolb	[Maximize] time to placement of backfill (room scale), and ventilate	4.22×10^{-4}		
		bsrolc	[Maximize] time to start resaturation process (i.e., maximize time to placement of backfill, room scale, while dewatering)	1.72×10^{-2}		
	Waste Package Scale	bshl	[Minimize] time to placement of backfill around waste package	6.48×10^{-4}		
		bshol	[Maximize] time to placement of backfill around waste package, and ventilate	7.88×10^{-4}		
PROCEDURES	Room Scale	bprl	[Minimize] volume of backfill (room scale) (if placed during retrieval period)	8.40×10^{-4}		
	Room and Waste Package Scale	bp1	[Maximize] use of safe/reliable equipment for backfilling	3.60×10^{-3}		
		bp2	[Maximize] monitoring of potentially hazardous underground conditions as backfilling occurs	4.32×10^{-3}		
		bp3	[Maximize] quick and efficient mitigation of detected underground hazards as backfilling occurs	4.32×10^{-3}		
		bp4	[Minimize] personnel requirements for backfilling (i.e., maximize mechanization and remote operations)	2.27×10^{-3}		
		bp5	[Minimize] total effort required for backfilling (e.g., no backfilling)	9.72×10^{-4}		

(SEE KEY AT END OF TABLE)

SUMMARY OF WEIGHTS OF BACKFILL DESIGN OBJECTIVES

Table B.2
2 of 4

(REFERENCE TABLE A.2)

	BACKFILL DESIGN OBJECTIVES			RELATIVE WEIGHT OF BACKFILL DESIGN OBJECTIVES WITH RESPECT TO ACHIEVING REPOSITORY SYSTEM PERFORMANCE OBJECTIVES (see Table B.1)		
				PERIOD OF CONCERN		
	Scale	Code	Objective	-1) During Retrieval Period	-2) Post Decommissioning To Resaturation	-3) Post Resaturation
MECHANICAL CHARACTERISTICS	Room Scale	bmr1	[Minimize] integrity (compaction) of backfill (room scale) (if placed during retrieval period)	3.36×10^{-4}		
		bmr2a	[Maximize] support pressure (or structural support) provided by backfill (room scale)	2.49×10^{-3}		
		bmr2b	[Maximize] increase in support pressure (or structural support) provided by backfill (room scale)		4.84×10^{-5}	6.97×10^{-5}
		bmr2c	[Minimize] decrease in support pressure (or structural support) provided by backfill (room scale)		6.99×10^{-5}	9.61×10^{-5}
		bmro2a	[Minimize] support pressure (or structural support) provided by backfill (room scale)	3.00×10^{-4}		
		bmro2c	[Maximize] decrease in support pressure (or structural support) provided by backfill (room scale)		5.68×10^{-6}	4.17×10^{-6}
	Waste Package Scale	bmh1	[Minimize] stress transfer through backfill around waste package	8.84×10^{-4}	5.38×10^{-4}	1.61×10^{-3}
		bmh2a	[Minimize] swelling pressure of backfill around waste package	4.42×10^{-4}		
		bmh2b	[Minimize] increase in swelling pressure of backfill around waste package		2.69×10^{-4}	9.06×10^{-4}
THERMAL CHARACTERISTICS	Room Scale	btr1	[Maximize] insulation of waste package from rock mass around underground opening (room scale)	2.78×10^{-4}	2.58×10^{-5}	1.60×10^{-5}
		btro1	[Minimize] insulation of waste package from rock mass around underground opening (room scale)	8.58×10^{-5}	2.49×10^{-6}	1.55×10^{-6}
	Waste Package Scale	bth1	[Maximize] insulation of waste package from rock mass around emplacement hole	6.19×10^{-5}	2.59×10^{-5}	6.98×10^{-5}
		btho1	[Minimize] insulation of waste package from rock mass around emplacement hole	3.27×10^{-4}	5.38×10^{-4}	1.61×10^{-3}

(SEE KEY AT END OF TABLE)

SUMMARY OF WEIGHTS OF BACKFILL DESIGN OBJECTIVES

Table B.2
3 of 4

(REFERENCE TABLE A.2)

	BACKFILL DESIGN OBJECTIVES			RELATIVE WEIGHT OF BACKFILL DESIGN OBJECTIVES WITH RESPECT TO ACHIEVING REPOSITORY SYSTEM PERFORMANCE OBJECTIVES (see Table B.1) — PERIOD OF CONCERN		
	Scale	Code	Objective	-1) During Retrieval Period	-2) Post Decommissioning To Resaturation	-3) Post Resaturation
HYDROLOGIC CHARACTERISTICS	Room Scale	bhr1a	[Minimize] hydraulic conductivity (and effective porosity) of backfill and interface (room scale)	8.51×10^{-5}	4.23×10^{-3}	1.61×10^{-2}
		bhr1b	[Maximize] decrease in hydraulic conductivity (and effective porosity) of rock mass (room scale) (i.e., sealing/filling of discontinuities) by backfill			2.06×10^{-3}
		bhr2	[Maximize] porosity of backfill (room scale)	2.58×10^{-3}	2.58×10^{-3}	
	Room and Waste Package Scale	bh1	[Maximize] distance from waste package through repository along flow path due to backfill			1.61×10^{-2}
GEOCHEMICAL CHARACTERISTICS	Room Scale	bgr1	[Maximize] protection of exposed rock surface underground (room scale) by backfill	1.37×10^{-5}	4.23×10^{-6}	4.34×10^{-6}
		bgr2	[Maximize] thickness/adsorption of backfill (room scale)	1.08×10^{-3}		
	Waste Package Scale	bgh1	[Maximize] mitigation of corrosive groundwater by backfill (waste package scale)	1.12×10^{-3}	1.08×10^{-3}	3.23×10^{-3}
		bgh2	[Maximize] thickness/adsorption of backfill around waste package	9.72×10^{-4}		
	Room and Waste Package Scale	bg1	[Maximize] length of flow path from waste package through backfill adsorbing material			7.56×10^{-3}
		bg2	[Maximize] cross-sectional area of flow path from waste package through backfill adsorbing material (i.e., maximize volume of backfill)			7.56×10^{-3}
		bg3	[Maximize] surface area per unit volume of backfill adsorbing material along flow path from waste package			3.78×10^{-3}
		bg4	[Maximize] adsorption potential of backfill along flow path from waste package to accessible environment			4.41×10^{-2}

(SEE KEY AT END OF TABLE)

SUMMARY OF WEIGHTS OF BACKFILL DESIGN OBJECTIVES

Table B.2
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KEY FOR CODE:

	Subject of Concern	Scale	Opposite to Identifier No.	Identifier No.	Similarity with Identifier No.		Time Period
b	s-schedule p-procedure m-mechanical t-thermal h-hydrologic g-geochemical	r-room scale h-waste package scale blank-room and waste package scale	blank o-opposite objective	1 2 3 . . .	blank a-similar b- " c- " . .	-	1-during retrieval period 2-post decommissioning to resaturation 3-post resaturation

For example:

b	s	r		1	a	-	1

Note: The weights of these backfill design objectives with respect to their relative contribution to achieving the repository system performance objectives have been explicitly derived (Table B.1); the relative weights of all occurrences of each backfill design objective have then been summed to determine the overall weight of that objective, as given here. This development has been based on preconceived repository design concepts (specifically vertical waste emplacement), performance assessment methodology, and generic site conditions (see Section 2 - Main Text); should these premises change, the weights may change. Also, even though the relative weights have been presented to three significant digits, their assessment entails significant subjectivity, however, so that these weights should be considered only as approximate indicators of relative significance. Although deemed sufficient for the purposes of this study (i.e., a design basis for comparative evaluations of alternative backfill schemes), these weights have not been derived rigorously enough for actual design purposes. Hence, prior to any use in guiding backfill design, which has not been intended here, the assessment of relative weights must be refined on a site-specific basis by quantitative performance assessment.

PRIORITIZED SUMMARY OF WEIGHTED BACKFILL DESIGN OBJECTIVES

Table B.3
1 of 5

(Listed in approximate decreasing order of significance)

Code	Objective (see Table B.2)	Relative Weight*
bg4-3	[Maximize] adsorption potential of backfill along flow path from waste package to accessible environment (post resaturation)	4.41×10^{-2}
bsrolc-1	[Maximize] time to start resaturation process (i.e., maximize time to placement of backfill, room scale, while dewatering) (during retrieval period)	1.72×10^{-2}
bhrla-3	[Minimize] hydraulic conductivity (and effective porosity) of backfill and interface (room scale) (post resaturation)	1.61×10^{-2}
bhl-3	[Maximize] distance from waste package through repository along flow path due to backfill (post resaturation)	1.61×10^{-2}
bgl-3	[Maximize] length of flow path from waste package through backfill adsorbing material (post resaturation)	7.56×10^{-3}
bg2-3	[Maximize] cross-sectional area of flow path from waste package through backfill adsorbing material (i.e., maximize volume of backfill) (post resaturation)	7.56×10^{-3}
bp2-1	[Maximize] monitoring of potentially hazardous underground conditions as backfilling occurs (during retrieval period)	4.32×10^{-3}
bp3-1	[Maximize] quick and efficient mitigation of detected underground hazards as backfilling occurs (during retrieval period)	4.32×10^{-3}
bhrla-2	[Minimize] hydraulic conductivity (and effective porosity) of backfill and interface (room scale) (post decommissioning to resaturation)	4.23×10^{-3}
bg3-3	[Maximize] surface area per unit volume of backfill adsorbing material along flow path from waste package (post resaturation)	3.78×10^{-3}
bpl-1	[Maximize] use of safe/reliable equipment for backfilling (during retrieval period)	3.60×10^{-3}
bghl-3	[Maximize] mitigation of corrosive groundwater by backfill (waste package scale) (post resaturation)	3.23×10^{-3}
bsrla-1	[Minimize] time to placement of backfill (room scale) (during retrieval period)	3.02×10^{-3}

PRIORITIZED SUMMARY OF WEIGHTED BACKFILL DESIGN OBJECTIVES

Table B.3
2 of 5

(Listed in approximate decreasing order of significance)

Code	Objective (see Table B.2)	Relative Weight*
bhr2-1	[Maximize] porosity of backfill (room scale) (during retrieval period)	2.58×10^{-3}
bhr2-2	[Maximize] porosity of backfill (room scale) (post decommissioning to resaturation)	2.58×10^{-3}
bmr2a-1	[Maximize] support pressure (or structural support) provided by backfill (room scale) (during retrieval period)	2.49×10^{-3}
bp4-1	[Minimize] personnel requirements for backfilling (i.e., maximize mechanization and remote operations) (during retrieval period)	2.27×10^{-3}
bhr1b-3	[Maximize] decrease in hydraulic conductivity (and effective porosity) of rock mass (room scale) (i.e., sealing/filling of discontinuities) by backfill (post resaturation)	2.06×10^{-3}
bmh1-3	[Minimize] stress transfer through backfill around waste package (post resaturation)	1.61×10^{-3}
btho1-3	[Minimize] insulation of waste package from rock mass around emplacement hole (post resaturation)	1.61×10^{-3}
bgh1-1	[Maximize] mitigation of corrosive groundwater by backfill (waste package scale) (during retrieval period)	1.12×10^{-3}
bgr2-1	[Maximize] thickness/adsorption of backfill (room scale) (during retrieval period)	1.08×10^{-3}
bgh1-2	[Maximize] mitigation of corrosive groundwater by backfill (waste package scale) (post decommissioning to resaturation)	1.08×10^{-3}
bp5-1	[Minimize] total effort required for backfilling (e.g., no backfilling) (during retrieval period)	9.72×10^{-4}
bgh2-1	[Maximize] thickness/adsorption of backfill around waste package (during retrieval period)	9.72×10^{-4}
bmh1-1	[Minimize] stress transfer through backfill around waste package (during retrieval period)	8.84×10^{-4}
bpr1-1	[Minimize] volume of backfill (room scale) (if placed, during retrieval period)	8.40×10^{-4}
bmh2b-3	[Minimize] increase in swelling pressure of backfill around waste package (post resaturation)	8.06×10^{-4}

PRIORITIZED SUMMARY OF WEIGHTED BACKFILL DESIGN OBJECTIVES

Table B.3
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(Listed in approximate decreasing order of significance)

Code	Objective (see Table B.2)	Relative Weight*
bshol-1	[Maximize] time to placement of backfill around waste package, and ventilate (during retrieval period)	7.88×10^{-4}
bshl-1	[Minimize] time to placement of backfill around waste package (during retrieval period)	6.48×10^{-4}
bmhl-2	[Minimize] stress transfer through backfill around waste package (post decommissioning to resaturation)	5.38×10^{-4}
bthol-2	[Minimize] insulation of waste package from rock mass around emplacement hole (post decommissioning to resaturation)	5.38×10^{-4}
bsrola-1	[Maximize] time to placement of backfill (room scale) (during retrieval period)	5.04×10^{-4}
bmh2a-1	[Minimize] swelling pressure of backfill around waste package (during retrieval period)	4.42×10^{-4}
bsrolb-1	[Maximize] time to placement of backfill, and ventilate (room scale) (during retrieval period)	4.22×10^{-4}
bmrl-1	[Minimize] integrity (compaction) of backfill (room scale) (if placed, during retrieval period)	3.36×10^{-4}
bthol-1	[Minimize] insulation of waste package from rock mass around emplacement hole (during retrieval period)	3.27×10^{-4}
bsrlb-1	[Delay and minimize] backfilling of tunnels along possible egress routes (room scale)(during retrieval period)	3.02×10^{-4}
bmro2a-1	[Minimize] support pressure (or structural support) provided by backfill (room scale) (during retrieval period)	3.00×10^{-4}
btrl-1	[Maximize] insulation of waste package from rock mass around underground opening (room scale) (during retrieval period)	2.78×10^{-4}
bmh2b-2	[Minimize] increase in swelling pressure of backfill around waste package (post decommissioning to resaturation)	2.69×10^{-4}

PRIORITIZED SUMMARY OF WEIGHTED BACKFILL DESIGN OBJECTIVES

Table B.3
4 of 5

(Listed in approximate decreasing order of significance)

Code	Objective (see Table B.2)	Relative Weight*
bmr2c-3	[Minimize] decrease in support pressure (or structural support) provided by backfill (room scale) (post resaturation)	9.61×10^{-5}
btrol-1	[Minimize] insulation of waste package from rock mass around underground opening (room scale) (during retrieval period)	8.58×10^{-5}
bhrla-1	[Minimize] hydraulic conductivity (and effective porosity) of backfill and interface (room scale) (during retrieval period)	8.51×10^{-5}
bmr2c-2	[Minimize] decrease in support pressure (or structural support) provided by backfill (room scale) (post decommissioning to resaturation)	6.99×10^{-5}
bmr2b-3	[Maximize] increase in support pressure (or structural support) provided by backfill (room scale) (post resaturation)	6.97×10^{-5}
bthl-3	[Maximize] insulation of waste package from rock mass around emplacement hole (post resaturation)	6.88×10^{-5}
bthl-1	[Maximize] insulation of waste package from rock mass around emplacement hole (during retrieval period)	6.19×10^{-5}
bmr2b-2	[Maximize] increase in support pressure (or structural support) provided by backfill (room scale) (post decommissioning to resaturation)	4.84×10^{-5}
bthl-2	[Maximize] insulation of waste package from rock mass around emplacement hole (post decommissioning to resaturation)	2.59×10^{-5}
btrl-2	[Maximize] insulation of waste package from rock mass around underground opening (room scale) (post decommissioning to resaturation)	2.58×10^{-5}
btrl-3	[Maximize] insulation of waste package from rock mass around underground opening (room scale) (post resaturation)	1.60×10^{-5}
bgrl-1	[Maximize] protection of exposed rock surface underground by backfill (room scale) (during retrieval period)	1.37×10^{-5}
bmro2c-2	[Maximize] decrease in support pressure (or structural support) provided by backfill (room scale) (post decommissioning to resaturation)	5.68×10^{-6}

(Listed in approximate decreasing order of significance)

Code	Objective (see Table B.2)	Relative Weight*
bgr1-3	[Maximize] protection of exposed rock surface underground by backfill (room scale) (post resaturation)	4.34×10^{-6}
bgr1-2	[Maximize] protection of exposed rock surface underground by backfill (room scale) (post decommissioning to resaturation)	4.23×10^{-6}
bmro2c-3	[Maximize] decrease in support pressure (or structural support) provided by backfill (room scale) (post resaturation)	4.17×10^{-6}
btro1-2	[Minimize] insulation of waste package from rock mass around underground opening (room scale) (post decommissioning to resaturation)	2.49×10^{-6}
btro1-3	[Minimize] insulation of waste package from rock mass around underground opening (room scale) (post resaturation)	1.55×10^{-6}

*The relative weight of each backfill design objective has been explicitly assessed with respect to its perceived contribution, relative to all other repository variables, to achieving the repository system performance objectives (Table B.1). This assessment has been based on preconceived repository design concepts (specifically vertical waste emplacement), performance assessment methodology, and generic site conditions (see Section 2 - Main Text); should these premises change, the weights may change. Also, even though the relative weights have been presented to three significant digits, their assessment entails significant subjectivity, so that these weights should be considered only as approximate indicators of relative significance. Although deemed sufficient for the purposes of this study (i.e., a design basis for comparative evaluations of alternative backfill schemes), these weights have not been derived rigorously enough for actual design purposes. Hence, prior to any use in guiding backfill design, which has not been intended here, the assessment of relative weights must be refined on a site-specific basis by quantitative performance assessment.

APPENDIX C
SUMMARIES OF DOE-PROPOSED BACKFILL SCHEMES

TABLE OF CONTENTS

NOTE: Each of the summaries (Sections C.1 through C.11) follows the same format, as detailed in the Introduction (Section C.0).

LIST OF TABLES

APPENDIX C - SUMMARIES OF DOE-PROPOSED BACKFILL SCHEMES

C.0 INTRODUCTION

A number of design documents pertaining to backfill and authored by DOE contractors have been identified, primarily utilizing a literature data base developed by SAI (1981). These documents have been grouped into a total of 11 studies (see Table C.1). Each of these studies has been reviewed in order to establish a representative set of alternative backfill schemes. Details of these schemes, which represent a basic data source for the present study (see Section 5 - Main Text), have been summarized in the following sections of this appendix. The description of each scheme has been given in the following format:

1. Backfill Perspective
    - 1.1 Media/Site
    - 1.2 Backfill Objectives
    - 1.3 Backfill Schedule
    - 1.4 Expected Environmental Conditions at Backfilling and Thereafter
    - 1.5 Reference(s)

2. Backfill Material and Additive(s)
    - 2.1 Backfill Material
    - 2.2 Backfill Additive(s)

3. Backfill Procedures
    - 3.1 Preparation of Backfill Material/Additive(s)
    - 3.2 Placement and Compaction (if any) of Backfill

4. Backfill Characteristics
    - 4.1 Anticipated Characteristics of Backfill (in place)
    - 4.2 Tests to Assess Characteristics of Backfill (in place)

It must be pointed out that certain factors and assumptions on which these backfill designs have been based may have changed, or will change in the future. Hence, these preconceptual or conceptual backfill designs may change with time, sometimes significantly. However, they serve to indicate what is presently being considered, or has been considered, by the DOE for backfill.

SUMMARY OF REFERENCED DOE DESIGN PUBLICATIONS RELATED TO BACKFILL

Table C.1

Study No.	Reference(s)	Applicable Media	Section in Appendix
1)	Parsons et al (1978c)	Basalt	C.1
2)	BWIP (1980)	Basalt	C.2
3)	Kaiser et al (1980)	Basalt	C.3
4)	Kaiser et al (1982)	Basalt	C.4
5)	Westinghouse (1981a)	Basalt	C.5
6)	Parsons et al (1978a)	Salt	C.6
7)	Stearns-Roger (1978) Stearns-Roger (1979a) Stearns-Roger (1979b) Woodward-Clyde (1978)	Domal Salt	C.7
8)	Kaiser (1978a) Kaiser (1978b)	Bedded Salt	C.8
9)	Bechtel (1979)	Domal Salt	C.9
10)	Westinghouse (1981b)	Salt	C.10
11)	Parsons et al (1978b)	Granite	C.11

C.1 SUMMARY OF BACKFILL SCHEME NO. 1

C.1.1 BACKFILL PERSPECTIVE

C.1.1.1 Media/Site

The repository would be in basalt. No site has been specified.

C.1.1.2 Backfill Objectives

No objectives have been mentioned.

C.1.1.3 Backfill Schedule

Backfill would be placed after a retrievability period of 5 years. However, an option for 25-year retrievability has been discussed; backfill for this alternative has only been considered at decommissioning. Storage of waste packages would be either in holes or trenches. Spent fuel waste for the 5-year retrievability case would be placed in holes lined with steel sleeves and no backfill.

C.1.1.4 Expected Environmental Conditions at Backfilling and Thereafter

Relatively impermeable basalt (with flows into the repository of 265 gpm) and elevated temperatures and rock stress would be expected during and after backfilling.

C.1.1.5 Reference(s)

This summary has been based on Parsons, Brinckerhoff, Quade and Douglas, Inc. "Technical Support for GEIS: Radioactive Waste Isolation in Geologic Formations, 14--Repository Preconceptual Design Studies: Basalt", Y/OWI/TM-36/14, Office of Nuclear Waste Isolation, Oak Ridge, TN, April 1978c.

C.1.2 BACKFILL MATERIAL AND ADDITIVE(S)

C.1.2.1 Backfill Material

Crushed basalt, obtained from excavated material, would be used in the room. A steel pipe sleeve would be used in the waste emplacement hole with no backfill.

C.1.2.2 Backfill Additive(s)

No additives have been mentioned.

C.1.3 BACKFILL PROCEDURES

C.1.3.1 Preparation of Backfill Material/Additive(s)

Preparation of backfill would include crushing of basalt underground. The operation would utilize a crusher, rail cars, trucks, conveyor belts and storage bins.

C.1.3.2 Placement and Compaction (if any) of Backfill

The backfill would be trucked to the backfill corridor servicing the rooms, transported to rooms and placed using a front-end loader to within five feet of the ceiling. The equipment used would include trucks, front-end loader and unspecified equipment to transport material through the backfill corridor to rooms. One corridor would be designated solely for backfilling to avoid conflicts with other operations.

Compaction has not been mentioned.

C.1.4 BACKFILL CHARACTERISTICS

C.1.4.1 Anticipated Characteristics of Backfill (in place)

Anticipated in-place density of the backfill would be 124 lbs/cu.ft. No other backfill characteristics have been mentioned.

C.1.4.2 Tests to Assess Characteristics of Backfill (in place)

Tests to assess backfill have not been mentioned.

C.2 SUMMARY OF BACKFILL SCHEME NO. 2

C.2.1 BACKFILL PERSPECTIVE

C.2.1.1 Media/Site

The repository would be in basalt at Hanford, Washington.

C.2.1.2 Backfill Objectives

Room backfill should:

- Possess low permeability to reduce groundwater inflow into the repository
- Be stable in terms of resistance to fluid flow
- Possess ion exchange properties equal to that of the basalt
- Provide passive support for the rock mass
- Be deformable (compared to basalt) to accommodate moderate strains.

Waste emplacement would be in horizontal holes lined with grouted steel cylinders.

C.2.1.3 Backfill Schedule

Placement rooms would be backfilled after the operational period (waste emplacement), a one- to two-year period. Reaming rooms would be backfilled after five years; this would be a function of placement of waste in panels serviced by the reaming room. Panel accesses would be backfilled after the 25-year retrievability period following last waste placement in the panel.

C.2.1.4 Expected Environmental Conditions at Backfilling and Thereafter

High temperatures (i.e., 60 to 75°C) would be expected within the room at 2 years after waste emplacement. Stresses in the rock would be expected to be below acceptable limits; specified factors of safety vary with type of stress condition and operational stage of the repository. Confined aquifers would be expected to be present within the host rock at the repository horizon.

C.2.1.5 Reference(s)

This summary has been based on Basalt Waste Isolation Project Staff, "Nuclear Waste Repository in Basalt, Project B-301, Preconceptual Design Report," RHO-BWI-CD-35, Rockwell Hanford Operations, Richland, WA, February 1980.

C.2.2 BACKFILL MATERIAL AND ADDITIVE(S)

C.2.2.1 Backfill Material

Around the waste package, grout (possibly cementatious and absorptive materials) has been proposed. A source for this material has not been mentioned. Filler material around the waste package might also be utilized. Within the rooms, the lower two-thirds of the room would be backfilled using previously excavated, crushed and sized basalt (sand- and silt-size particles), while the upper one-third would be backfilled with a concretious mixture.

C.2.2.2 Backfill Additive(s)

Expansive clay has been considered as a potential additive. Post-grouting of room backfill has been specified.

C.2.3 BACKFILL PROCEDURES

C.2.3.1 Preparation of Backfill Material/Additive(s)

Grout for backfilling around the waste package would be mixed underground. Room backfilling activities would include crushing and sizing of basalt, and mixing of a concretious mixture and preparation of aggregate, all of which would be carried out underground until backfilling of panel accesses and shafts. Equipment has not been mentioned.

C.2.3.2 Placement and Compaction (if any) of Backfill

Grout would be pumped around the sleeve in the waste emplacement hole. Within the room, basalt would be mechanically placed and compacted, whereas the concretious mixture would be pneumatically placed. Equipment specified includes trucks, rail haulage system, mechanical compactors, and dozers. Grouting of the panel access backfill after placement of bulkheads has also been mentioned.

C.2.4 BACKFILL CHARACTERISTICS

C.2.4.1 Anticipated Characteristics of Backfill (in place)

Characteristics, based on expected performance, would include:

- Low permeability in the long term
- Ion-exchange characteristics, similar to in-place basalt
- Long-term durability
- High strength, to provide passive support, but higher deformability than in-place basalt.

C.2.4.2 Tests to Assess Characteristics of Backfill (in place)

A testing program has been recommended to demonstrate the backfill's ability to support openings and inhibit groundwater migration. Instrumentation would monitor air and water quality, temperature buildup, and rock microseismic activity.

C.3 SUMMARY OF BACKFILL SCHEME NO. 3

C.3.1 BACKFILL PERSPECTIVE

C.3.1.1 Media/Site

The repository would be in basalt at Hanford, Washington.

C.3.1.2 Backfill Objectives

Room backfill should provide permanent support and act as a chemical and physical barrier against radionuclide migration. Backfill around the waste package should perform as an engineered barrier.

C.3.1.3 Backfill Schedule

The room would be backfilled after the retrieval period, i.e., 25 years after any emplacement. This repository design has been based on 10-year old fuel and a 20-year period of storage.

C.3.1.4 Expected Environmental Conditions at Backfilling and Thereafter

Elevated temperatures would be expected, with limits of:

- Spent fuel cladding: 300°C
- Basalt around waste packages: 500°C
- Bentonite: 300°C
- Host rock: 70°C to 150°C.

A potential for corrosion and a requirement for rock support have been mentioned.

C.3.1.5 Reference(s)

This summary has been based on Kaiser Engineers/Parsons, Brinckerhoff, Quade and Douglas, Inc., "Nuclear Waste Repository in Basalt, Project B-301, Functional Design Criteria," RHO-BWI-CD-38 Rev. 3, Rockwell Hanford Operations, Richland, WA, November 1980.

C.3.2 BACKFILL MATERIAL AND ADDITIVE(S)

C.3.2.1 Backfill Material

Within the waste package, bentonite has been specified. Around the waste package, bentonite at the bottom of the hole and zircon sand at the top of the hole have been specified. The room backfill has been specified to be 50% crushed basalt, 40% bentonite powder, and 10% bentonite pellets. The source of the basalt would be excavated material.

C.3.2.2 Backfill Additive(s)

No backfill additives, other than bentonite, have been mentioned.

C.3.3 BACKFILL PROCEDURES

C.3.3.1 Preparation of Backfill Material/Additive(s)

Preparation activities would include:

- Excavate, transport and size basalt at the surface
- Crush and mix backfill materials at the surface; room backfill would have a water content of 10 to 15%
- Transport backfill using shaft skips and surge bins.

C.3.3.2 Placement and Compaction (if any) of Backfill

Placement methods and equipment used for backfilling of waste emplacement holes and rooms have not been specified. Compaction methods and equipment used have not been specified, except that the method of placement/compaction of room backfill should achieve a high density.

C.3.4 BACKFILL CHARACTERISTICS

C.3.4.1 Anticipated Characteristics of Backfill (in place)

Anticipated backfill characteristics have not been specified, except that room backfill should have a high density.

C.3.4.2 Tests to Assess Characteristics of Backfill (in place)

An experimental panel has been planned to examine alternate waste storage configurations and backfilling procedures.

C.4 SUMMARY OF BACKFILL SCHEME NO. 4

C.4.1 BACKFILL PERSPECTIVE

C.4.1.1 Media/Site

The repository would be in basalt at Hanford, Washington.

C.4.1.2 Backfill Objectives

The objective would be to isolate radionuclides by a multi-barrier system of which backfill would be a part. Also included in the system would be a storage position component around the waste package, contained in an aluminum sleeve. The storage position component would be basically bentonite, and has not been considered to be backfill. A small amount of bentonite topped by sand would surround the storage position component, and has been considered to be backfill.

C.4.1.3 Backfill Schedule

The waste emplacement hole would be backfilled after storage position component emplacement. The room would be backfilled after the retrievability period, i.e., 25 years after waste emplacement.

C.4.1.4 Expected Environmental Conditions at Backfilling and Thereafter

Elevated temperatures, (i.e., approximately 200°C) and slow movement of groundwater in basalt would be expected during and after backfilling.

C.4.1.5 Reference(s)

This summary has been based on Kaiser Engineers/Parsons, Brinckerhoff, Quade and Douglas, Inc., "Nuclear Waste Repository in Basalt, Project B-301, Conceptual System Design Description," Draft, Vol. 1, RHO-BWI-C-116, Rockwell Hanford Operations, Richland, WA, March 1982.

C.4.2 BACKFILL MATERIAL AND ADDITIVE(S)

C.4.2.1 Backfill Material

Crushed basalt would comprise 50 percent of the total room backfill. Inconsistencies exist in the description of the basalt, and would be either 2.5" particles or graded from -3" to +#200 mesh. The crushed basalt would be from underground excavations.

C.4.2.2 Backfill Additive(s)

Bentonite (40% powder + 10% pellets = 50% of total backfill) would be added to the room backfill. Bentonite and zircon sand would be added to backfill around the waste package. Bentonite would be used in the storage position component.

C.4.3 BACKFILL PROCEDURES

C.4.3.1 Preparation of Backfill Material/Additive(s)

Preparation activities for waste emplacement hole and storage position back- fill have not been mentioned. For room backfill, basalt would be crushed, bentonite added at the surface, and the backfill mix transported down the basalt hoisting shaft to skips and eventually transported to a surge bin. From there, mine cars would take backfill to work places. Once in the panel, the backfill would be unloaded into portable mixers for re-mixing and the addition of water. Material would then be transported by battery-powered shuttle cars to the room being backfilled. Moisture content of backfill would be 10 to 15%.

Equipment used would include bentonite storage bins, crushers, material handling equipment (skips, hoists, conveyors, surge bins, batch plants), battery operated shuttle cars, portable mixers, rail haulage system.

C.4.3.2 Placement and Compaction (if any) of Backfill

For room backfill, placement and compaction would be performed in three stages after rooms have been precooled to 27°C:

- In Stage 1, the backfill would be hauled and dumped into the room and spread by a dozer in 8-inch lifts. Compaction would be performed by large equipment. This stage would continue until the backfill has reached 10 feet in height.
- Stage 2 would be identical to Stage 1, but low-profile equipment would be used up to 14 feet of backfill height.
- In Stage 3, the backfill material would be placed through a hole in the top of a traveling shield. The shield would then compress the backfill once the space behind it is full. The traveling shield has not yet been developed, but would incorporate hydraulic cylinders for jacking against room walls and a ram for compacting the fill. After compaction, the shield would retreat and the process repeated until the room has been closed. The traveling shield would complete the backfill to a final room height of 20 feet.

Inherent to room backfill would be the construction of a fill fence (or bulkhead) of aluminum on the backside (or confinement return side). The fence would be constructed as the backfill is brought up in elevation.

The equipment used for room backfilling would include normal and low-profile size construction equipment (dozers, compactors) and a yet-to-be-developed traveling shield.

C.4.4 BACKFILL CHARACTERISTICS

C.4.4.1 Anticipated Characteristics of Backfill (in place)

Storage position and room backfill would be expected to have low permeability and high ion-exchange capabilities. No other backfill characteristics have been mentioned.

C.4.4.2 Tests to Assess Characteristics of Backfill (in place)

An experimental panel has been planned with monitoring systems. No other tests have been mentioned.

C.5 SUMMARY OF BACKFILL SCHEME NO. 5

C.5.1 BACKFILL PERSPECTIVE

C.5.1.1 Media/Site

The repository would be in basalt. No site has been specified.

C.5.1.2 Backfill Objectives

Two concepts of waste storage have been presented: hole emplacement and self-shielded emplacement in the tunnel floor. Backfill in the self-shielded concept would be over the packages in the room, while backfill in the hole scheme would be around the package in the hole. However, this summary has been concerned with the hole waste placement scheme only.

The primary objectives of the backfill would be to provide radiation shielding for other operations in the area and to control groundwater in the region of the waste package.

C.5.1.3 Backfill Schedule

Backfill would be placed around the waste package during emplacement. Backfill would be placed in the room as soon as reasonably possible after the last emplacement has been made and before the bentonite has absorbed significant quantities of water.

C.5.1.4 Expected Environmental Conditions at Backfilling and Thereafter

At backfilling of the waste emplacement hole, the following would be expected:

- Radiation of 590 (max.) mrem/hour at the tunnel floor (after waste is emplaced)
- Presence of both static and migratory water, the latter caused by the effects of waste emplacement
- Possible elevated temperatures.

At backfilling of the tunnel, the following would be expected:

- Lower radiation (1.0 mrem/hour (max.) at the tunnel floor)
- Presence of water
- Possible elevated temperatures.

After backfilling, the following would be expected:

- Presence of water
- External pressures (from host rock and swelling bentonite)

- Elevated temperatures (peak temperature will occur approximately 10 years after waste emplacement, depending on location).

C.5.1.5 Reference(s)

This summary has been based on Westinghouse Electric Corporation, Advanced Energy Systems Division, "Engineered Waste Package Conceptual Design Defense High Level Waste (Form 1), Commercial High Level Waste (Form 1), and Spent Fuel (Form 2), Disposal in Basalt," AESD-TME-3113, September 1981a.

C.5.2 BACKFILL MATERIAL AND ADDITIVE(S)

C.5.2.1 Backfill Material

For the waste emplacement hole, backfill would be pre-formed, compacted sodium bentonite shapes. Crushed basalt would be required at the bottom of the hole to level the placement area and would also be placed around the outside annulus of the bentonite backfill. The source of the bentonite has not been specified. Room backfill material has not been specified.

C.5.2.2 Backfill Additive(s)

No backfill additives have been discussed.

C.5.3 BACKFILL PROCEDURES

C.5.3.1 Preparation of Backfill Material/Additive(s)

Preparation activities would consist of refining and pressing sodium bentonite into various shapes, and then storing the bentonite blocks in acceptable atmospheric conditions. Refining and pressing of bentonite would probably occur on site. The storage of bentonite would occur underground or in an atmospherically controlled surface storage facility.

C.5.3.2 Placement and Compaction (if any) of Backfill

Placement activities would include:

- Adding crushed basalt at the bottom of the hole to provide a level surface and control the emplacement depth of the waste package
- Placing the bentonite shapes (base and rings) in the hole
- Placing the top pad of bentonite after waste package installation
- Placing crushed basalt between the bentonite and hole wall after the top pad has been placed or when the tunnel is backfilled

- Backfilling the tunnel (6 months to 1 year) after waste package emplacement.

Equipment used in the placement of the hole backfill would include:

- A vehicle capable of lifting bentonite shapes (semi-remote operation would be needed for placemnt of the top pad)
- Some means of placing crushed basalt (no equipment has been specified).

Compaction activities, other than pre-forming of bentonite shapes, have not been specified.

C.5.4 BACKFILL CHARACTERISTICS

C.5.4.1 Anticipated Characteristics of Backfill (in place)

Waste emplacement hole backfill would be expected to exhibit the following characteristics:

- Thermal Conductivity: Dry = 0.33 W/m°K
  Wet = 0.75 W/m°K
- Hydraulic Conductivity: Maximum = 10^{-13} m/s
  (Flow takes place via diffusion instead of convection)
- Density: Pre-compacted: 2.1 gm/cc
  Smear: 1.75 gm/cc (expansion into backfilled
  (after swelling) tunnel limited to a few
  percent)
- Swelling presure: 2 MPa maximum.

Bentonite would not be expected to swell until after the first 50 years, as the bentonite temperature would be expected to be above the groundwater boiling point. The temperature limit for bentonite is approximately 250°C and would be exceeded slightly during early years (4 to 10 years) if dry conditions exist. Bentonite might be a carrier of chemical reagents.

The tunnel backfill would be expected to contain the swelling bentonite within the waste emplacement hole.

C.5.4.2 Tests to Assess Characteristics of Backfill (in place)

No tests have been specified, but the need for fabrication tests and mock emplacement tests, along with further tests to define properties of bentonite shapes, has been recognized.

C.6 SUMMARY OF BACKFILL SCHEME NO. 6

C.6.1 BACKFILL PERSPECTIVE

C.6.1.1 Media/Site

The repository would be in salt. No site has been specified.

C.6.1.2 Backfill Objectives

No backfill objectives have been mentioned.

C.6.1.3 Backfill Schedule

Room backfill would be placed after the retrievability period (5 years). A 25-year retrievability period has also been considered. Backfill in the waste emplacement hole would be placed only during the retrievability period.

C.6.1.4 Expected Environmental Conditions at Backfilling and Thereafter

The following conditions would be expected during and after backfilling:

- No water inflow into the repository, provided no major disturbance of the salt has occurred
- Increased temperatures
- Increased rock stresses.

C.6.1.5 Reference(s)

This summary has been based on Parsons, Brinckerhoff, Quade and Douglas, Inc., "Technical Support for GEIS: Radioactive Waste Isolation in Geologic Formations, V. 8--Repository Preconceptual Design Studies: Salt," Y/OWI/TM-36/8, Office of Waste Isolation, Oak Ridge, TN, April 1978a.

C.6.2 BACKFILL MATERIAL AND ADDITIVE(S)

C.6.2.1 Backfill Material

Excavated salt would be used in both the waste emplacement hole and the room. Salt backfill in the hole would be around a steel sleeve and would only be required during the retrievability period.

C.6.2.2 Backfill Additive(s)

No additives have been discussed.

C.6.3 BACKFILL PROCEDURES

C.6.3.1 Preparation of Backfill Material/Additive(s)

Transport and storage of excavated salt underground would utilize trucks, conveyor belts and storage bins.

C.6.3.2 Placement and Compaction (if any) of Backfill

A conveyor, suspended from the ceiling of the waste emplacement corridor, would place salt in the room to within two feet of the ceiling. Some backfill might be necessary around sleeves to ensure that the canister will remain plumb during emplacement and the retrievability period.

Equipment used would include a conveyor and hoisting systems. Reversible conveyors might be needed.

Compaction has not been mentioned.

C.6.4 BACKFILL CHARACTERISTICS

C.6.4.1 Anticipated Characteristics of Backfill (in place)

Density of room backfill would be 89 lbs./cu.ft. No other backfill characteristics have been discussed.

C.6.4.2 Tests to Assess Characteristics of Backfill (in place)

No tests to assess the backfill have been mentioned.

C.7 SUMMARY OF BACKFILL SCHEME NO. 7

C.7.1 BACKFILL PERSPECTIVE

C.7.1.1 Media/Site

The repository would be in domal salt. No site has been specified.

C.7.1.2 Backfill Objectives

No backfill objectives have been mentioned.

C.7.1.3 Backfill Schedule

The room would be backfilled after the first five years of waste emplacement. The waste emplacement hole would be backfilled after waste package emplacement. The proposed depth of boreholes would be 250 feet.

C.7.1.4 Expected Environmental Conditions at Backfilling and Thereafter

Increased temperatures and the presence of moisture would be expected during and after backfilling.

C.7.1.5 Reference(s)

This summary has been based on the following four reports:

- Stearns-Roger Engineering Co., "National Waste Terminal Storage Repository No. 1, Special Study No. 2: Waste Retrieval from Backfilled Regions," S-R, Denver, CO, 1978.
- Stearns-Roger Engineering Co., "National Waste Terminal Storage Repository No. 1, Volume No. 1, Conceptual Design Report," ONWI-0127, U.S. Department of Energy, Oak Ridge, TN, January 1979a.
- Stearns-Roger Engineering Co., "National Waste Terminal Storage Repository No. 1, Conceptual Design Descriptions," ONWI-0129, U.S. Department of Energy, Oak Ridge, TN, January 1979b.
- Woodward-Clyde Consultants, "NWTS Repository No. 1, Supporting Studies for Conceptual Design of Underground Facilities," Vols. 1 and 4, March 1978.

C.7.2 BACKFILL MATERIAL AND ADDITIVE(S)

C.7.2.1 Backfill Material

A steel sleeve or bentonite backfill has been proposed for around the waste package and excavated salt has been proposed for above.

Excavated salt has been proposed for backfilling the room.

C.7.2.2 Backfill Additive(s)

No additives have been discussed.

C.7.3 BACKFILL PROCEDURES

C.7.3.1 Preparation of Backfill Material/Additive(s)

Preparation activities would include stockpiling of excavated salt on the surface before backfilling commences. A hoisting system would be used for transport. There has been no mention of bentonite preparation.

C.7.3.2 Placement and Compaction (if any) of Backfill

The room would be backfilled to within two feet of the ceiling by a centrifugal thrower. After backfilling, openings would be sealed with block brattice. Hole placement has not been mentioned.

C.7.4 BACKFILL CHARACTERISTICS

C.7.4.1 Anticipated Characteristics of Backfill (in place)

Characteristics of backfill (in place) have not been discussed.

C.7.4.2 Tests to Assess Characteristics of Backfill (in place)

Tests to assess the backfill have not been discussed.

C.8 SUMMARY OF BACKFILL SCHEME NO. 8

C.8.1 BACKFILL PERSPECTIVE

C.8.1.1 Media/Site

The repository would be in bedded salt. No site has been specified.

C.8.1.2 Backfill Objectives

No objectives have been stated other than radiation shielding by backfill in the waste emplacement hole.

C.8.1.3 Backfill Schedule

Backfill would be placed in the waste emplacement hole depending on whether waste has been emplaced during or after the initial retrieval period, i.e., the first five years. During this retrieval period, there would be no backfill around the emplaced waste package or sleeve surrounding the package. Waste packages emplaced after the five-year retrievability period would not be placed in sleeves and would be backfilled immediately. Backfill would be around and on top of the canister.

After the end of the five-year retrievability period, the rooms would be backfilled. Six rooms would be backfilled halfway to the room ceiling to facilitate ventilation until decommissioning.

C.8.1.4 Expected Environmental Conditions at Backfilling and Thereafter

The following conditions would be expected during and after backfilling:

- Closure of boreholes and rooms
- Increased temperature of salt (from 83°F initially to 284°F peak)
- Low water in salt (0.1 weight % of moisture)
- Migration of water in salt due to thermal gradient
- Radiation in room during retrieval period (less than 1.2 mrem/hr)

C.8.1.5 Reference(s)

This summary has been based on the following two reports:

- Kaiser Engineers, "Conceptual Design Description Report for a National Waste Terminal Storage Repository in a Bedded Salt Formation for Spent Unreprocessed Fuel," 78-58-R, KE, Oakland, CA, December 1978a.
- Kaiser Engineers, "Conceptual Design Report for a National Waste Terminal Storage Repository in a Bedded Salt Formation for Spent

Unreprocessed Fuel," Vol. 1, 78-57-RE, KE, Oakland, CA, December 1978b.

C.8.2 BACKFILL MATERIAL AND ADDITIVE(S)

C.8.2.1 Backfill Material

Salt from the excavation of underground facilities would be used for backfill. Crushed salt has been mentioned, but specific grain size has not been given.

C.8.2.2 Backfill Additive(s)

No additives have been discussed.

C.8.3 BACKFILL PROCEDURES

C.8.3.1 Preparation of Backfill Material/Additive(s)

Excavated salt would be transported from the room being mined to underground surge bins, crushed, and then taken to the room being backfilled.

For final backfill, crushing would be at the surface using a front-end loader and feeder-breaker type crusher. The backfill would be transported underground using a hoist. Underground activities would utilize surge bins, conveyor belts and trucks. Trucks would take salt to the rooms after loading by surge bins at the first crosscut location. Belts would feed surge bins. Crushing would also take place underground using a small feeder-breaker. Six adjacent storage rooms must be backfilled at one time to accommodate the ventilation sequence and to segregate backfilling operations from waste emplacement operations.

C.8.3.2 Placement and Compaction (if any) of Backfill

Truckloads of backfill would be dumped at the rib of the storage room near the working face. A dozer would then push the backfill into position at the face. "Low profile" equipment has been specified to fill the last half of selected rooms at decommissioning, e.g., 20-cu.yd. capacity Wagoner teletrams fitted with a blade for dozing would transport backfill to the working face. Six rooms (three on the north side, three on the south side) would be backfilled halfway to the ceiling height to facilitate ventilation.

The transporter, modified for backfill placement with auxiliary salt hopper, agitator, crusher, blower and dust control system, would be used for backfilling around the waste package.

Compaction procedures have not been specified.

C.8.4 BACKFILL CHARACTERISTICS

C.8.4.1 Anticipated Characteristics of Backfill (in place)

No backfill characteristics have been described. However, salt around the fuel assembly has been modeled as having a density of 2.16 g/cc and 0.1% of total weight as moisture.

C.8.4.2 Tests to Assess Characteristics of Backfill (in place)

No tests to assess the backfill have been mentioned; however, instrumentation has been specified to monitor:

- Closure
- Creep
- Seismic activity
- Microseismic activity
- Dynamic rock pressure
- Internal rock temperatures
- Radiation.

C.9 SUMMARY OF BACKFILL SCHEME NO. 9

C.9.1 BACKFILL PERSPECTIVE

C.9.1.1 Media/Site

The repository would be in domal salt. No site has been specified.

C.9.1.2 Backfill Objectives

Waste emplacement hole backfill should improve the heat transfer characteristics during the retrievability period. Room backfill should provide more complete isolation of stored waste.

C.9.1.3 Backfill Schedule

For holes with an innersleeve (i.e., during the retrievability period), backfill would be placed between the sleeve and hole immediately after waste emplacement. For holes without an inner sleeve (i.e., during the recovery period), backfill would be placed only on top of the waste package immediately after waste emplacement.

Room backfill would begin after the retrievability period (i.e., five years after first waste emplacement). The retrievability period would not require special procedures or equipment. The recovery period may require special equipment, mining operations or procedures. The time allowed for recovery of spent fuel assemblies would be 50 years after initiation of the recovery period.

C.9.1.4 Expected Environmental Conditions at Backfilling and Thereafter

Conditions expected during backfilling of the room would include:

- Closure of room and borehole
- Temperatures of less than 392°F at the canister centerline
- Radiation shielding not required (concrete plugs should achieve shielding)
- Presence of moisture
- Corrosion of the canister.

Conditions expected during the recovery stage include:

- Corrosion of the canister
- Settling of room backfill and closure of room
- High temperature (approx. 200°F in [illegible] 25 years).

C.9.1.5 Reference(s)

This summary has been based on Bechtel National, Inc., "National Waste Terminal Storage (NWTS), Conceptual Reference Repository Description (CRRD) (Draft)," Vols. I, II, III, IV, ONWI/Sub-79/E512-01600.16, September 1979.

C.9.2 BACKFILL MATERIAL/ADDITIVE(S)

C.9.2.1 Backfill Material

Crushed salt used for backfilling in the waste emplacement hole and room would be obtained from underground excavations.

C.9.2.2 Backfill Additive(s)

No additives have been discussed.

C.9.3 BACKFILL PROCEDURES

C.9.3.1 Preparation of Backfill Material/Additive(s)

Backfill preparation activities would include excavation and crushing, screening and storage of salt. Crushing and screening of salt, which has been brought to the surface, would be required for use in the centrifugal thrower used for backfilling the room; however, no crushing has been mentioned for salt used as backfill coming directly from the excavation.

Equipment used for backfill preparation would include shuttle cars, conveyor belts, surge bins, skip and hoist system, crushers, screens, front-end loaders, dozers, chutes, and feeders.

C.9.3.2 Placement and Compaction (if any) of Backfill

The liner and plug emplacement machine would place and vibrate salt around the sleeve in the waste emplacement hole.

A portable and traveling conveyor belt would feed salt through a brattice wall to a centrifugal thrower, which would then place the salt in the room. The thrower would handle lumps of approximately the maximum size produced by the mining machine.

Other than vibration of the backfill placed around the sleeve in the waste emplacement hole during the retrieval stage, no compaction has been specified.

C.9.4 BACKFILL CHARACTERISTICS

C.9.4.1 Anticipated Characteristics of Backfill (in place)

Consolidation of the crushed salt backfill in the waste emplacement hole (during the retrieval stage) would be expected from intact salt closure.

Density on the order of 100 pcf would be expected for room backfill. A void equal to 1/10 of the room height would be expected to form at the roof due to settling.

No other backfill characteristics have been mentioned.

C.9.4.2 Tests to Assess Characteristics of Backfill (in place)

No tests have been specifically mentioned for monitoring backfill performance, but instrumentation for observing repository structural stability, radiation levels, and salt temperature levels would be included.

C.10 SUMMARY OF BACKFILL SCHEME NO. 10

C.10.1 BACKFILL PERSPECTIVE

C.10.1.1 Media/Site

The repository would be in salt. No site has been specified.

C.10.1.2 Backfill Objectives

Two schemes of waste storage have been proposed:

- Placement of waste in hole
- Placement of waste on the floor of a low-height tunnel, utilizing a self-shielding waste package that requires no additional radiation shielding.

Only the hole emplacement scheme has been summarized here.

The objective of backfill in the waste emplacement hole would be to provide radiation shielding while other emplacement and repository operations in the area are in progress. The backfill would not be intended to be a rigid filler.

C.10.1.3 Backfill Schedule

Backfill on top of the waste package would be placed immediately after waste emplacement. Backfilling of the tunnels would be planned shortly (6 months to 1 year) after waste package emplacement.

C.10.1.4 Expected Environmental Conditions at Backfilling and Thereafter

The following conditions would be expected during and after backfilling:

- High temperatures, on the order of 110°C in the overpack and host rock
- Creep of salt, closing boreholes and tunnels
- Groundwater/brine inflow, in quantities of tens of liters
- Radiation in room above waste package.

C.10.1.5 Reference(s)

This summary has been based on Westinghouse Electric Corporation, Advanced Energy Systems Division, "Engineered Waste Package Conceptual Design Defense High-Level Waste (Form 1), Commercial High-Level Waste (Form 1), and Spent Fuel (Form 2), Disposal in Salt," AESD-TME-3131, November 1981b.

C.10.2 BACKFILL MATERIAL AND ADDITIVE(S)

C.10.2.1 Backfill Material

Crushed salt obtained from underground excavation would be used for backfill. No gradation of crushed salt has been given.

C.10.2.2 Backfill Additive(s)

No additives have been discussed.

C.10.3 BACKFILL PROCEDURES

C.10.3.1 Preparation of Backfill Material/Additive(s)

No preparation activities have been mentioned.

C.10.3.2 Placement and Compaction (if any) of Backfill

Placement activities would depend on the choice of the waste storage scheme and the location of backfill.

Crushed salt would be placed in the bottom of the waste emplacement hole, if necessary, to level the hole bottom. After the waste package has been placed, crushed salt would be poured into the void above the package. Some salt might fall into the annulus around the waste package, but no filler in the annulus would be intended. At some point (6 months to 1 year after waste package emplacement), the room would be backfilled with crushed salt.

Compaction has not been specified.

Remote controlled equipment would be recommended for backfilling the waste emplacement hole. Shielding would be recommended during room backfilling.

C.10.4 BACKFILL CHARACTERISTICS

C.10.4.1 Anticipated Characteristics of Backfill (in place)

No backfill characteristics have been described.

C.10.4.2 Tests to Assess Characteristics of Backfill (in place)

No tests to assess the backfill have been specified.

C.11 SUMMARY OF BACKFILL SCHEME NO. 11

C.11.1 BACKFILL PERSPECTIVE

C.11.1.1 Media/Site

The repository would be in granite. No site has been specified.

C.11.1.2 Backfill Objectives

No backfill objectives have been mentioned.

C.11.1.3 Backfill Schedule

Backfilling would occur after the retrievability period (5 years). An option of 25-year retrievability has been discussed. Backfill for this alternative has been considered only at decommissioning.

C.11.1.4 Expected Environmental Conditions at Backfilling and Thereafter

Minimal flow into the repository and increased rock temperatures and stresses would be expected during and after backfilling.

C.11.1.5 Reference(s)

This summary has been based on Parsons, Brinckerhoff, Quade and Douglas, Inc., "Technical Support for GEIS: Radioactive Waste Isolation in Geologic Formations, V. 10--Repository Preconceptual Design Studies: Granite," Y/OWI/TM-36/10, Office of Nuclear Waste Isolation, Oak Ridge, TN, April 1978b.

C.11.2 BACKFILL MATERIAL AND ADDITIVE(S)

C.11.2.1 Backfill Material

Excavated, crushed granite would be placed in the room. A steel pipe sleeve would be used in the waste emplacement hole with no backfill.

C.11.2.2 Backfill Additive(s)

No additives have been discussed.

C.11.3 BACKFILL PROCEDURES

C.11.3.1 Preparation of Backfill Material/Additive(s)

Preparation of backfill material would involve crushing of granite underground. Equipment used would include a crusher, rail cars, trucks, conveyor belts, and storage bins.

C.11.3.2 Placement and Compaction (if any) of Backfill

One corridor would be designed solely for backfill operations to avoid conflicts with other operations. Backfill would be trucked to this backfill corridor servicing the rooms and then transported to the rooms. A front-end loader would place material to within five feet of the ceiling. Equipment used would include trucks, front-end loaders and undetermined equipment to transport material through the backfill corridor to rooms. Compaction of backfill has not been mentioned.

C.11.4 BACKFILL CHARACTERISTICS

C.11.4.1 Anticipated Characteristics of Backfill (in place)

No backfill characteristics have been described.

C.11.4.2 Tests to Assess Characteristics of Backfill (in place)

No tests to assess the backfill have been mentioned.

REFERENCES FOR APPENDIX C

Basalt Waste Isolation Project Staff, "Nuclear Waste Repository in Basalt, Project B-301, Preconceptual Design Report," RHO-BWI-CD-35, Rockwell Hanford Operations, Richland, WA, February 1980. Available from RHO.

Bechtel National, Inc., "National Waste Terminal Storage (NWTS), Conceptual Reference Repository Description (CRRD) (Draft)," Vols. I, II, III, IV, ONWI/Sub-79/E512-01600.16, September 1979. Available from ONWI.

Kaiser Engineers, "Conceptual Design Description Report for a National Waste Terminal Storage Repository in a Bedded Salt Formation for Spent Unreprocessed Fuel," 78-58-R, KE, Oakland, CA, December 1978a. Available from ONWI.

Kaiser Engineers, "Conceptual Design Report for a National Waste Terminal Storage Repository in a Bedded Salt Formation for Spent Unreprocessed Fuel," Vol. 1, 78-57-RE, KE, Oakland, CA, December 1978b. Available from ONWI.

Kaiser Engineers/Parsons, Brinckerhoff, Quade and Douglas, Inc., "Nuclear Waste Repository in Basalt, Project B-301, Functional Design Criteria," RHO-BWI-CD-38 Rev. 3, Rockwell Hanford Operations, Richland, WA, November 1980. Available from RHO.

Kaiser Engineers/Parsons, Brinckerhoff, Quade and Douglas, Inc., "Nuclear Waste Repository in Basalt, Project B-301, Conceptual System Design Description," Draft, Vol. 1, RHO-BWI-C-116, Rockwell Hanford Operations, Richland, WA, March 1982. Available from RHO.

Parsons, Brinckerhoff, Quade and Douglas, Inc., "Technical Support for GEIS: Radioactive Waste Isolation in Geologic Formations, V. 8--Repository Preconceptual Design Studies: Salt," Y/OWI/TM-36/8, Office of Waste Isolation, Oak Ridge, TN, April 1978a. Available for purchase from NTIS.

Parsons, Brinckerhoff, Quade and Douglas, Inc., "Technical Support for GEIS: Radioactive Waste Isolation in Geologic Formations, V. 10--Repository Preconceptual Design Studies: Granite," Y/OWI/TM-36/10, Office of Nuclear Waste Isolation, Oak Ridge, TN, April 1978b. Available for purchase from NTIS.

Parsons, Brinckerhoff, Quade and Douglas, Inc., "Technical Support for GEIS: Radioactive Waste Isolation in Geologic Formations, v. 14--Repository Preconceptual Design Studies: Basalt," Y/OWI/TM-36/14, Office of Nuclear Waste Isolation, Oak Ridge, TN, April 1978c. Available for purchase from NTIS.

Science Applications, Inc., "Performance of Engineered Barriers in a Geologic Repository, Task 2 Progress Report," draft report for Golder Associates, SAI, La Jolla, CA, December 1981. Available in NRC PDR for inspection and copying for a fee.

Stearns-Roger Engineering Co., "National Waste Terminal Storage Repository No. 1, Special Study No. 2: Waste Retrieval from Backfilled Regions," S-R, Denver, CO, 1978. Available from ONWI.

Stearns-Roger Engineering Co., "National Waste Terminal Storage Repository No. 1, Vol. 1, Conceptual Design Report," ONWI-0127, U.S. Department of Energy, Oak Ridge, TN, January 1979a. Available from ONWI.

Stearns-Roger Engineering Co., "National Waste Terminal Storage Repository No. 1, Conceptual Design Descriptions," ONWI-0129, U.S. Department of Energy, Oak Ridge, TN, January 1979b. Available from ONWI.

Westinghouse Electric Corporation, Advanced Energy Systems Division, "Engineered Waste Package Conceptual Design Defense High Level Waste (Form 1), Commercial High Level Waste (Form 1), and Spent Fuel (Form 2), Disposal in Basalt," AESD-TME-3113, September 1981a. Available from ONWI.

Westinghouse Electric Corporation, Advanced Energy Systems Division, "Engineered Waste Package Conceptual Design Defense High-Level Waste (Form 1), Commercial High-Level Waste (Form 1), and Spent Fuel (Form 2), Disposal in Salt," AESD-TME-3131, November 1981b. Available from ONWI.

Woodward-Clyde Consultants, "NWTS Repository No. 1, Supporting Studies for Conceptual Design of Underground Facilities," Vols. 1 and 4, March 1978. Available from ONWI.

APPENDIX D
COMPILATION OF SELECTED BACKFILL PROPERTIES

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APPENDIX D - COMPILATION OF SELECTED BACKFILL PROPERTIES

The selection of backfill materials to satisfy certain backfill objectives requires a knowledge of the expected backfill properties. Depending on the backfill materials and their utilization, a large amount of data concerning backfill properties presently exists, some of which has been compiled herein. However, the existing data is generally for conditions that are vastly different than at the repository level. At this time, there is little data on backfill properties at conditions that simulate those in a repository. Therefore, the compiled data can only be used as an indication of what would reasonably be expected for properties of backfill materials.

This compilation represents the data easily obtained and representative of a material type. The compilation is not an all-encompassing set of data nor has such a set been considered necessary. It is obvious from the data that the values of a parameter are dependent and usually sensitive to a number of variables; therefore, preparation of an all-encompassing set of data would be inefficient for determining backfill properties unless the set includes data for repository conditions.

This compilation of selected backfill properties is useful as a guide to possible property values and, more importantly, as a comparison between backfill materials. For example, the compilation would be useful in determining the relative difference in hydraulic conductivity between two backfill material types.

This compilation has been prepared for those materials and, in some cases, associated placement procedures which have been considered for backfill in this study (see Section 5 - Main Text).

- Mechanically-placed muck or rockfill (see Table D.1)
- Hydraulically-placed fine sand or silt (see Table D.2)
- Pneumatically-placed sand/gravel backfill (see Table D.3)
- Hydraulically-placed fine sand or silt with cement and additives (see Table D.4)
- Clay (see Table D.5)
- Excavated rock (sand or gravel) and clay mixtures (see Table D.6)
- Concrete (see Table D.7)
- Zeolite/Clinoptilolite (see Table D.8)

For each backfill type, representative data have been compiled, where available and appropriate, on pertinent properties, including:

- Strength characteristics
- Deformation characteristics
- Hydraulic conductivity
- Void ratio (or porosity) and Density (including relative density)
- Thermal conductivity.

It is evident from this compilation that many variables affect parameter values. These variables, which are reasonably apparent from the data, include:

- Type and gradation of material and/or particle shape
- Type and percentage of additive
- Time
- Test conditions (type of test, rate of loading, magnitude of loads, hydraulic head, temperature, hydraulic or thermal gradients, strain rate, confining conditions, modeling assumptions, scale effects, level of stress or strain, stress history)
- Material conditions (degree of saturation, moisture content, dry density, particle angularity, material structure, pore water chemistry, photo-chemical characteristics)
- Preparation activities (type of compaction, degree of compaction, mixing and curing procedure, placement method).

The adsorption/retardation characteristics of backfill types will clearly be an important property to be considered for design. However, there is little data currently available on the adsorption/retardation characteristics of various backfill types, and there is large uncertainty in this existing data due to the large differences between the measurement conditions and those conditions which will exist at the repository level, as well as problems in measurement. Hence, data on these characteristics have not been included in the compilation (Tables D.1 through D.8). Solely for the purposes of comparative studies, the distribution coefficient (Kd) of various backfill types, for specific radionuclides, have been estimated (based on available information and experience) under the complementary NRC contract (NRC-02-81-027) entitled "Performance of Engineered Barriers in a Geologic Repository," and summarized (see Table D.9). There is significant uncertainty in these estimates.

Although the compilation of selected backfill properties presented in this Appendix D is sufficient for the purposes of this study, i.e., comparative evaluations, this would not typically be sufficient for definitive performance assessment. More and better information would be needed, especially regarding values of properties at the expected repository conditions, in order to estimate backfill property values with reasonable levels of confidence.

COMPILATION OF DATA ON SELECTED PROPERTIES OF MECHANICALLY PLACED MUCK/ROCKFILL

Table D.1
1 of 2

PARAMETER	MATERIAL OR OTHER METHODS UTILIZED	RANGE OF VALUES	REFERENCES	APPLICATION IN REFERENCE	COMMENTS
STRENGTH CHARACTERISTICS					
Compressive Strength (after consolidation at 15 to 25% volumetric strain)	Avery Island - crushed salt	350 to 850 psi	Stearns-Roger, 1978	Backfill in repositories	Values given in text and summarized in plot.
Shear Strength	65 values of Ø for 34 soils with maximum particle size ranging from medium sand to cobbles (up to 8")	cohesion = 0 ave. max. Ø = 44°, δ=4.88° (low normal stresses)	Marsal, 1973 Leps, 1970	Rockfill for dams, embankments	Values typically depend on gradation, type of material, type of test and strain rate, density, confining stress, particle shape. Test data given in tabular form.
	14 values for 14 soils with maximum particle size ranging from medium sand to cobbles	ave. min. Ø = 33.9°, $\bar{\delta}$=3.35° (high normal stresses of 15-25 kg/cm^2)	Marsal, 1973	Rockfill for dams, embankments	Test data given in tabular form.
DEFORMATION CHARACTERISTICS					
Volumetric Strain (during consolidation)	Avery Island - crushed salt	up to 25% strain	Stearns-Roger, 1978	Backfill in repositories	Values depend on applied stresses and applied temperatures (70 to 125°F). Values given in text.
Average Deformation Modulus (unconfined compression)	Avery Island - crushed salt	200,000 psi after consolidation	Stearns-Roger, 1978	Backfill in repositories	Value given in text.
One-dimensional Modulus of Deformation	One-dimensional compression of 3 soils (sands and gravels)	280 to 830 kg/cm^2 (3970 to 11780 psi)	Marsal, 1973	Rockfill for dams, embankments	Values typically depend on void ratio (density), gradation, type of material, stress history. Values reported here are for a loading sequence (as opposed to unloading) and were derived from test data given in the reference.

Table D.1
2 of 2

COMPILATION OF DATA ON SELECTED PROPERTIES OF MECHANICALLY PLACED MUCK/ROCKFILL

PARAMETER	MATERIAL OR OTHER METHODS UTILIZED	RANGE OF VALUES	REFERENCES	APPLICATION IN REFERENCE	COMMENTS
HYDRAULIC CONDUCTIVITY					
Hydraulic Conductivity	Gravel to clean sand	10^2 to 10^{-4} cm/sec	Freeze and Cherry, 1979	-	Average values for gradation range of gravel to clean sand.
	Gravel to clean sand	10^2 to 10^{-3} cm/sec	Terzaghi and Peck, 1967	-	
	Run of mine rock	400 cm/sec	SAI, 1982	Backfill in repository	
VOID RATIO/DENSITY					
Void Ratio	Cobbles, gravel and sand, with little or no fine-grained material	.28 to 1.07	Marsal, 1973 Leps, 1970	Rockfill for dams, embankments	Values typically depend on placement/compaction methods. Test data summarized in tables.
Dry Density	Gravel and sand (no gradations as to amount of fine-grained material)	95 to 150 lb/ft^3	Leps, 1970	Rockfill for dams, embankments	Values typically depend on placement/compaction methods. Test data summarized in tables.
THERMAL CONDUCTIVITY					
Coefficient of Thermal Conductivity	Run of mine rock	1.4 $\frac{\text{Joules}}{\text{m-sec-}^{\circ}\text{C}}$	SAI, 1982	Backfill in repository	

Note: This is a compilation of readily available data and is not intended to be comprehensive, only representative. Due to this and due to possible significant differences between measurement conditions and conditions expected in the repository, the data compiled here should be used only as an indication of what can reasonably be expected for properties of backfill; this will be sufficient for the purposes of this study, i.e., comparative evaluations, but would not be sufficient for definitive performance assessment.

COMPILATION OF DATA ON SELECTED PROPERTIES OF HYDRAULICALLY PLACED FINE SAND/SILT

Table D.2
1 of 2

PARAMETER	MATERIAL OR OTHER METHODS UTILIZED	RANGE OF VALUES	REFERENCES	APPLICATION IN REFERENCE	COMMENTS
STRENGTH CHARACTERISTICS Strength - Angle of Internal Friction	Glacial sand and gravel and uncemented hydraulic tailings	Ø = 35° (only one value reported)	Ford, 1978	Tailings for use as underground backfill	No raw data given.
DEFORMATION CHARACTERISTICS					
Tangent Modulus of Deformation	Fine sand to silty fine sand; one-dimensional compression	2000 to 100,000 psi	Nicholson and Busch, 1968	Waste ore tailings for use as underground backfill	Values depend on material gradation and type and level of strain. Test data given.
Young's Modulus	- low to medium quality hydraulic fill - medium to high quality fill w/chemical additives and/or compaction	10,000 psi 60,000 psi	Hill, McDonald, McNay, 1974	Waste ore tailings for use as underground backfill	Values were derived from field and laboratory research. No test data given.
Modulus of Elasticity	Penetration test on sand fill	600 to 2800 psi	Stout and Friel, 1980	Backfill for underground mines	Methods of placement included conventional, or backfill introduced at bottom of lift; vibratory compaction performed on some samples. Values typically depend on level of strain, as well as above factors.
	Penetration tests on double-placed coarse rock and fine slurry	800 to 3400 psi	Stout and Friel, 1980	Backfill for underground mines	Method of placement was double-placing, i.e., placing coarse material first and then placing fine material or cement to fill the voids; some samples had vibratory compaction. Values also typically depend on level of strain.
	Cylinder tests on conventional fill; backfill placed at bottom of lift; and waste rock.	1700 to 8000 psi	Stout and Friel, 1980	Backfill for underground mines	Values typically depend on method of placement, level of strain, test method. All values quoted by Stout and Friel were summarized in tables.

COMPILATION OF DATA ON SELECTED PROPERTIES OF HYDRAULICALLY PLACED FINE SAND/SILT

Table D.2
2 of 2

PARAMETER	MATERIAL OR OTHER METHODS UTILIZED	RANGE OF VALUES	REFERENCES	APPLICATION IN REFERENCE	COMMENTS
HYDRAULIC CONDUCTIVITY					
Hydraulic Conductivity	Fine sand to silt	10^{-1} to 10^{-5} cm/sec	Freeze and Cherry, 1979	—	Values are for fine sands to silts with no specific gradation.
	Fine sand to silt	10^{-3} to 10^{-7} cm/sec	Terzhagi and Peck, 1967	—	
	Glacial sand and gravel	2.4×10^{-3} ft/min (1.2×10^{-3} cm/sec)	Ford, 1978	Backfill for underground mines	Values summarized in table.
	Uncemented hydraulic tailings	5×10^{-3} ft/min (2.54×10^{-3} cm/sec	Ford, 1978	Backfill for underground mines	
	Average of 3 conventional tests of uncemented hydraulic fill	4.2×10^{-3} cm/sec	Corson, 1970	Backfill for underground mines	Plot of test results given.
VOID RATIO/DENSITY					
Density Maximum Minimum	Classified mill tailings (silty fine sand); laboratory tests	117 pcf 87 pcf	Corson, 1971	Backfill for underground mines	Values typically depend on lift thickness, water content, amount of standing water.
Relative Density, achieved using vibratory compaction (dry density)	Field density on above material	44 to 92% (ave.=64%) (98 to 114 pcf, ave.=104 pcf)	Corson, 1971	Backfill for underground mines	
Relative Density, placed "normally" - assume no compaction		51%	Corson, 1971	Backfill for underground mines	
Void Ratio (Density) (Relative Density)	Laboratory tests on selected hydraulic fills (sand)	0.37 to 1.0 (127.9 to 87.3 pcf) (139% to 1.5%)	Stout and Friel, 1980	Backfill in underground mines	Values typically depend on placement method or compaction (vibratory, if used). Placement included at bottom of lift and double-placed backfill. Values summarized in table.

Note: This is a compilation of readily available data and is not intended to be comprehensive, only representative. Due to this and due to possible significant differences between measurement conditions and conditions expected in the repository, the data compiled here should be used only as an indication of what can reasonably be expected for properties of backfill; this will be sufficient for the purposes of this study, i.e., comparative evaluations, but would not be sufficient for definitive performance assessment.

Table D.3

COMPILATION OF DATA ON SELECTED PROPERTIES OF PNEUMATICALLY PLACED SAND/GRAVEL BACKFILL

PARAMETER	MATERIAL OR OTHER METHODS UTILIZED	RANGE OF VALUES	REFERENCES	APPLICATION IN REFERENCE	COMMENTS
<u>VOID RATIO/DENSITY</u>					
Density (Relative Density, D_r)	Pneumatic stowing in underground opening using various mixtures of sand and gravel (25 to 64% sand, 75 to 36% gravel)	% gravel | γ_d (pcf) 36 | 123 50 | 95-124 66.7 | 101-139 75 | 99-115	Soderberg and Corson, 1976	Backfill for ground support in underground mines	Used in place density tests.
	Pneumatic stowing into fabricated bin using various mixtures of sand, gravel, quartzite and coal shale	-minus 1½" quartzite Dr = 4 to 80%, γ_d = 109 to 120.7 pcf -minus 3/4" quartzite Dr = 4 to 72%, γ_d = 112.9 to 120.5 pcf -equal amounts of fine sand, medium sand to fine gravel, and coarse gravel γ_d = 103.8 to 129.6 pcf -coal shale γ_d = 60.4 to 75.8			
Density	3-inch minus crushed waste rock	Approximately 100 pcf	Reynolds, 1972	Backfill in underground mines for support of hanging wall	No data given.
In-place Density	3-inch minus crushed rock	140 pcf	Ball, 1970	Backfill in underground mines for roof support	No data given.

Note: This is a compilation of readily available data and is not intended to be comprehensive, only representative. Due to this and due to possible significant differences between measurement conditions and conditions expected in the repository, the data compiled here should be used only as an indication of what can reasonably be expected for properties of backfill; this will be sufficient for the purposes of this study, i.e., comparative evaluations, but would <u>not</u> be sufficient for definitive performance assessment.

COMPILATION OF DATA ON SELECTED PROPERTIES OF HYDRAULICALLY PLACED FINE SAND/SILT WITH CEMENT AND ADDITIVES

Table D.4
1 of 6

PARAMETER	MATERIAL OR OTHER METHODS UTILIZED	RANGE OF VALUES		REFERENCES	APPLICATION IN REFERENCE	COMMENTS
STRENGTH CHARACTERISTICS						
Unconfined Compressive Strength	Zinc final tailings	15 to 30 psi @ 1:30 C/T 30 to 60 psi @ 1:20 C/T 50 to 90 psi @ 1:15 C/T		Ford, 1978	Underground mine backfill for pillar recovery	Placement utilized 3" dia. borehole and 3" dia. plastic or steel pipelines. Test data given in plots.
	Classified mill tailings, mostly fine sand and 20 to 30.5% silt-sized particles	Strength	Cement/Fly Ash	Askew, McCarthy, Fitzgerald, 1978	Underground mine backfill for pillar recovery	Backfill utilized 1% solution of "Alfloc 6701 polymavic flocculant". Test results summarized in plots.
		.25 to .5 MPa (36 to 72 psi)	5% cement (28 to 224 day curing time)			
		5 to 8 MPa (725 to 1160 psi)	20% cement (28 to 224 day curing time)			
		1.1 to 1.4 MPa (160 to 203 psi)	40% to 20% fly ash respectively with 9.1% cement @ 50 days curing time			
		1.6 to 1.9 MPa (232 to 275 psi)	40% to 20% fly ash respectively with 9.1% cement @ 100 days curing time			
		1.35 to 1.5 MPa (196 to 218 psi)	Values for 9.1% cement and 50 day curing time			
		1.75 to 1.85 MPa (254 to 268 psi)	As above, but @ 100 days curing time			

COMPILATION OF DATA ON SELECTED PROPERTIES OF HYDRAULICALLY PLACED FINE SAND/SILT WITH CEMENT AND ADDITIVES

Table D.4
2 of 6

PARAMETER	MATERIAL OR OTHER METHODS UTILIZED	RANGE OF VALUES	REFERENCES	APPLICATION IN REFERENCE	COMMENTS
Unconfined Compressive Strength	Tailings (silty fine sand), plus 2.2% cement	10 to 90 kPa (1.4 to 13 psi) for 4 to 25 hr. curing time	Mitchell, Olsen, Smith, 1982	Underground mine backfill - concerned with vertical fill faces	Test data given in figure.
	Fine to medium sand, plus 2.2% cement	10 to 50 kPa (1.4 to 7.2 psi)	Mitchell, Olsen, Smith, 1982	As above	
	Tailings (silty fine sand), with 1:30 C/S	75 to 150 kN/m^2 (11 to 22 psi) for less than 20 to 150 days curing time	Mitchell, Smith, Libby, 1975	Backfilling to prevent mine subsidence and facilitate pillar recovery	Average values of tests plotted in figure.
Unconfined Compressive Strength (@ 28 days curing time)	Classified mill sand (silty fine sand), with flocculant additive	1:7 C/S with Ferric Sulfate (FS) 0% FS : 384 to 445 psi 0.5% FS : 521 to 536 psi 1.0% FS : 262 to 267 psi 1:15 C/S with Ferric Sulfate (FS) 0% FS : 131 to 150 psi 0.5% FS : 144 to 176 psi 1.0% FS : 138 to 140 psi 1:30 C/S with Ferric Sulfate (FS) 0% FS : 49 to 61 psi 0.5% FS : 144 to 176 psi 1.0% FS : 138 to 140 psi 1:7 C/S with Polyacrylamide (P) 0.5% P : 404 to 446 psi 1.0% P : 428 to 453 psi 1:15 C/S with Polyacrylamide (P) 0.5% P : 144 to 176 psi 1.0% P : 310 to 330 psi	McNay and Hill, 1976	Backfill for undercut and fill mining operation	Test data given in figures and tables.

COMPILATION OF DATA ON SELECTED PROPERTIES OF HYDRAULICALLY PLACED FINE SAND/SILT WITH CEMENT AND ADDITIVES

Table D.4
3 of 6

PARAMETER	MATERIAL OR OTHER METHODS UTILIZED	RANGE OF VALUES	REFERENCES	APPLICATION IN REFERENCE	COMMENTS
Unconfined Compressive Strength (@ 28 days curing time)	Classified mill sand (silty fine sand), with flocculant additive	1:30 C/S with Polyacrylamide (P) 0.5% P: 105 to 122 psi 1.0% P: 189 to 210 psi	McNay and Hill, 1976	Backfill for undercut and fill mining operation	Test data given in figures and tables.
Unconfined Compressive Strength (@ 7 days curing time)	Fill materials from 8 mines, with gradation of silty fine sand to fine sandy silt	1:40 C/S : 16 to 41 psi 1:20 C/S : 42 to 99 psi 1:5 C/S : 251 to 711 psi	Corson, 1970	Backfill to facilitate mining below or adjacent to filled areas to enable underhand stoping methods, to provide abrasion-resistant scraping floors, and to increase the load-carrying capability of the fill.	Test data given in tables.
Shear Strength	Classified mill tailings, fine sand with 20% silt-sized particles	@ 5% cement: C = .7 to 1.3 MPa (100 to 190 psi) Ø = 36° to 40° @ 16% cement: C = 7.6 to 9.5 MPa (1100 to 1400 psi) Ø = 35° to 47°	Askew, McCarthy, Fitzgerald, 1978	Underground mine backfill for pillar recovery	Values are for 28 to 224 day curing times. (Higher values at longer curing times.) Test results summarized in plots.
Shear Strength (@ 28 days curing time)	Tailings, approx. 60% fine sand, remainder silt-sized, various amounts of slag, 6% cement	C = 50 kPa, Ø = 35° @ 0% slag C = 242kPa, Ø = 37° @ 6% slag C = 346kPa, Ø = 30° @ 12% slag C = 730kPa, Ø = 21° @ 18% slag	McGuire, 1978	Underground mine backfill	Test data given in tables and plots.
Shear Strength	Tailings (silty fine sand), plus 2.2% cement @ 2 hrs. curing time	1.5 to 2.5 kPa for normal stresses of 2 to 10 kPa	Mitchell, Olsen, Smith, 1982	Underground mine backfill - concerned with vertical fill faces	Test data given in plots.
	(Medium to fine) sand, plus 2.2% cement @ 3 hrs. curing time	3.0 to 4.0 kPa for normal stresses of 2 to 10 kPa			

COMPILATION OF DATA ON SELECTED PROPERTIES OF HYDRAULICALLY PLACED FINE SAND/SILT WITH CEMENT AND ADDITIVES

Table D.4
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PARAMETER	MATERIAL OR OTHER METHODS UTILIZED	RANGE OF VALUES	REFERENCES	APPLICATION IN REFERENCE	COMMENTS
Shear Strength	Fill materials from 8 mines, with gradations of silty fine sand to fine sandy silt and various percentages of cement and fly ash (coarse or fine) added	@ 1:40 C/S: Ø = 32 to 37° C = 9 to 16 psi @ 1:20 C/S: Ø = 30 to 45° C = 7 to 50 psi @ 1:5 C/S: Ø = 26 to 52° C = 69 to 148 psi @ 1:2:60 C/FA/S: Ø = 34 to 40° C = 8 to 28 psi @ 2:1:60 C/FA/S: Ø = 30 to 32° C = 33 to 42 psi	Corson, 1970	Underground mine backfill - concerned with vertical fill faces	Range of average test values given in tables.
	Zinc final tailings	@ 1:30 C/T: C = 1728 to 2938 psf Ø = 24.6 to 34.5°	Ford, 1978	Underground mine backfill for pillar recovery	According to reference, higher parameter values represent total stress condition while lower numbers respresent in-situ consolidated backfill. Values summarized in table; no test data given.
	Hydraulic fill, with: 3% cement, 6% slag	C = .22 MPa, Ø = 35°	Barrett, Coulthard, Dight, 1978	Underground mine back fill for pillar recovery	Typical fill properties only; no gradation of fill given; no test data given. Drained strength parameters.
	6.25% cement	C = .17 MPa, Ø = 36°			
	4.8% cement	C = .14 MPa, Ø = 26°			
	Rockfill, with hydraulic fill plus 3% cement and 6% slag	C = .60 MPa, Ø - 35-40°			

COMPILATION OF DATA ON SELECTED PROPERTIES OF HYDRAULICALLY PLACED FINE SAND/SILT WITH CEMENT AND ADDITIVES

Table D.4
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PARAMETER	MATERIAL OR OTHER METHODS UTILIZED	RANGE OF VALUES		REFERENCES	APPLICATION IN REFERENCE	COMMENTS
Shear Strength	Hydraulic fill with: 1:30 C/T	C = 15 psi,	ø = 30°	Cundall, Shillabeer, Herget, 1978	Underground mine backfill for pillar recovery	Values summarized in table; no test data given.
	1:8 C/T	C = 68 psi,	ø = 36°			
	Cemented rockfill	C = 135 psi,	ø = 40°			
Compressive Strength (at 0.10 MPa (14.5 psi) confining pressure and 28 days curing time)	Deslimed copper sulphide tailings, approx. 55% fine sand and 45% silt	Strength	Cement/Slag	Thomas and Cowling, 1978	Underground mine backfill	Test data given in figures and table.
		.41 to .32 MPa (59 to 46 psi)	1% cement and 0 to 10% slag, respectively			
		.50 to .77 MPa (73 to 112 psi)	2% cement and 0 to 10% slag, respectively			
		.59 to 1.16 MPa (86 to 168 psi)	3% cement and 0 to 15% slag, respectively			
		.63 to 1.73 MPa (91 to 251 psi)	4% cement and 0 to 16% slag, respectively			
		.76 MPa (110 psi)	5% cement and 0% slag			
Uniaxial Compressive Strength (@ 28 days curing time)	Tailings, approx. 60% fine sand, remainder silt-sized, 6% cement, various amounts of slag	480 kPa (70 psi)	@ 0% slag	McGuire, 1978	Underground mine backfill	Test data given in figures and tables.
		970 kPa (140 psi)	@ 6% slag			
		1201 kPa (174 psi)	@12% slag			
		2122 kPa (308 psi)	@18% slag			

COMPILATION OF DATA ON SELECTED PROPERTIES OF HYDRAULICALLY PLACED FINE SAND/SILT WITH CEMENT AND ADDITIVES

Table D.4
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PARAMETER	MATERIAL OR OTHER METHODS UTILIZED	RANGE OF VALUES	REFERENCES	APPLICATION IN REFERENCE	COMMENTS
DEFORMATION CHARACTERISTICS					
Modulus of Deformation	Cemented hydraulic fill and rockfill	8700 psi (@ 4.8% cement) - 41300 psi (@ 3% cement, 6% slag)	Barrett, Coulthard, Dight, 1978	Backfill in underground mines	Typical fill properties; no test data given.
	Cemented hydraulic fill and rockfill	6000 psi (@ 1:30 C/T) - 300000 psi (for cemented rock fill)	Cundall, Shillabeer, Herget, 1978	Backfill in underground mines	Values summarized in table; no test data given.
	Cemented sandfill, some double-placed fill, some vibration performed	Penetration Tests 1:20 C/S: 1600 - 12800 psi 1:10 C/S: 4000 - 45600 psi Cylinder Compression Tests 1:20 C/S: 5200 - 12000 psi	Stout and Friel, 1980	Backfill in underground mines	Test data summarized in table.
HYDRAULIC CONDUCTIVITY					
Hydraulic Conductivity	Silty fine sand tailings; 1:30 C/T	1.5×10^{-3} cm/sec (lab.@ 20 days) 7×10^{-4} cm/sec (lab.@ 80-150 days) $(2 \text{ to } 6.4)\times10^{-4}$ cm/sec (field)	Mitchell, Smith, Libby, 1975	Backfill in underground mines	Values given in figure and stated in text.
	Silty fine sand, with various cement contents	@ 1:20 C/S: 3.5×10^{-4} to 3.5×10^{-5} cm/sc @ 1:5 C/S: 1×10^{-5} to 2×10^{-6} cm/sec	Corson, 1970	Backfill in underground mines	Test data given in figures.
VOID RATIO/DENSITY					
Density	Fine sand to silty fine sand tailing; 1:40 to 1:5 C/T; 60:2:1 and 60:1:2 tailings to cement to fly ash ratio	103 to 127 pcf	Corson, 1970	Backfill in underground mines	Range of average test values given in table.
	Silty fine sand tailings and fine to medium sand, with 2.2% cement	115 to 127 pcf (total density)	Mitchell, Olsen, Smith, 1982	Backfill in underground mines	Range of values from model stope tests; test data summarized in table.
	Cemented tailing and rockfill	145 pcf (@ 1:30 & 1:8 C/T) 155 pcf (cemented rockfill)	Cundall, Shillabeer, Herget, 1978	Backfill in underground mines	Values summarized in table; no test data given.
Porosity	Silty fine sand tailings, 1:30 C/T	0.48 (average value)	Mitchell, Smith, Libby, 1975	Backfill in underground mines	Average value given in text; no test data given.
	Sand tailings, 1:30 C/T	0.72 to .84	Ford, 1978	Backfill in underground mines	Values summarized in table; no test data given. Lower porosity is for backfill plant product; higher value represents in-situ backfill.

Note: This is a compilation of readily available data and is not intended to be comprehensive, only representative. Due to this and due to possible significant differences between measurement conditions and conditions expected in the repository, the data compiled here should be used only as an indication of what can reasonably be expected for properties of backfill; this will be sufficient for the purposes of this study, i.e., comparative evaluations, but would not be sufficient for definitive performance assessment.

COMPILATION OF DATA ON SELECTED PROPERTIES OF CLAY

Table D.5
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PARAMETER	MATERIAL OR OTHER METHODS UTILIZED	RANGE OF VALUES	REFERENCES	APPLICATION IN REFERENCE	COMMENTS
STRENGTH CHARACTERISTICS					
Drained Shear Strength (saturated clays)	Kaolinite Illite Montmorillonite	$\bar{c} = 0$, $\bar{\phi} = 25$ to 31° $\bar{c} = 0$, $\bar{\phi} = 16$ to 26° $\bar{c} = 0$, $\bar{\phi} = 6$ to 16°	Olson, 1974	Research of soil properties	Laboratory tests on prepared samples of saturated clays. Values derived from plots of $\frac{1}{2}(\sigma_1 - \sigma_3)$ vs. $\frac{1}{2}(\sigma_1 + \sigma_3)$.
Undrained Shear Strength	Laboratory vane shear tests on: Bentonite (water content = 56%) Kaolinite (water content = 36%) Kaolinite (water content = 47%)	2 to 3 psi .8 to 2.6 psi .6 to 0.9 psi	Mitchell, 1976	Presentation of property of soils	Test values are summarized in plot.
Shear Strength (assume undrained)	Water saturated Sodium Bentonite	<2psi to 230 psi	Westinghouse, 1981	Backfill in repository	Values given depend on bulk density which varied from 1.05 to 2.2 ton/m^3. Values summaried in table; no test data given.
Compressive Strength	Kaolinite; unconfined compression	9 to 50 psi	Mitchell, 1976 (after Sherif and Burrous, 1969)	Presentation of property of soils	Average test values given in plot.
	Normally consolidated Illite	11 to 43 psi	Mitchell, 1976	Presentation of property of soils	Test values given in plot.
	Compacted Kaolinite (partially saturated)	14 to 71 psi	Seed and Chan, 1959	Research of soil properties	Test data given.
	Kaolinite; consolidated-undrained test	26 to 27 psi	Seed and Chan, 1959	Research of soil properties	Test data given.
	Moist (w.c. = 17%) to air-dried (w.c. = 7%) Sodium Montmorillonite	55 to 195 psi	Pacific Northwest Laboratory, [illegible] (after Mielenz & King, 1955)	—	Values summarized in table, no test data given.
	Moist (w.c. = 14%) to air-dried (w.c. = 0.4%) Kaolinite	100 to 66 psi			

COMPILATION OF DATA ON SELECTED PROPERTIES OF CLAY

Table D.5
2 of 4

PARAMETER	MATERIAL OR OTHER METHODS UTILIZED	RANGE OF VALUES	REFERENCES	APPLICATION IN REFERENCE	COMMENTS
DEFORMATION CHARACTERISTICS					
One-Dimensional Strain (per logarithmic cycle of normal stress)	Sodium Kaolinite Calcium Kaolinite Calcium Illite Sodium Illite Calcium Smectite Sodium Smectite	.09 to .45 .11 to .45 .22 to .68 .25 to .48 .23 to .51 .53 to .83	Olson and Mesri, 1970	Research of soil properties	Values given are for laboratory prepared saturated, normally consolidated clays. Test results given on figure; values were derived from data shown.
Initial Tangent Modulus (from triaxial compression tests for confining stresses 100 to 1000 psi, undrained tests)	Lean clay from Clinton Dam Silty clay (CL) from Canyon Dam Fat clay (CH) from Monroe Dam Lean clay (CL) from Monroe Dam	1700 to 23000 psi 1100 to 91000 psi 300 to 1700 psi 150 to 970 psi	Wong and Duncan, 1974	Material from embankment dams	Values derived from reported hyperbolic stress-strain parameters.
	Remolded Grundite clay; cubical triaxial test	21600 to 113500 psi	Lade, 1979	Stress-strain theory for clay	Values derived from reported hyperbolic stress-strain parameters.
Normalized Stress-strain Tangent Modulus (undrained conditions):					
A. E/Su where Su = undrained shear strength from unconfined compression tests or vane shear tests	Normally consolidated Norwegian clays	250 to 500	Ladd (1964)(after Bjerrum, 1964)	Research of soil properties	Values given in text; no test data given.
B. $E/\bar{\sigma}_c$, where	Remolded Boston Blue clay: ● Normally consolidated ● Over-consolidated	 approx. 240 to 75 approx. 580 to 100	Ladd (1964)	Research of soil properties	Test results given in figure.
	Remolded Vicksburg Buckshot clay: ● Normally consolidated ● Over-consolidated	 approx. 170 to 50 approx. 850 to 125			Test results given in figure.
C. E/Cu, where Cu = max. applied horizontal shear stress in simple shear tests	Six normally consolidated, naturally occuring clays (CL, CH, CH-OH)	approx. 1500 to 55	Ladd et al (1976)	Summary of soil properties	Stress level (q/q_f)= .2 to .8. Test results given in figure.
	Five naturally occuring clays (CL, CH, CH-OH)	approx. 850 to 50			Stress level (q/q_f) = .33 to .67. Over-consolidation ratio varies from 1 to 10. Test results given in figure.

COMPILATION OF DATA ON SELECTED PROPERTIES OF CLAY

Table D.5
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PARAMETER	MATERIAL OR OTHER METHODS UTILIZED	RANGE OF VALUES	REFERENCES	APPLICATION IN REFERENCE	COMMENTS
Initial Tangent Modulus (from triaxial compression tests for confining pressures of 100 to 1000 psi, drained tests)	Silty clay (CL) from Canyon Dam	5900 to 30000 psi	Wong and Duncan, 1974	Material from embankment dams	Values derived from reported hyperbolic stress-strain parameters.
Creep (strain rate)	Remolded Illite; undrained test	1×10^{-2} %/sec to 3×10^{-7} %/sec (undrained and at various values of $\sigma_1 - \sigma_3$)	Mitchell, 1976	Presentation of properties of soils	Test results summarized in figure.
	Dry Illite	4×10^{-4} %/sec to 4×10^{-7} %/sec @ 60% stress level (q/q_f)	Singh and Mitchell, 1968	Research of soil properties	Test results summarized in figure.
	Remolded Illite (varied temperature during test)	increase in temperature from 68°F to 97°F increased strain rate from .000115 %/min. to .0032%/min.	Singh and Mitchell, 1968	Research of soil properties	Test results summarized in figure.
	Overconsolidated London clay; drained test	.0001 to 1.0%/day (10%/day @ failure)	Bishop and Lovenbury, 1969	Research of soil properties	Test results summarized in figure.
	Normally consolidated Pancone clay; drained test	.005%/day to 10%/day	Bishop and Lovenbury, 1969	Research of soil properties	Test results summarized in figure.
	Osaka clay; undrained tests	Increase of temperature from 10°C to 40°C increased strain rate from .045 to .102%/logarithmic cycle of time	Mitchell, 1976 (after Murayama, 1969)	Presentation of properties of soils	Test results given in figure; values derived from data shown.
HYDRAULIC CONDUCTIVITY					
Hydraulic Conductivity	Bentonite	2×10^{-11} to 7×10^{-13} cm/sec	Westinghouse, 1981	Backfill for repository	Values from various sources summarized in table.
	Sodium Bentonite	5.6×10^{-13} to 6.7×10^{-13} cm/sec	Pacific Northwest Laboratory, 1981	Backfill for repository	Test values summarized in table.
	Calcium Bentonite	1.3×10^{-12} to 1.6×10^{-12} cm/sec	Pacific Northwest Laboratory, 1981	Backfill for repository	Test values summarized in table.
	Taylor marl clay (CH)	4×10^{-7} to 1×10^{-9} cm/sec	Kleppe, 1981	Research of soil properties	Test data given in figures and tables.
	Elgin fire clay (CH)	2×10^{-7} to 2×10^{-8} cm/sec			

COMPILATION OF DATA ON SELECTED PROPERTIES OF CLAY

Table D.5
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PARAMETER	MATERIAL OR OTHER METHODS UTILIZED	RANGE OF VALUES	REFERENCES	APPLICATION IN REFERENCE	COMMENTS
Hydraulic Conductivity	Kaolinite	2×10^{-5} to 3×10^{-8} cm/sec	Olsen, 1966	Research of soil properties	Test data given in table.
		10^{-5} to 10^{-8} cm/sec	Mesri and Olson, 1971	Research of soil properties	Test results summarized in figure.
	Illite	10^{-5} to 10^{-10} cm/sec			
	Smectite	10^{-5} to 10^{-11} cm/sec			
<u>VOID RATIO/DENSITY</u>					
Void Ratio	Kaolinite	3 to 0.8	Mesri and Olson, 1971	Research of soil properties	Values on consolidated laboratory samples. Test results summarized in figure.
	Illite	5 to 0.75			
	Smectite	35 to 1.2			
Dry Density	Lean clay (CL) from Clinton Dam	97 to 103 pcf	Wong and Duncan, 1974	Material from embankment dams	Test results given in table.
	Silty clay (CL) from Canyon Dam	104 to 116 pcf			
	Fat clay (CH) from Monroe Dam	89 to 96 pcf			
	Lean clay (CL) from Monroe Dam	102 to 107 pcf			
	Taylor marl clay (CH)	89 to 95 pcf	Kleppe, 1981	Research of soil properties	Laboratory standard Proctor density values. Test results given in figure.
	Elgin fire clay (CH)	100 to 103 pcf			
<u>THERMAL CONDUCTIVITY</u>					
Coefficient of Thermal Conductivity	Bentonite	0.1 to 1.0 $\frac{\text{watts}}{\text{m} - {}^{\circ}\text{C}}$ or $^{\circ}$K	Westinghouse, 1981	Backfill in nuclear waste repositories	Range of values summarized in figure.
	Bentonite	0.33 $\frac{\text{watts}}{\text{m} - {}^{\circ}\text{K}}$	SAI, 1982	Backfill in nuclear waste repositories	Values summarized in table.

Note: This is a compilation of readily available data and is not intended to be comprehensive, only representative. Due to this and due to possible significant differences between measurement conditions and conditions expected in the repository, the data compiled here should be used only as an indication of what can reasonably be expected for properties of backfill; this will be sufficient for the purposes of this study, i.e., comparative evaluations, but would not be sufficient for definitive performance assessment.

COMPILATION OF DATA ON SELECTED PROPERTIES OF EXCAVATED ROCK (SAND OR GRAVEL) AND CLAY MIXTURES

Table D.6
1 of 2

PARAMETER	MATERIAL OR OTHER METHODS UTILIZED	RANGE OF VALUES	REFERENCES	APPLICATION IN REFERENCE	COMMENTS
STRENGTH CHARACTERISTICS Compressive Strength	75% sand, 25% kaolinite	Moist: 42 psi Air-Dried: 541.0 psi	Pacific Northwest Laboratory, 1981 (after Mielenz and King, 1955)	Backfill in repository	Tabulated values contained in reference.
	75% sand, 25% bentonite	85.5 psi 533.5 psi			
	50% sand, 25% kaolinite, 25% bentonite	9.1 psi 76.5 psi			
Undrained Shear Strength	Pittsburgh sandy clay (33% sand, 66% silt and clay)	C (psi): 12.8 to 45.8 ø (degrees): 6 to 32	Wong and Duncan, 1974	Materials used in embankment dams	Values from triaxial compression test series. Test data given.
	Sommerville Dam sandy clay (24 to 38% sand, 62 to 76% silt and clay)	6.2 to 20.8 1 to 28			
	Proctor Dam clayey gravelly sand	C = 1.8 TSF ø = 4°	Wong and Duncan, 1974	Material used in embankment dams	Test data given.
Drained Shear Strength	Mica Dam core silty clayey sand	C = .31 to .85 TSF ø = 33 to 34°			
	New Hogan Dam core clayey gravel (not fully saturated)	C = .28 TSF ø = 19°			
DEFORMATION CHARACTERISTICS Undrained Initial Tangent Modulus (for confining stresses of 100 to 1000 psi)	Pittsburgh sandy clay	1100 to 11000 psi	Wong and Duncan, 1974	Materials used in embankment	Values calculated from hyperbolic stress-strain equation and hyperbolic parameters given in reference assuming the confining stress.
	Sommerville Dam sandy clay	1300 to 12000 psi			
	Proctor Dam clayey gravelly sand	15000 to 36000 psi			
Drained Initial Tangent Modulus (for confining stresses of 100 to 1000 psi)	New Hogan Dam core clayey gravel	5600 to 28000 psi	Wong and Duncan, 1974	Material used in embankment dams	Values calculated from hyperbolic stress-strain equation and hyperbolic parameters given in reference assuming the confining stress.
	Mica Dam core silty clayey sand	11000 to 72000 psi			
Creep (strain rate)	40% kaolinite, 60% sand	.55x10^{-7}/min (@ 70% stress level - q/q_f) .90x10^{-7}/min (@ 90% stress level - q/q_f)	Singh and Mitchell, 1968	Research of soil properties	Data points given with strain rates.

COMPILATION OF DATA ON SELECTED PROPERTIES OF EXCAVATED ROCK (SAND OR GRAVEL) AND CLAY MIXTURES

Table D.6
2 of 2

PARAMETER	MATERIAL OR OTHER METHODS UTILIZED	RANGE OF VALUES	REFERENCES	APPLICATION IN REFERENCE	COMMENTS
<u>HYDRAULIC CONDUCTIVITY</u>					
Hydraulic Conductivity	4% bentonite, 96% quartz sand	3×10^{-4} cm/sec	Pacific Northwest Laboratory, 1981	Backfill in repository	Values given in text (no test data presented).
	8% bentonite, 92% quartz sand	1.5×10^{-5} cm/sec			
	20% bentonite, 80% sand	$\sim 10^{-7}$ cm/sec			
	50% sodium bentonite, 50% sand	3.3×10^{-12} to 6.4×10^{-12} cm/sec	Pacific Northwest Laboratory, 1981	Backfill in repository	Summary of laboratory test results given including some test data.
	25% sodium bentonite, 75% sand	6.6×10^{-10} cm/sec			
	50% Volclay saline seal, 50% sand	2.9×10^{-12} to 4.1×10^{-12} cm/sec			
	10% bentonite, 90% sand	5.9×10^{-7} cm/sec	Westinghouse, 1981	Backfill in repository	Values tabulated in reference.
	25% bentonite, 75% sand	2×10^{-9} cm/sec			
	50% bentonite, 50% sand	3×10^{-12} cm/sec			
	12% clay (w/high plasticity), 88% sand	2×10^{-4} to 6×10^{-6} cm/sec	Kleppe, 1981	Research in properties of soils	Test data given.
	25% clay (w/high plasticity), 75% sand	1×10^{-3} to 1×10^{-9} cm/sec			
	50% clay (w/high plasticity), 50% sand	4×10^{-5} to 2×10^{-9} cm/sec			
<u>VOID RATIO/DENSITY</u>					
Dry Density	Sommerville Dam sandy clay	98 to 107 pcf	Wong and Duncan, 1974	Material from embankment dams	Test data given.
	12 to 50% highly plastic clay, 88 to 50% sand	103 to 130 pcf	Kleppe, 1981	Research in desiccation	Test data given.
<u>THERMAL CONDUCTIVITY</u>					
Coefficient of Thermal Conductivity	10 to 50% bentonite 90 to 50% sand	.33 to 3 watts/m-°C	Westinghouse, 1981	Backfill in repository	Values from several references summarized in plot.

Note: This is a compilation of readily available data and is not intended to be comprehensive, only representative. Due to this and due to possible significant differences between measurement conditions and conditions expected in the repository, the data compiled here should be used only as an indication of what can reasonably be expected for properties of backfill; this will be sufficient for the purposes of this study, i.e., comparative evaluations, but would not be sufficient for definitive performance assessment.

Table D.7

COMPILATION OF DATA ON SELECTED PROPERTIES OF CONCRETE

PARAMETER	MATERIAL OR OTHER METHODS UTILIZED	RANGE OF VALUES	REFERENCES	APPLICATION IN REFERENCE	COMMENTS
<u>STRENGTH CHARACTERISTICS</u>					
Compressive Strength	Tests on core samples, maximum aggregate size varied from 1½ to 8 inches; cement content varied from 177 to 530 lb/yd^3	3000 to 8200 psi	U.S. Bureau of Reclamation, 1975	Mass concrete for dams	Summary of test data given in table.
	Roller - compacted concrete	@ 1 month, ~3% cement + fly ash: 600 psi ~6% cement + fly ash: 1800 psi @ 1 year, ~3% cement + fly ash: 1600 psi ~6% cement + fly ash: 4500 psi	Schrader, 1982	Mass concrete for dams	Plot of test data given. "Angle of Repose" during placement of concrete by dozers is ~ 0.7 horiz. to 1.0 vertical.
<u>DEFORMATION CHARACTERISTICS</u>					
Modulus of Elasticity	Ordinary concretes, at 28 days	2 million to 6 million psi	U.S. Bureau of Reclamation, 1975	Mass concrete for dams	Typical range in values given.
<u>HYDRAULIC CONDUCTIVITY</u>					
Hydraulic Conductivity	Concrete, w/1½ to 4½ inch maximum aggregate size and water to cement ratios of 0.5 to 0.8	10^{-8} to 10^{-9} cm/sec	U.S. Bureau of Reclamation, 1975	Mass concrete for dams	
<u>VOID RATIO/DENSITY</u>					
Bulk Density	Concrete, with maximum aggregate size of 3/4 to 6 inches	137 to 157 pcf	U.S. Bureau of Reclamation, 1975	Mass concrete for dams	Average values of fresh concrete; however, values are also indicative of cured concrete.
<u>THERMAL CONDUCTIVITY</u>					
Coefficient of Thermal Conductivity	Concrete	0.87 watts/m-°K	SAI, 1982	Backfill for nuclear waste repositories	No data given.

Note: This is a compilation of readily available data and is not intended to be comprehensive, only representative. Due to this and due to possible significant differences between measurement conditions and conditions expected in the repository, the data compiled here should be used only as an indication of what can reasonably be expected for properties of backfill; this will be sufficient for the purposes of this study, i.e., comparative evaluations, but would <u>not</u> be sufficient for definitive performance assessment.

Table D.8

COMPILATION OF DATA ON SELECTED PROPERTIES OF ZEOLITE/CLINOPTILOLITE

PARAMETER	MATERIAL OR OTHER METHODS UTILIZED	RANGE OF VALUES	REFERENCES	APPLICATION IN REFERENCE	COMMENTS
HYDRAULIC CONDUCTIVITY					
Hydraulic Conductivity	Clinoptilolite	1×10^{-2} cm/sec	SAI (1982)	Backfill in repository	No data given.
	Synthetic Zeolite	1×10^{-1} cm/sec (estimated value)			
THERMAL CONDUCTIVITY					
Coefficient of Thermal Conductivity	Clinoptilolite	0.7 watts/m - °K	SAI (1982)	Backfill in repository	No data given.
	Synthetic Zeolite	0.2 watts/m - °K (estimated value)			

Note:

This is a compilation of readily available data and is not intended to be comprehensive, only representative. Due to this and due to possible significant differences between measurement conditions and conditions expected in the repository, the data compiled here should be used only as an indication of what can reasonably be expected for properties of the backfill; this will be sufficient for the purposes of this study, i.e., comparative evaluations, but would not be sufficient for definitive performance assessment.

ESTIMATED DISTRIBUTION COEFFICIENT FOR VARIOUS BACKFILL MATERIALS/TYPES

Table D.9

RADIONUCLIDE	BACKFILL MATERIALS						
	Bentonite	Bentonite/ Quartz	Concrete	Bentonite/ Basalt	Clinoptilolite	Synthetic Zeolite	Illite
Strontium (Sr)	100	10	10	250	360	360	360
Technetium (Te)	0	0	0	0	0	0	0
Radium (Ra)	100	100	10	100	100	100	100
Neptunium (Np)	50	16	46	16	100	100	50
Uranium (U)	2000	6.3	5	6.3	1000	1000	1000

a) Distribution Coefficients (Kd - ml/gm) of Various Backfill Materials for a Few Selected Radionuclides (from SAI, 1982)

RADIONUCLIDE	ELEMENTAL SOLUBILITY (gm/cm^3)	BACKFILL TYPES		
		LOW PERMEABILITY BACKFILL	HIGH PERMEABILITY BACKFILL	CRUSHED BASALT
Cm	10^{-9}	10^{4}	10^{3}	5×10^{2}
Am	10^{-9}	10^{4}	10^{3}	5×10^{2}
Pu	10^{-9}	2×10^{3}	4×10^{3}	6×10^{1}
Np	10^{-9}	5×10^{1}	10^{2}	5
U	10^{-9}	2×10^{3}	10^{3}	3
Pa	10^{-9}	0	0	5
Th	10^{-9}	10^{4}	10^{4}	10^{2}
Ra	10^{-9}	10^{2}	10^{2}	7×10^{2}
Cs	4.5×10^{-6}	3.2×10^{1}	5×10^{3}	3×10^{2}
I	1.3×10^{-4}	0	0	2
Sn	1.9×10^{-6}	0	0	5×10^{1}
Tc	10^{-8}	0	0	10^{2}
Zr	3.5×10^{-6}	10^{4}	4×10^{3}	5×10^{1}
Se	10^{-5}	3	0	1.1×10^{1}
Ni	1.9×10^{-5}	0	0	5×10^{1}
C	3.0×10^{-5}	0	0	2

b) Distribution Coefficients (Kd - ml/gm) of Various Backfill Types for Pertinent Radionuclides (from SAI, 1982)

Note: These values have been estimated based on available information and experience for the purposes of comparative studies; they entail significant uncertainty.

LIST OF SYMBOLS AND ABBREVIATIONS

q_u = unconfined compressive strength

S_u, C_u = undrained shear strength

c' or $\bar{c}$, c = drained or undrained cohesion, respectively

ϕ' or $\bar{\phi}$, ϕ = drained or undrained angle of internal friction, respectively

q or $(\sigma_1-\sigma_3)$ = principal stress differences

q_f or $(\sigma_1-\sigma_3)_f$ = principal stress differences at failure

σ_1 = major principal stress

σ_3 = minor principal stress

$\bar{\sigma}_c$ = effective stress at consolidation

E = modulus of elasticity, Young's modulus

R_c = one-dimensional strain per logarithmic cycle of normal stress (dimensionless)

γ_d = dry density

D_r = relative density

$\bar{s}$ = standard deviation

C/T = cement-to-tailings ratio

C/S = cement-to-sand ratio

C/FA/S = cement-to-flyash-to-sand ratio

REFERENCES FOR APPENDIX D

Askew, J.E., P.L. McCarthy, and D.J. Fitzgerald, "Backfill Research for Pillar Extraction at AC/NBHC," p. 100 in Mining with Backfill: 12th Canadian Rock Mechanics Symposium, Canadian Institute of Mines and Metallurgy, Ontario, 1978. Available in public technical libraries.

Ball, D.G., "Pneumatic Backfilling," Western Miner v. 43 (1), pp. 22-24, January 1970. Available in public technical libraries.

Barrett, J.R., M.A. Coulthard, and P.M. Dight, "Determination of Fill Stability," p. 85 in Mining with Backfill: 12th Canadian Rock Mechanics Symposium, Canadian Institute of Mines and Metallurgy, Ontario, 1978. Available in public technical libraries.

Bishop, A.W. and H.T. Lovenbury, "Creep Characteristics of Two Undisturbed Clays," p. 29 in Proc. 7th Intl. Conf. Soil Mech. Founda. Eng., v. 1, Mexico, 1969. Available in public technical libraries.

Corson, D.R., "Stabilization of Hydraulic Backfill with Portland Cement," U.S. Bureau of Mines Report of Investigation 7327, 1970. Available in public technical libraries.

Corson, D.R., "Field Evaluation of Hydraulic Backfill Compaction at the Lucky Friday Mine, Mullan, Idaho," U.S. Bureau of Mines Report of Investigation 7546, 1971. Available in public technical libraries.

Cundall, P., J.H. Shillabeer, and G. Herget, "Modelling to Predict Backfill Stability in Transverse Pillar Extraction," p. 92 in Mining with Backfill: 12th Canadian Rock Mechanics Symposium, Canadian Institute of Mines and Metallurgy, Ontario, 1978. Available in public technical libraries.

Ford, R.A., "Review of Backfill Mining Practices and Technology at the Fox Mine," p. 1 in Mining with Backfill: 12th Canadian Rock Mechanics Symposium, Canadian Institute of Mines and Metallurgy, Ontario, 1978. Available in public technical libraries.

Freeze, R.A. and J.A. Cherry, Groundwater, Prentice-Hall Inc., Englewood Cliffs, N.J., 1979. Available in public technical libraries.

Hill, J.R.M., M.M. McDonald, and L.M. McNay, "Support Performance of Hydraulic Backfill, a Preliminary Analysis," U.S. Bureau of Mines Report of Investigation 7850, 1974. Available in public technical libraries.

Kleppe, J.H., "Desiccation Cracking of Compacted Soil," Master's Thesis, University of Texas at Austin, 1981. Available at the University of Texas.

Ladd, C.C., "Stress-Strain Modulus in Undrained Shear," *J. Soil Mechn. Founda. Div., ASCE* v. 90 (SM5), pp. 103-132, 1964. Available in public technical libraries.

Ladd, C.C., et al, "Stress-Deformation and Strength Characteristics," p. 421 in *Proc. 9th Intl. Conf. Soil Mech. Founda. Eng.*, Tokyo, 1976. Available in public technical libraries.

Lade, P.V., "Stress-Strain Theory for Normally Consolidated Clay," p. 1325 in *Proc. 3rd Intl. Conf. Numerical Methods in Geomechanics* v. 4, 1979. Available in public technical libraries.

Leps, T.M., "Review of Shearing Strength of Rockfill," *J. Soil Mech. Founda. Div., ASCE* v. 96 (SM4), pp. 1159-1170, 1970. Available in public technical libraries.

Marsal, R.J., "Mechanical Properties of Rockfill," p. 109 in *Embankment-Dam Engineering Casagrande Volume*, John Wiley & Sons, New York, 1973. Available in public technical libraries.

McGuire, A.J., "Falconbridge Slag as a Cementing Agent in Backfill," p. 133 in *Mining with Backfill: 12th Canadian Rock Mechanics Symposium*, Canadian Institute of Mines and Metallurgy, Ontario, 1978. Available in public technical libraries.

McNay, L.M. and J.R.M. Hill, "Strength of Cemented Hydraulic Sandfill Modified by Flocculants," U.S. Bureau of Mines Report of Investigation 8126, 1976. Available in public technical libraries.

Mesri, G. and R.E. Olson, "Mechanisms Controlling the Permeability of Clays," *Clays and Clay Minerals* v. 19, pp. 151-158, 1971. Available in public technical libraries.

Mitchell, J.K., *Fundamentals of Soil Behavior*, John Wiley & Sons, New York, 1976. Available in public technical libraries.

Mitchell, R.J., J.D. Smith and D.J. Libby, "Bulkhead Pressures Due to Cemented Hydraulic Mine Backfills," *Canadian Geotech. J.* v. 12, pp. 362-371, 1975. Available in public technical libraries.

Mitchell, R.J., R.S. Olsen and J.D. Smith, "Model Studies in Cemented Tailings Used in Mine Backfills," *Canadian Geotech. J.* v. 19, pp. 14-28, 1982. Available in public technical libraries.

Nicholson, D.E. and R.A. Busch, "Earth Pressure at Rest and One-Dimensional Compression in Mine Hydraulic Backfills," U.S. Bureau of Mines Report of Investigation 7198, 1968. Available in public technical libraries.

Olsen, H.W., "Darcy's Law in Saturated Kaolinite," *Water Resources Research* v. 2 (2), pp. 287-295, 1966. Available in public technical libraries.

Olson, R.E. and G. Mesri, "Mechanisms Controlling Compressibility of Clays," J. Soil Mech. Founda. Div., ASCE v. 96 (SM6), pp. 1863-1878, November 1970. Available in public technical libraries.

Olson, R.E., "Shearing Strengths of Kaolinite, Illite and Montmorillonite," J. Geotech. Div., ASCE v. 100 (GT11), pp. 1215-1229, November 1974. Available in public technical libraries.

Pacific Northwest Laboratory, "Development of Backfill Material as an Engineered Barrier in the Waste Package System--Interim Topical Report," PNL-3873, Battelle Memorial Institute, Columbus, OH, September 1981. Available from Pacific Northwest Laboratory.

Reynolds, J.W., "Pneumatic Backfilling with Crushed Rock at the Sullivan Mine," Canadian Min. Metall. Bull. v. 65 (723), pp. 31-36, July 1972. Available in public technical libraries.

Schrader, E.K., "World's First All-Rollcrete Dam," Civil Engineering - ASCE, v. 52 (4), pp. 45-48, April 1982. Available in public technical libraries.

Science Applications, Inc., "Task 3 (Basalt) Final Report, Performance of Engineered Barriers in a Geologic Repository, Volume II--Appendices," report to Golder Associates, July 1982. Available in NRC PDR for inspection and copying for a fee.

Seed, H.B. and C.K. Chan, "Structure and Strength Characteristics of Compacted Clays," J. Soil Mech. Founda. Div., ASCE v. 85 (SM5), pp. 87-128, October 1959. Available in public technical libraries.

Singh, A. and J.K. Mitchell, "General Stress-Strain-Time Function for Soils," J. Soil Mech. Founda. Div., ASCE v. 94 (SM1), pp. 21-46, January 1968. Available in public technical libraries.

Soderberg, R.L. and D.R. Corson, "Support Capabilities of Pneumatically Stowed Materials," U.S. Bureau of Mines Report of Investigation 8202, 1976. Available in public technical libraries.

Stearns-Roger Engineering Co., "National Waste Terminal Storage Repository No. 1, Special Study No. 2: Waste Retrieval from Backfilled Regions," S-R, Denver, CO, 1978. Available from ONWI.

Stout, K. and Dr. L. Friel, "Early High-Strength Hydraulic Backfill," Eng. Mining J. v. 181(7), pp. 93-103, July 1980. Available in public technical libraries.

Terzhagi, K. and R.B. Peck, Soil Mechanics in Engineering Practice, 2nd Ed., John Wiley & Sons, New York, 1967. Available in public technical libraries.

Thomas, E.G. and R. Cowling, "Pozzolanic Behavior of Ground Isa Mine Slag in Cemented Hydraulic Mine Fill at High Slag/Cement Ratios," p. 129 in Mining with Backfill: 12th Canadian Rock Mechanics Symposium, Canadian Institute of Mines and Metallurgy, Ontario, 1978. Available in public technical libraries.

U.S. Bureau of Reclamation, Concrete Manual, 8th Ed., 1975. Available in public technical libraries.

Westinghouse Electric Corporation, Advanced Energy Systems Division, "Engineered Waste Package Conceptual Design Defense High Level Waste (Form 1), Commercial High Level Waste (Form 1), and Spent Fuel (Form 2), Disposal in Basalt," AESD-TME-3113, September 1981. Available from ONWI.

Wong, K.S. and J.M. Duncan, "Hyperbolic Stress-Strain Parameters for Nonlinear Finite Element Analyses of Stresses and Movements in Soil Masses," Report No. TE-74-3, University of California at Berkeley, July 1974. Available at University of California.

APPENDIX E
PRELIMINARY EVALUATION OF ALTERNATIVE BACKFILL SCHEMES

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APPENDIX E - PRELIMINARY EVALUATION OF ALTERNATIVE BACKFILL SCHEMES

A total of 60 viable combinations of waste emplacement hole and room backfill materials/additives have been identified (see Section 6.2.1 - Main Text) (see Table E.1). These alternative backfill schemes have been subjectively and yet explicitly evaluated, in a preliminary fashion, with respect to each one's perceived effectiveness in achieving the generic backfill design basis developed for this study (see Section 3 - Main Text). This preliminary evaluation of apparent effectiveness has utilized a specific evaluation methodology (see Section 4 - Main Text). This evaluation essentially consists of:

- Subjectively assessing the contribution each alternative backfill scheme is perceived to have, relative to the other alternatives, in achieving each weighted backfill design objective, ranging from 0.0 (no contribution) to 1.0 (complete achievement), based on each backfill scheme's expected performance at a generic site.

- Multiplying the backfill scheme's perceived contribution in achieving each backfill design objective by the relative weight of that objective, and then summing the products for all objectives to determine the relative contribution of each backfill scheme towards achieving the generic backfill design basis.

The backfill design basis for this study consists of weighted backfill design objectives, which can be categorized in a variety of ways. For the purpose of evaluating different combinations of waste emplacement hole and room backfill materials/additives, it has been useful to first categorize the weighted backfill design objectives into the following comprehensive and mutually exclusive subsets:

- Waste package scale objectives
- Room scale objectives
- Room/waste package scale objectives
- Schedule/procedures objectives.

Since 12 different materials/additives have been considered for backfill around the waste package or in the room, the two sets of objectives related to either the waste package scale or the room scale need only be assessed for each of the 12 different materials/additives, and not for all 60 combinations. In other words, the assessment of contribution by a given room backfill material/additive to achieving the set of backfill design objectives related only to the room scale can be assumed to be independent of the backfill material/additive used around the waste package, and vice versa. Once the contribution to achieving the sets of room scale or waste package scale objectives has been assessed for each material/additive, these can be combined with the assessed contribution of each combination to achieving the sets of room/waste package scale and schedule/procedures objectives.

In accordance with the above, the weighted backfill design objectives related to either the waste package scale or the room scale have been identified (see Tables E.2 and E.3, respectively). Each of the 12 different backfill materials/additives have then been assessed in how well they might meet each objective, ranging from 0 for no contribution at all to 1 for complete achievement. The case of no backfill has been used as an extreme case, with values of either 0 or 1. Otherwise, the contributions have been subjectively assessed by considering the expected properties of each backfill material/additive (see Appendix D) and comparing each backfill/additive with respect to achieving a given backfill design objective. Then, based on the perceived future performance of each backfill material/additive, the best and worst backfill material/additive for achieving the given backfill design objective have been identified and their score, relative to the perceived ideal, assessed; the best has not necessarily been assessed as 1, nor the worst as 0. The other backfill materials/additives have then been scored relative to the best and worst. In this way, although there may be some uncertainty in the high and low scores, the scores of the different backfill materials/additives should properly reflect the relative contribution of each.

Subsequent to the assessment of relative contributions of the different backfill materials/additives to achieving each of the backfill design objectives related to either waste package scale or room scale, this contribution has been multiplied by the relative weight of that objective and the products then summed over all objectives; this summation indicates the perceived contribution of each backfill material/additive to achieving the sets of waste package scale and room scale backfill design objectives (see Table E.4).

Next, the weighted backfill design objectives related to either the room and waste package scale or schedule and procedures have been identified (see Table E.5). Each of the 60 different combinations of waste emplacement hole and room backfill materials/additives have then been assessed in how well they might meet each of these objectives. This assessment has been conducted in an identical fashion to that conducted with respect to the sets of waste package scale or room scale objectives.

Again, subsequent to the assessment of relative contributions of the different combinations to achieving each of the backfill design objectives related to either room/waste package scale or schedule/procedures, this contribution has been multiplied by the relative weight of that objective and the products summed over all objectives; this summation indicates the perceived contribution of each backfill material/additive to achieving the sets of room/waste package scale and schedule/procedures backfill design objectives (Table E.5). The perceived contributions of the given waste emplacement hole backfill material/additive to achieving the set of waste package scale backfill design objectives and of the given room backfill material/additive to the set of room scale backfill design objectives (Table E.4) have then been added to the perceived contributions of that combination to achieving the sets of room/waste package scale and schedule/procedures backfill design objectives. In this way, the perceived contribution of each combination of waste emplacement hole and room backfill materials/additives to achieving the entire backfill design basis has been determined. The apparent effectiveness of each combination in achieving the backfill design basis has then been determined by dividing the perceived contribution by the summation of relative weights of all the backfill design objectives (i.e., 0.16445556). This assessed value of apparent effectiveness can range from 0.0 (no effectiveness) to 1.0 (total effectiveness or complete achievement of the backfill design basis used in this study).

The apparent effectiveness of each viable combination of waste emplacement hole and room backfill material/additive, with respect to achieving the generic backfill design basis used in this study (see Section 3 - Main Text), has thus been determined using a subjective and yet explicit evaluation methodology (see Section 4 - Main Text). These values have been summarized (see Tables E.6 and E.7). Although numerical values for apparent effectiveness have been presented, these should only be used as an approximate indication of the extent to which the generic backfill design basis used in this study might be achieved by any given backfill scheme, as there is inherent uncertainty in the subjective assessments of both the relative weights of backfill design objectives and the perceived contributions towards achieving each by any backfill scheme. This semi-quantitative approach is considered to be sufficient for the purposes of this study and has the advantage of being explicit and clearly exposed. However, site-specific quantitative performance assessment, which is outside the scope of this study, will eventually be necessary to refine the backfill design basis and to rigorously evaluate, including a determination of the acceptability of, any proposed backfill scheme.

VIABLE COMBINATIONS OF WASTE EMPLACEMENT HOLE AND ROOM BACKFILL MATERIALS /ADDITIVES

Table E.1

ROOM BACKFILL MATERIAL/ADDITIVE (See NOTE)

WASTE EMPLACEMENT HOLE BACKFILL MATERIAL/ADDITIVE (See NOTE)

	1	2	2A	3	3A	3B	4	4A	4B	5	6	7
1	●			●								
2	●	●	●	●	●	●						
2A		●	●	●	●	●				●		
3	●			●								
3A	●			●	●							
3B	●			●	●	●						
4	●			●			●					
4A	●			●	●			●				
4B	●			●	●	●			●			
5	●	●	●	●	●	●				●	●	
6	●	●	●	●	●	●				●	●	
7	●	●	●	●	●	●				●	●	●

NOTE:

(from Section 6.2.1 - Main Text)

Code- Material	Additive	Material/Additive	Primary Objectives - Structural Support	Water Attenuation	Radionuclide Attenuation
1		None			
2		Concrete	x	o	
2	A	Concrete with sand-cement grout	x	x	
3		Muck	x		
3	A	Muck with sand-cement grout	x	x	
3	B	Muck mixed with bentonite	x	x	
4		Sand	x		
4	A	Sand with sand-cement grout	x	x	
4	B	Sand mixed with bentonite	x	x	
5		Bentonite		x	
6		Illite		o	x
7		Clinoptilolite/Zeolite (synthetic)			x

(Room Scale or Waste Package Scale)

x = Principal objective of backfill material/additive

o = Secondary objective of backfill material/additive

ASSESSMENT OF EACH VIABLE BACKFILL MATERIAL/ ADDITIVE'S CONTRIBUTION TO ACHIEVING THE SET OF WASTE PACKAGE SCALE BACKFILL DESIGN OBJECTIVES

Table E.2

WASTE PACKAGE SCALE BACKFILL DESIGN OBJECTIVES (Listed in approximate decreasing order of significance)			ALTERNATIVE BACKFILL MATERIAL/ADDITIVE (See Table E.1)											
Code	Objective	Relative Weight	1	2	2A	3	3A	3B	4	4A	4B	5	6	7
bgh1-3	[Maximize] mitigation of corrosive groundwater by backfill (waste package scale) (post resaturation)	[.00323]	0.	.2	.2	.3	.3	.3	.3	.3	.3	.3	.4	.4
bmh1-3	[Minimize] stress transfer through backfill around waste package (post resaturation)	[.00161]	1.	.3	.2	.4	.3	.5	.4	.3	.5	.7	.6	.4
bthol-3	[Minimize] insulation of waste package from rock mass around emplacement hole (post resaturation)	[.00161]	1.	.6	.5	.8	.6	.3	.6	.6	.3	.2	.3	.6
bgh1-1	[Maximize] mitigation of corrosive groundwater by backfill (waste package scale) (during retrieval period)	[.00112]	0.	.2	.2	.3	.3	.3	.3	.3	.3	.3	.4	.4
bgh1-2	[Maximize] mitigation of corrosive groundwater by backfill (waste package scale) (post decommissioning to resaturation)	[.00108]	0.	.2	.2	.3	.3	.3	.3	.3	.3	.3	.4	.4
bgh2-1	[Maximize] thickness/adsorption of backfill around waste package (during retrieval period)	[.000972]	0.	.5	.5	.3	.5	.4	.4	.5	.4	.4	.6	.8
bmh1-1	[Minimize] stress transfer through backfill around waste package (during retrieval period)	[.000884]	1.	.2	.1	.4	.2	.5	.4	.2	.5	.6	.6	.4
bmh2b-3	[Minimize] increase in swelling pressure of backfill around waste package (post resaturation)	[.000806]	1.	.7	.5	.8	.7	.4	.8	.7	.4	.3	.5	.7
bmh1-2	[Minimize] stress transfer through backfill around waste package (post decommissioning to resaturation)	[.000538]	1.	.2	.1	.4	.2	.5	.4	.2	.5	.7	.6	.4
bthol-2	[Minimize] insulation of waste package from rock mass around emplacement hole (post decommissioning to resaturation)	[.000538]	1.	.5	.5	.8	.6	.4	.6	.6	.4	.3	.7	.4
bmh2a-1	[Minimize] swelling pressure of backfill around waste package (during retrieval period)	[.000442]	1.	.5	.4	.8	.6	.2	.8	.6	.2	.1	.3	.7
bthol-1	[Minimize] insulation of waste package from rock mass around emplacement hole (during retrieval period)	[.000327]	1.	.5	.5	.8	.6	.4	.6	.6	.4	.3	.7	.4
bmh2b-2	[Minimize] increase in swelling pressure of backfill around waste package (post decommissioning to resaturation)	[.000269]	1.	.6	.4	.8	.6	.3	.8	.6	.3	.2	.4	.7
bth1-3	[Maximize] insulation of waste package from rock mass around emplacement hole (post resaturation)	[.0000688]	0.	.4	.5	.2	.4	.7	.4	.4	.7	.8	.7	.4
bth1-1	[Maximize] insulation of waste package from rock mass around emplacement hole (during retrieval period)	[.0000619]	0.	.5	.5	.2	.4	.6	.4	.4	.6	.7	.7	.4
bth1-2	[Maximize] insulation of waste package from rock mass around emplacement hole (post decommissioning to resaturation)	[.0000259]	0.	.5	.5	.2	.4	.6	.4	.4	.6	.7	.7	.4
Backfill material/additive's perceived contribution to achieving set of waste package scale backfill design objectives, equals summation of products of assessed contribution and relative weight.			.0070240	.0048001	.0041200	.0063583	.0054208	.0049551	.0059918	.0054208	.0049551	.0050896	.0064157	.0065989

Note: The relative contributions, as well as the relative weights, entail significant uncertainty due to the subjective nature of their assessment; the assessment of relative contribution has been based on perceptions regarding each backfill material/additive's expected performance (see Appendix D). These perceptions are subject to change. The objectives and their relative weight are a subset of the generic backfill design basis developed for this study (see Section 3 - Main Text).

ASSESSMENT OF EACH VIABLE BACKFILL MATERIAL / ADDITIVE'S CONTRIBUTION TO ACHIEVING THE SET OF ROOM SCALE BACKFILL DESIGN OBJECTIVES

Table E.3

ROOM SCALE BACKFILL DESIGN OBJECTIVES (Listed in approximate decreasing order of significance)			ALTERNATIVE BACKFILL MATERIAL/ADDITIVE (See Table E.1)											
Code	Objective	Relative Weight	1	2	2A	3	3A	3B	4	4A	4B	5	6	7
bhrla-3	[Minimize] hydraulic conductivity (and effective porosity) of backfill and interface (room scale) (post resaturation)	[.0161]	0.	.4	.6	.1	.6	.7	.2	.4	.7	.8	.7	.2
bhrla-2	[Minimize] hydraulic conductivity (and effective porosity) of backfill and interface (room scale) (post decommissioning to resaturation)	[.00423]	0.	.5	.7	.1	.7	.7	.2	.5	.7	.8	.7	.2
bhr2-1	[Maximize] porosity of backfill (room scale) (during retrieval period)	[.00258]	1.	.1	.1	.7	.5	.4	.5	.4	.3	.2	.2	.5
bhr2-2	[Maximize] porosity of backfill (room scale) (post decommissioning to resaturation)	[.00258]	1.	.1	.1	.7	.5	.3	.5	.4	.2	.1	.2	.5
bmr2a-1	[Maximize] support pressure (or structural support) provided by backfill (room scale) (during retrieval period)	[.00249]	0.	.8	.9	.7	.8	.5	.7	.8	.4	.3	.4	.6
bhrlb-3	[Maximize] decrease in hydraulic conductivity (and effective porosity) of rock mass (room scale) (i.e., sealing/filling of discontinuities) by backfill (post resaturation)	[.00206]	0.	.1	.2	.2	.3	.7	.3	.4	.7	.8	.7	.3
bgr2-1	[Maximize] thickness/adsorption of backfill (room scale) (during retrieval period)	[.00108]	0.	.5	.5	.2	.4	.4	.3	.4	.4	.4	.6	.8
bmrl-1	[Minimize] integrity (compaction) of backfill (room scale) (if placed, during retrieval period)	[.000336]	1.	.1	.1	.7	.2	.4	.8	.2	.5	.6	.6	.7
bmro2a-1	[Minimize] support pressure (or structural support) provided by backfill (room scale) (during retrieval period)	[.000300]	1.	.2	.1	.3	.2	.5	.3	.2	.6	.7	.6	.4
btrl-1	[Maximize] insulation of waste package from rock mass around underground opening (room scale) (during retrieval period)	[.000278]	0.	.5	.5	.3	.4	.5	.4	.4	.5	.6	.6	.4
bmr2c-3	[Minimize] decrease in support pressure (or structural support) provided by backfill (room scale) (post resaturation)	[.0000961]	0.	.7	.8	.6	.7	.5	.5	.6	.4	.2	.3	.5
btrol-1	[Minimize] insulation of waste package from rock mass around underground opening (room scale) (during retrieval period)	[.0000858]	1.	.5	.5	.7	.6	.5	.6	.6	.5	.4	.4	.6
bhrla-1	[Minimize] hydraulic conductivity (and effective porosity) of backfill and interface (room scale) (during retrieval period)	[.0000851]	0.	.6	.8	.1	.7	.7	.2	.6	.7	.8	.7	.2
bmr2c-2	[Minimize] decrease in support pressure (or structural support) provided by backfill (room scale) (post decommissioning to resaturation)	[.0000699]	0.	.7	.8	.6	.7	.5	.5	.6	.4	.3	.4	.5
bmr2b-3	[Maximize] increase in support pressure (or structural support) provided by backfill (room scale) (post resaturation)	[.0000697]	0.	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1
bmr2b-2	[Maximize] increase in support pressure (or structural support) provided by backfill (room scale) (post decommissioning to resaturation)	[.0000484]	0.	.1	.1	.1	.1	.2	.1	.1	.2	.2	.2	.1
btrl-2	[Maximize] insulation of waste package from rock mass around underground opening (room scale) (post decommissioning to resaturation)	[.0000258]	0.	.5	.5	.3	.4	.6	.4	.4	.6	.7	.7	.4
btrl-3	[Maximize] insulation of waste package from rock mass around underground opening (room scale) (post resaturation)	[.0000160]	0.	.4	.5	.3	.4	.6	.4	.4	.6	.7	.7	.4
bgrl-1	[Maximize] protection of exposed rock surfaces underground by backfill (room scale) (during retrieval period)	[.0000137]	0.	.6	.7	.2	.6	.5	.2	.6	.5	.6	.7	.6
bmro2c-2	[Maximize] decrease in support pressure (or structural support) provided by backfill (room scale) (post decommissioning to resaturation)	[.00000568]	1.	.3	.2	.4	.3	.5	.5	.4	.6	.7	.6	.5
bgrl-3	[Maximize] protection of exposed rock surfaces underground by backfill (room scale) (post resaturation)	[.00000434]	0.	.4	.5	.2	.4	.6	.2	.4	.6	.7	.8	.6
bgrl-2	[Maximize] protection of exposed rock surfaces underground by backfill (room scale) (post decommissioning to resaturation)	[.00000423]	0.	.5	.6	.2	.5	.6	.2	.5	.6	.7	.8	.6
bmro2c-3	[Maximize] decrease in support pressure (or structural support) provided by backfill (room scale) (post resaturation)	[.00000417]	1.	.3	.2	.4	.3	.5	.5	.4	.6	.8	.7	.5
btrol-2	[Minimize] insulation of waste package from rock mass around underground opening (room scale) (post decommissioning to resaturation)	[.00000249]	1.	.5	.5	.7	.6	.4	.6	.6	.4	.3	.3	.6
btrol-3	[Minimize] insulation of waste package from rock mass around underground opening (room scale) (post resaturation)	[.00000155]	1.	.6	.5	.7	.6	.4	.6	.6	.4	.3	.3	.6
Backfill material/ additive's perceived contribution to achieving set of room scale backfill design objectives, equals summation of products of assessed contribution and relative weight.			.0056957	.0123001	.0168274	.0086283	.0187546	.0198251	.0099928	.0143545	.0191081	.0206546	.0191180	.0102891

Note: The relative contributions, as well as the relative weights, entail inherent uncertainty due to the subjective nature of their assessment; the assessment of relative contribution has been based on perceptions regarding each backfill material/additive's expected performance (see Appendix D). These perceptions are subject to change. The objectives and their relative weights are a subset of the generic backfill design basis developed for this study (see Section 3 - Main Text).

PERCEIVED CONTRIBUTION OF EACH VIABLE BACKFILL MATERIAL/ADDITIVE TO ACHIEVING THE SETS OF WASTE PACKAGE SCALE AND ROOM SCALE BACKFILL DESIGN OBJECTIVES

Table E.4

	Perceived Contribution to Achieving Sets of Backfill Design Objectives	
Backfill Material/Additive	Waste Package Scale (see Table E.2)	Room Scale (see Table E.3)
1. None	.0070240	.0058957
2. Concrete	.0048001	.0123001
2A. Concrete with sand-cement grout	.0041200	.0168274
3. Muck	.0063583	.0086283
3A. Muck with sand-cement grout	.0054208	.0187546
3B. Muck mixed with bentonite	.0049551	.0198251
4. Sand	.0059918	.0099928
4A. Sand with sand-cement grout	.0054208	.0143545
4B. Sand mixed with bentonite	.0049551	.0191081
5. Bentonite	.0050896	.0206546
6. Illite	.0064157	.0191180
7. Clinoptilolite/Zeolite (synthetic)	.0065989	.0102891

NOTE: These perceived contributions entail inherent uncertainty, as they have been based on each backfill material/additive's expected performance. Perceptions regarding expected performance, as well as the relative weights of backfill design objectives, are subject to change.

Table E.5
1 of 8

ASSESSMENT OF EACH ALTERNATIVE BACKFILL SCHEME'S CONTRIBUTION TO ACHIEVING THE BACKFILL DESIGN BASIS

	BACKFILL DESIGN OBJECTIVE CODE (1)	RELATIVE WEIGHT	COMBINATION OF WASTE EMPLACEMENT HOLE: ROOM BACKFILL MATERIAL/ADDITIVE(2)									
			1:1	1:3	2:1	2:2	2:2A	2:3	2:3A	2:3B	2A:2	2A:2A
ROOM/WASTE PACKAGE SCALE	bq4-3	0 044100	0 00	0 20	0 10	0 30	0 30	0 30	0 30	0 30	0 30	0 30
	bh1-3	0 016100	0 00	0 20	0 20	0 40	0 60	0 30	0 60	0 60	0 50	0 70
	bq1-3	0 007560	0 00	0 20	0 10	0 20	0 40	0 40	0 50	0 30	0 30	0 40
	bq2-3	0 007560	0 00	0 40	0 10	0 20	0 30	0 60	0 50	0 20	0 20	0 30
	bq3-3	0 003780	0 00	0 50	0 10	0 20	0 20	0 50	0 40	0 30	0 20	0 20
	Perceived contribution to achieving set of room/waste package scale backfill design objectives (3)		0	018466	00952	02345	028938	02751	031962	027804	025816	030548
SCHEDULES/PROCEDURES	bsrolc-1	0 017200	1 00	0 50	1 00	0 50	0 50	0 50	0 50	0 50	0 50	0 50
	bp2-1	0 004320	1 00	0 50	0 80	0 50	0 50	0 50	0 50	0 50	0 50	0 50
	bp3-1	0 004320	1 00	0 50	0 80	0 50	0 50	0 50	0 50	0 50	0 50	0 50
	bp1-1	0 003600	1 00	0 50	0 80	0 50	0 40	0 50	0 40	0 50	0 40	0 40
	bsrla-1	0 003020	0 00	0 50	0 00	0 50	0 50	0 50	0 50	0 50	0 50	0 50
	bp4-1	0 002270	1 00	0 50	0 90	0 70	0 50	0 40	0 30	0 40	0 50	0 40
	bp5-1	0 000972	1 00	0 50	0 90	0 60	0 50	0 40	0 30	0 40	0 50	0 40
	bpr1-1	0 000840	1 00	0 50	1 00	0 50	0 40	0 50	0 40	0 50	0 50	0 40
	bshol-1	0 000788	1 00	1 00	0 50	0 50	0 50	0 50	0 50	0 50	0 50	0 50
	bsh1-1	0 000648	0 00	0 00	0 50	0 50	0 50	0 50	0 50	0 50	0 50	0 50
	bsrola-1	0 000504	1 00	0 50	1 00	0 50	0 50	0 50	0 50	0 50	0 50	0 50
	bsrolb-1	0 000422	1 00	0 50	1 00	0 50	0 50	0 50	0 50	0 50	0 50	0 50
	bsrlb-1	0 000302	1 00	0 50	1 00	0 50	0 50	0 50	0 50	0 50	0 50	0 50
	Perceived contribution to achieving set of schedules/procedures backfill design objectives (3)		035538	019673	0326958	0201542	019159	0192788	0185106	0192788	019243	0188346
Perceived contribution to achieving set of waste package scale backfill design objectives (see Table E.4)			0 007024	0 007024	0 0048001	0 004800.	0 0048001	0 0048001	0 0048001	0 0048001	0 00412	0 00412
Perceived contribution to achieving set of room scale backfill design objectives (see Table E.4)			0 0058957	0 0086283	0 0058957	0 0123001	0 0168274	0 0086283	0 0187546	0 0198251	0 0123001	0 0168274
Perceived contribution to achieving backfill design basis (4)			0484577	0537913	0529116	0607044	0697245	0602172	0740273	071708	0614791	0703302
Apparent effectiveness (5)			.295	.327	.322	.369	.424	.366	.450	.436	.374	.428

ASSESSMENT OF EACH ALTERNATIVE BACKFILL SCHEME'S CONTRIBUTION TO ACHIEVING THE BACKFILL DESIGN BASIS

Table E.5
2 of 8

	BACKFILL DESIGN OBJECTIVE CODE (1)	RELATIVE WEIGHT	COMBINATION OF WASTE EMPLACEMENT HOLE: ROOM BACKFILL MATERIAL/ADDITIVE(2) 2A:3	2A 3A	2A:3B	2A:5	3:1	3:3	3A:1	3A:3	3A:3A	3B:1
ROOM/WASTE PACKAGE SCALE	bg4-3	0 044100	0 30	0 30	0 30	0 30	0 10	0 20	0 10	0 30	0 30	0 20
	bh1-3	0 016100	0 40	0 70	0 70	0 80	0 10	0 20	0 20	0 30	0 50	0 30
	bg1-3	0 007560	0 40	0 50	0 30	0 30	0 10	0 40	0 20	0 40	0 50	0 10
	bg2-3	0 007560	0 60	0 50	0 20	0 20	0 20	0 60	0 20	0 60	0 50	0 10
	bg3-3	0 003780	0 50	0 40	0 30	0 20	0 20	0 60	0 10	0 50	0 40	0 10
	Perceived contribution to achieving set of schedules/procedures backfill design objectives (3)		02912	033572	029414	030646	009044	021868	011032	02751	030352	01554
SCHEDULES/PROCEDURES	bsro1c-1	0 017200	0 50	0 50	0 50	0 50	1 00	0 50	1 00	0 50	0 50	1 00
	bp2-1	0 004320	0 50	0 50	0 50	0 50	0 80	0 50	0 80	0 50	0 50	0 80
	bp3-1	0 004320	0 50	0 50	0 50	0 50	0 80	0 50	0 80	0 50	0 50	0 80
	bp1-1	0 003600	0 40	0 40	0 40	0 40	0 80	0 50	0 70	0 40	0 40	0 80
	bsr1a-1	0 003020	0 50	0 50	0 50	0 50	0 00	0 50	0 00	0 50	0 50	0 00
	bp4-1	0 002270	0 40	0 30	0 40	0 60	0 80	0 40	0 70	0 20	0 10	0 80
	bp5-1	0 000972	0 40	0 30	0 40	0 50	0 80	0 40	0 70	0 30	0 20	0 80
	bpr1-1	0 000840	0 50	0 40	0 50	0 50	1 00	0 50	1 00	0 50	0 40	1 00
	bsho1-1	0 000788	0 50	0 50	0 50	0 50	0 50	0 50	0 50	0 50	0 50	0 50
	bsh1-1	0 000648	0 50	0 50	0 50	0 50	0 50	0 50	0 50	0 50	0 50	0 50
	bsro1a-1	0 000504	0 50	0 50	0 50	0 50	1 00	0 50	1 00	0 50	0 50	1 00
	bsro1b-1	0 000422	0 50	0 50	0 50	0 50	1 00	0 50	1 00	0 50	0 50	1 00
	bsr1b-1	0 000302	0 50	0 50	0 50	0 50	1 00	0 50	1 00	0 50	0 50	1 00
	Perceived contribution to achieving set of room/waste package scale backfill design objectives (3)		0189188	0185106	0189188	01947	0323716	0192788	0316874	0183676	0179594	0323716
Perceived contribution to achieving set of waste package scale backfill design objectives (see Table E.4)			0 00412	0 00412	0 00412	0 00412	0 0063583	0 0063583	0 0054208	0 0054208	0 0054208	0 0049557
Perceived contribution to achieving set of room scale backfill design objectives (see Table E.4)			0 0086283	0 0187546	0 0198251	0 0206546	0 0058957	0 0086283	0 0058957	0 0086283	0 0187546	0 0058957
Perceived contribution to achieving backfill design basis (4)			0607871	0749572	0722779	0748906	0536696	0561334	0540359	0599267	0724868	058763
Apparent effectiveness (5)			.370	.456	.439	.455	.326	.341	.329	.364	.441	.357

Table E.5
3 of 8

ASSESSMENT OF EACH ALTERNATIVE BACKFILL SCHEME'S CONTRIBUTION TO ACHIEVING THE BACKFILL DESIGN BASIS

	BACKFILL DESIGN OBJECTIVE CODE (1)	RELATIVE WEIGHT	COMBINATION OF WASTE EMPLACEMENT HOLE: ROOM BACKFILL MATERIAL/ADDITIVE(2)									
			3B:3	3B:3A	3B:3B	4:1	4:3	4:4	4A:1	4A:3	4A:3A	4A:4A
ROOM/WASTE PACKAGE SCALE	bq4-3	0 044100	0 30	0 30	0 30	0 10	0 20	0 20	0 10	0 30	0 30	0 30
	bh1-3	0 016100	0 30	0 60	0 70	0 10	0 20	0 30	0 20	0 30	0 50	0 50
	bq1-3	0 007560	0 30	0 50	0 30	0 10	0 40	0 40	0 20	0 40	0 50	0 50
	bq2-3	0 007560	0 50	0 40	0 20	0 20	0 60	0 60	0 20	0 60	0 50	0 50
	bq3-3	0 003700	0 50	0 40	0 30	0 20	0 60	0 60	0 10	0 50	0 40	0 40
	Perceived contribution to achieving set of schedules/procedures backfill design objectives (3)		025998	031206	029414	009044	021868	023478	011032	02751	030352	030352
SCHEDULES/PROCEDURES	bsrolc-1	0 017200	0 50	0 50	0 50	1 00	0 50	0 50	1 00	0 50	0 50	0 50
	bp2-1	0 004320	0 50	0 50	0 50	0 80	0 50	0 50	0 80	0 50	0 50	0 50
	bp3-1	0 004320	0 50	0 50	0 50	0 80	0 50	0 50	0 80	0 50	0 50	0 50
	bp1-1	0 003600	0 50	0 40	0 50	0 80	0 50	0 50	0 70	0 40	0 40	0 40
	bsr1a-1	0 003020	0 50	0 50	0 50	0 00	0 50	0 50	0 00	0 50	0 50	0 50
	bp4-1	0 002270	0 40	0 20	0 40	0 90	0 50	0 70	0 70	0 20	0 10	0 20
	bp5-1	0 000972	0 40	0 30	0 40	0 90	0 40	0 60	0 70	0 30	0 20	0 30
	bpr1-1	0 000840	0 50	0 40	0 50	1 00	0 50	0 50	1 00	0 50	0 40	0 40
	bshol-1	0 000788	0 50	0 50	0 50	0 50	0 50	0 50	0 50	0 50	0 50	0 50
	bsh1-1	0 000648	0 50	0 50	0 50	0 50	0 50	0 50	0 50	0 50	0 50	0 50
	bsrola-1	0 000504	0 50	0 50	0 50	1 00	0 50	0 50	1 00	0 50	0 50	0 50
	bsrolb-1	0 000422	0 50	0 50	0 50	1 00	0 50	0 50	1 00	0 50	0 50	0 50
	bsr1b-1	0 000302	0 50	0 50	0 50	1 00	0 50	0 50	1 00	0 50	0 50	0 50
	Perceived contribution to achieving set of room/waste package scale backfill design objectives (3)		0192788	0182836	0192788	0326958	0195058	0201542	0316874	0183676	0179594	0182836
Perceived contribution to achieving set of waste package scale backfill design objectives (see Table E.4)			0 0049551	0 0049551	0 0049551	0 0059918	0 0059918	0 0059918	0 0054208	0 0054208	0 0054208	0 0054208
Perceived contribution to achieving set of room scale backfill design objectives (see Table E.4)			0 0086283	0 0187546	0 0198251	0 0058957	0 0086283	0 0099928	0 0058957	0 0086283	0 0187546	0 0143545
Perceived contribution to achieving backfill design basis (4)			0588602	0731993	073473	0536273	0559939	0596168	0540359	0599267	0724868	0684109
Apparent effectiveness (5)			.358	.445	447	.326	.340	.363	.329	.364	.441	.416

ASSESSMENT OF EACH ALTERNATIVE BACKFILL SCHEME'S CONTRIBUTION TO ACHIEVING THE BACKFILL DESIGN BASIS

Table E.5
4 of 8

	BACKFILL DESIGN OBJECTIVE CODE (1)	RELATIVE WEIGHT	COMBINATION OF WASTE EMPLACEMENT HOLE: ROOM BACKFILL MATERIAL/ADDITIVE[2] 4B:1	4B:3	4B:3A	4B:3B	4B:4B	5:1	5:2	5:2A	5:3	5:3A
ROOM/WASTE PACKAGE SCALE	bq4-3	0 014100	0 20	0 30	0 30	0 30	0 30	0 20	0 30	0 30	0 30	0 30
	bh1-3	0 016100	0 30	0 30	0 60	0 70	0 70	0 30	0 50	0 80	0 40	0 80
	bq1-3	0 007560	0 10	0 30	0 50	0 30	0 30	0 20	0 30	0 40	0 30	0 50
	bq2-3	0 007560	0 10	0 50	0 40	0 20	0 20	0 10	0 20	0 30	0 50	0 40
	bq3-3	0 003780	0 10	0 50	0 40	0 30	0 30	0 10	0 20	0 20	0 50	0 40
	Perceived contribution to achieving set of schedules/procedures backfill design objectives (3)		01554	025998	031206	029414	029414	016296	025816	032158	027608	034426
SCHEDULES/PROCEDURES	bsrolc-1	0 017200	1 00	0 50	0 50	0 50	0 50	1 00	0 50	0 50	0 50	0 50
	bp2-1	0 004320	0 80	0 50	0 50	0 50	0 50	0 80	0 50	0 50	0 50	0 50
	bp3-1	0 004320	0 80	0 50	0 50	0 50	0 50	0 80	0 50	0 50	0 50	0 50
	bp1-1	0 003600	0 80	0 50	0 40	0 50	0 50	0 80	0 50	0 40	0 50	0 40
	bsrla-1	0 003020	0 00	0 50	0 50	0 50	0 50	0 00	0 50	0 50	0 50	0 50
	bp4-1	0 002270	0 90	0 40	0 20	0 40	0 50	0 80	0 60	0 40	0 40	0 30
	bp5-1	0 000972	0 90	0 40	0 30	0 40	0 50	0 80	0 60	0 50	0 40	0 30
	bpr1-1	0 000840	1 00	0 50	0 40	0 50	0 50	1 00	0 50	0 40	0 50	0 40
	bshol-1	0 000788	0 50	0 50	0 50	0 50	0 50	0 50	0 50	0 50	0 50	0 50
	bshl-1	0 000648	0 50	0 50	0 50	0 50	0 50	0 50	0 50	0 50	0 50	0 50
	bsrola-1	0 000504	1 00	0 50	0 50	0 50	0 50	1 00	0 50	0 50	0 50	0 50
	bsrolb-1	0 000422	1 00	0 50	0 50	0 50	0 50	1 00	0 50	0 50	0 50	0 50
	bsrlb-1	0 000302	1 00	0 50	0 50	0 50	0 50	1 00	0 50	0 50	0 50	0 50
	Perceived contribution to achieving set of room/waste package scale backfill design objectives (3)		0326958	0192788	0182836	0192788	019603	0323716	0199272	018932	0192788	0185106
Perceived contribution to achieving set of waste package scale backfill design objectives (see Table E.4)			0 0049551	0 0049551	0 0049551	0 0049551	0 0049551	0 0050896	0 0050896	0 0050896	0 0050896	0 0050896
Perceived contribution to achieving set of room scale backfill design objectives (see Table E.4)			0 0058957	0 0086283	0 0187546	0 0198251	0 0191081	0 0058957	0 0123001	0 0168374	0 0086283	0 0187546
Perceived contribution to achieving backfill design basis (4)			0590866	0588602	0731993	073473	0730802	0596329	0631329	073017	0606047	0767808
Apparent effectiveness (5)			.359	.358	.445	.447	.444	.363	.384	.444	.369	.467

ASSESSMENT OF EACH ALTERNATIVE BACKFILL SCHEME'S CONTRIBUTION TO ACHIEVING THE BACKFILL DESIGN BASIS

Table E.5
5 of 8

	BACKFILL DESIGN OBJECTIVE CODE (1)	RELATIVE WEIGHT	COMBINATION OF WASTE EMPLACEMENT HOLE: ROOM BACKFILL MATERIAL/ADDITIVE(2)									
			5:3B	5:5	5:6	6:1	6:2	6:2A	6:3	6:3A	6:3B	6:5
ROOM/WASTE PACKAGE SCALE	bg4-3	0 044100	0 40	0 40	0 60	0 30	0 50	0 50	0 40	0 40	0 50	0 50
	bh1-3	0 016100	0 70	0 80	0 60	0 20	0 50	0 70	0 30	0 70	0 60	0 70
	bg1-3	0 007560	0 30	0 20	0 50	0 30	0 40	0 60	0 40	0 60	0 50	0 40
	bg2-3	0 007560	0 20	0 20	0 30	0 10	0 20	0 30	0 50	0 40	0 20	0 20
	bg3-3	0 003780	0 30	0 30	0 60	0 20	0 30	0 30	0 50	0 50	0 40	0 40
	Perceived contribution to achieving set of schedules/procedures backfill design objectives (3)		033824	034678	044436	02023	03577	041258	031164	03836	038514	039368
SCHEDULES/PROCEDURES	bsro1c-1	0 017200	0 50	0 50	0 50	1 00	0 50	0 50	0 50	0 50	0 50	0 50
	bp2-1	0 004320	0 50	0 50	0 50	0 80	0 50	0 50	0 50	0 50	0 50	0 50
	bp3-1	0 004320	0 50	0 50	0 50	0 80	0 50	0 50	0 50	0 50	0 50	0 50
	bp1-1	0 003600	0 40	0 50	0 50	0 80	0 50	0 40	0 50	0 40	0 50	0 50
	bsr1a-1	0 003020	0 50	0 50	0 50	0 00	0 50	0 50	0 50	0 50	0 50	0 50
	bp4-1	0 002270	0 40	0 50	0 50	0 80	0 60	0 40	0 40	0 30	0 40	0 50
	bp5-1	0 000972	0 40	0 50	0 50	0 80	0 60	0 50	0 40	0 30	0 40	0 50
	bpr1-1	0 000840	0 50	0 50	0 50	1 00	0 50	0 40	0 50	0 40	0 50	0 50
	bsho1-1	0 000788	50	0 50	0 50	0 50	0 50	0 50	0 50	0 50	0 50	0 50
	bsh1-1	0 000648	[illegible]	0 50	0 50	0 50	0 50	0 50	0 50	0 50	0 50	0 50
	bsro1a-1	0 000504	0 50	0 50	0 50	1 00	0 50	0 50	0 50	0 50	0 50	0 50
	bsro1b-1	0 000422	0 50	0 50	0 50	1 00	0 50	0 50	0 50	0 50	0 50	0 50
	bsr1b-1	0 000302	0 50	0 50	0 50	1 00	0 50	0 50	0 50	0 50	0 50	0 50
	Perceived contribution to achieving set of room/waste package scale backfill design objectives (3)		0189188	019603	019603	0323716	0199272	018932	0192788	0185106	0192788	019603
Perceived contribution to achieving set of waste package scale backfill design objectives (see Table E.4)			0 0050896	0 0050896	0 0050896	0 0064157	0 0064157	0 0064157	0 0064157	0 0064157	0 0064157	0 0064157
Perceived contribution to achieving set of room scale backfill design objectives (see Table E.4)			0 0198251	0 0206546	0 019118	0 0058957	0 0123001	0 0168274	0 0086283	0 0187546	0 0198251	0 0206546
Perceived contribution to achieving backfill design basis (4)			0776575	0800252	0882466	064913	074413	0834331	0634868	0820409	0840336	0860413
Apparent effectiveness (5)			.472	.487	.537	.395	.452	.507	.401	.499	.511	.523

ASSESSMENT OF EACH ALTERNATIVE BACKFILL SCHEME'S CONTRIBUTION TO ACHIEVING THE BACKFILL DESIGN BASIS

Table E.5

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	BACKFILL DESIGN OBJECTIVE CODE (1)	RELATIVE WEIGHT	COMBINATION OF WASTE EMPLACEMENT HOLE: ROOM BACKFILL MATERIAL/ADDITIVE(2) 6:6	7:1	7:2	7:2A	7:3	7:3A	7:3B	7:5	7:6	7:7
ROOM/WASTE PACKAGE SCALE	bq4-3	0 044100	0 70	0 40	0 60	0 60	0 60	0 60	0 60	0 60	0 80	1 00
	bh1-3	0 016100	0 50	0 10	0 40	0 60	0 20	0 60	0 50	0 60	0 40	0 20
	bg1-3	0 007560	0 70	0 40	0 50	0 70	0 60	0 70	0 60	0 50	0 80	1 00
	bq2-3	0 007560	0 30	0 20	0 30	0 20	0 70	0 70	0 50	0 40	0 50	1 00
	bq3-3	0 003780	0 70	0 30	0 40	0 40	0 60	0 60	0 50	0 50	0 80	1 00
	Perceived contribution to achieving set of schedules/procedures backfill design objectives (3)		049126	02492	04046	044436	041776	048972	044716	044814	054572	06622
SCHEDULES/PROCEDURES	bsro1c-1	0 017200	0 50	1 00	0 50	0 50	0 50	0 50	0 50	0 50	0 50	0 50
	bp2-1	0 004320	0 50	0 80	0 50	0 50	0 50	0 50	0 50	0 50	0 50	0 50
	bp3-1	0 004320	0 50	0 80	0 50	0 50	0 50	0 50	0 50	0 50	0 50	0 50
	bp1-1	0 003600	0 50	0 80	0 50	0 40	0 50	0 40	0 50	0 50	0 50	0 50
	bsr1a-1	0 003020	0 50	0 00	0 50	0 50	0 50	0 50	0 50	0 50	0 50	0 50
	bp4-1	0 002270	0 50	0 80	0 60	0 40	0 40	0 30	0 40	0 50	0 50	0 50
	bp5-1	0 000972	0 50	0 80	0 60	0 50	0 40	0 30	0 40	0 50	0 50	0 50
	bpr1-1	0 000840	0 50	1 00	0 50	0 40	0 50	0 40	0 50	0 50	0 50	0 50
	bsho1-1	0 000788	0 50	0 50	0 50	0 50	0 50	0 50	0 50	0 50	0 50	0 50
	bsh1-1	0 000648	0 50	0 50	0 50	0 50	0 50	0 50	0 50	0 50	0 50	0 50
	bsro1a-1	0 000504	0 50	1 00	0 50	0 50	0 50	0 50	0 50	0 50	0 50	0 50
	bsro1b-1	0 000422	0 50	1 00	0 50	0 50	0 50	0 50	0 50	0 50	0 50	0 50
	bsr1b-1	0 000302	0 50	1 00	0 50	0 50	0 50	0 50	0 50	0 50	0 50	0 50
	Perceived contribution to achieving set of room/waste package scale backfill design objectives (3)		019603	0323716	0199272	018932	0192788	0185106	0192788	019603	019603	019603
Perceived contribution to achieving set of waste package scale backfill design objectives (see Table E.4)			0 0064157	0 0065989	0 0065989	0 0065989	0 0065989	0 0065989	0 0065989	0 0065989	0 0065989	0 0065989
Perceived contribution to achieving set of room scale backfill design objectives (see Table E.4)			0 019118	0 0058957	0 0123001	0 0168274	0 0086283	0 0187546	0 0198251	0 0206546	0 019118	0 010289
Perceived contribution to achieving backfill design basis (4)			0942627	0697862	0792862	0867943	076282	0928361 •	0904188	0916705	0998919	102711
Apparent effectiveness (5)			.573	.424	.482	.528	.464	.565	.550	.557	.607	.625

ASSESSMENT OF EACH ALTERNATIVE BACKFILL SCHEME'S CONTRIBUTION TO ACHIEVING THE BACKFILL DESIGN BASIS

Table E.5

NOTES:

(1) The backfill design objectives (and their relative weights) are a subset of the generic backfill design basis developed for this study (see Section 3 - Main Text), and have been coded as follows:

Code	Objective
bg4-3	[Maximize] adsorption potential of backfill along flow path from waste package to accessible environment (post resaturation)
bh1-3	[Maximize] distance from waste package through repository along flow path due to backfill (post resaturation)
bg1-3	[Maximize] length of flow path from waste package through backfill adsorbing material (post resaturation)
bg2-3	[Maximize] cross-sectional area of flow path from waste package through backfill adsorbing material (i.e., maximize volume of backfill) (post resaturation)
bg3-3	[Maximize] surface area per unit volume of backfill adsorbing material along flow path from waste package (post resaturation)
bsro1c-1	[Maximize] time to start resaturation process (i.e., maximize time to placement of backfill, room scale, while dewatering) (during retrieval period)
bp2-1	[Maximize] monitoring of potentially hazardous underground conditions as backfilling occurs (during retrieval period)
bp3-1	[Maximize] quick and efficient mitigation of detected underground hazards as backfilling occurs (during retrieval period)
bp1-1	[Maximize] use of safe/reliable equipment for backfilling (during retrieval period)
bsr1a-1	[Minimize] time to placement of backfill (room scale) (during retrieval period)
bp4-1	[Minimize] personnel requirements for backfilling (i.e., maximize mechanization and remote operations) (during retrieval period)
bp5-1	[Minimize] total effort required for backfilling (e.g., no backfilling) (during retrieval period)
bpr1-1	[Minimize] volume of backfill (room scale) (if placed, during retrieval period)
bsho1-1	[Maximize] time to placement of backfill around waste package, and ventilate (during retrieval period)
bsh1-1	[Minimize] time to placement of backfill around waste package (during retrieval period)
bsro1a-1	[Maximize] time to placement of backfill (room scale) (during retrieval period)
bsro1b-1	[Maximize] time to placement of backfill and ventilate (room scale) (during retrieval period)
bsr1b-1	[Delay and minimize] backfilling of tunnels along possible egress routes (room scale)(during retrieval period)

(2) See Table E.1 for the viable combinations of waste emplacement hole backfill material/additive (X) and room backfill material/additive (Y), denoted as X:Y.

(3) The perceived contribution of a given backfill scheme to achieving any set of backfill design objectives equals the summation (over all objectives in the set) of the products of the relative weight of each objective and the perceived contribution of the given scheme to achieving that objective.

(4) The perceived contribution of a given backfill scheme to achieving the generic backfill design basis used in this study equals the summation of the perceived contributions of that scheme in achieving the four mutually exclusive subsets of backfill design objectives (i.e., waste package scale, room scale, room/waste package scale, and schedule/procedures) which comprise the backfill design basis.

(5) The apparent effectiveness of a given backfill scheme in achieving the generic backfill design basis used in this study is determined by dividing the perceived contribution by the sum of the relative weights of all the backfill design objectives (i.e., 0.16445556). The apparent effectiveness can range from 0.0 (no effectiveness at all) to 1.0 (total effectiveness or complete achievement of the backfill design basis used in this study).

The relative contributions of any backfill scheme to achieving any backfill design objective, as well as the relative weights of each backfill design objective, entail significant uncertainty due to the subjective nature of their assessment. The assessment of relative contribution has been based on perceptions regarding each backfill scheme's expected performance. These perceptions are subject to change. Hence, the results of these assessments (i.e., apparent effectiveness) should be used only as an approximate indication of the extent to which the generic backfill design basis used in this study might be achieved by any backfill scheme.

APPARENT EFFECTIVENESS OF ALTERNATIVE BACKFILL SCHEMES

Table E.6

ROOM BACKFILL MATERIAL/ADDITIVE (See Table E.1)

WASTE EMPLACEMENT HOLE BACKFILL MATERIAL/ADDITIVE (See Table E.1)	1	2	2A	3	3A	3B	4	4A	4B	5	6	7
1	.295			.327								
2	.322	.369	.424	.366	.450	.436						
2A		.374	.428	.370	.456	.439				.455		
3	.326			.341								
3A	.329			.364	.441							
3B	.357			.358	.445	.447						
4	.326			.340			.363					
4A	.329			.364	.441			.416				
4B	.359			.358	.445	.447			.444			
5	.363	.384	.444	.369	.467	.472				.487	.537	
6	.395	.452	.507	.401	.499	.511				.523	.573	
7	.424	.482	.528	.464	.565	.550				.557	.607	.625

NOTE: The apparent effectiveness of each combination of waste emplacement hole and room backfill materials/additives is based on a preliminary evaluation of each (see Table E.5) using the subjective and yet explicit evaluation methodology developed in this study (see Section 4 - Main Text), and should be considered only as an approximate indication of the extent to which the generic backfill design basis used in this study (see Section 3 - Main Text) might be achieved by that combination. The apparent effectiveness can range from 0.0 (no effectiveness at all) to 1.0 (total effectiveness or complete achievement of the backfill design basis used in this study).

PRIORITIZED SUMMARY OF APPARENT EFFECTIVENESS OF ALTERNATIVE BACKFILL SCHEMES

Table E.7
1 of 3

ALTERNATIVE BACKFILL SCHEMES (MATERIALS/ADDITIVES)
(listed in approximate decreasing order of effectiveness)

Code	Waste Emplacement Hole	Room	Apparent Effectiveness
7:7	clinoptilolite around waste package	: room backfilled with clinoptilolite	.625
7:6	clinoptilolite around waste package	: room backfilled with illite	.607
6:6	illite around waste package	: room backfilled with illite	.573
7:3A	clinoptilolite around waste package	: room backfilled with muck & grouted	.565
7:5	clinoptilolite around waste package	: room backfilled with bentonite	.557
7:3B	clinoptilolite around waste package	: room backfilled with muck mixed w/bentonite	.550
5:6	bentonite around waste package	: room backfilled with illite	.537
7:2A	clinoptilolite around waste package	: room backfilled with concrete & grouted	.528
6:5	illite around waste package	: room backfilled with bentonite	.523
6:3B	illite around waste package	: room backfilled with muck mixed w/bentonite	.511
6:2A	illite around waste package	: room backfilled with concrete & grouted	.507
6:3A	illite around waste package	: room backfilled with muck & grouted	.499
5:5	bentonite around waste package	: room backfilled with bentonite	.487
7:2	clinoptilolite around waste package	: room backfilled with concrete	.482
5:3B	bentonite around waste package	: room backfilled with muck mixed w/bentonite	.472
5:3A	bentonite around waste package	: room backfilled with muck & grouted	.467
7:3	clinoptilolite around waste package	: room backfilled with muck	.464
2A:3A	concrete around waste package & grouted	: room backfilled with muck & grouted	.456
2A:5	concrete around waste package & grouted	: room backfilled with bentonite	.455
6:2	illite around waste package	: room backfilled with concrete	.452
2:3A	concrete around waste package	: room backfilled with muck & grouted	.450
3B:3B	muck mixed w/bentonite around waste package & grouted	: room backfilled with muck mixed w/bentonite	.447
4B:3B	sand mixed w/bentonite around waste package	: room backfilled with muck mixed w/bentonite	.447

PRIORITIZED SUMMARY OF APPARENT EFFECTIVENESS OF ALTERNATIVE BACKFILL SCHEMES

Table E.7
2 of 3

ALTERNATIVE BACKFILL SCHEMES (MATERIALS/ADDITIVES)
(listed in approximate decreasing order of effectiveness)

Code	Waste Emplacement Hole	Room	Apparent Effectiveness
3B:3A	muck mixed w/bentonite around waste package	: room backfilled with muck & grouted	.445
4B:3A	sand mixed w/bentonite around waste package	: room backfilled with muck & grouted	.445
4B:4B	sand mixed w/bentonite around waste package	: room backfilled with sand mixed w/bentonite	.444
5:2A	bentonite around waste package	: room backfilled with concrete & grouted	.444
3A:3A	muck mixed w/bentonite around waste package	: room backfilled with muck & grouted	.441
4A:3A	sand mixed w/bentonite around waste package	: room backfilled with muck & grouted	.441
2A:3B	concrete around waste package & grouted	: room backfilled with muck mixed w/bentonite	.439
2:3B	concrete around waste package	: room backfilled with muck mixed w/bentonite	.436
2A:2A	concrete around waste package & grouted	: room backfilled with concrete & grouted	.428
2:2A	concrete around waste package	: room backfilled with concrete & grouted	.424
7:1	clinoptilolite around waste package	: no room backfill	.424
4A:4A	sand around waste package & grouted	: room backfilled with sand & grouted	.416
6:3	illite around waste package	: room backfilled with muck	.401
6:1	illite around waste package	: no room backfill	.395
5:2	bentonite around waste package	: room backfilled with concrete	.384
2A:2	concrete around waste package & grouted	: room backfilled with concrete	.374
2A:3	concrete around waste package & grouted	: room backfilled with muck	.370
2:2	concrete around waste package	: room backfilled with concrete	.369
5:3	bentonite around waste package	: room backfilled with muck	.369
2:3	concrete around waste package	: room backfilled with muck	.366
3A:3	muck around waste package & grouted	: room backfilled with muck	.364
4A:3	sand around waste package & grouted	: room backfilled with muck	.364
4:4	sand around waste package	: room backfilled with sand	.363
5:1	bentonite around waste package	: no room backfill	.363

Table E.7
3 of 3

PRIORITIZED SUMMARY OF APPARENT EFFECTIVENESS OF ALTERNATIVE BACKFILL SCHEMES

ALTERNATIVE BACKFILL SCHEMES (MATERIALS/ADDITIVES)
(listed in approximate decreasing order of effectiveness)

Code	Waste Emplacement Hole	Room	Apparent Effectiveness
4B:1	sand mixed w/bentonite around waste package	: no room backfill	.359
3B:3	muck mixed w/bentonite around waste package	: room backfilled with muck	.358
4B:3	sand mixed w/bentonite around waste package	: room backfilled with muck	.358
3B:1	muck mixed w/bentonite around waste package	: no room backfill	.357
3:3	muck mixed w/bentonite around waste package	: room backfilled with muck	.341
4:3	sand around waste package	: room backfilled with muck	.340
3A:1	muck around waste package & grouted	: no room backfill	.329
4A:1	sand around waste package & grouted	: no room backfill	.329
1:3	no backfill around waste package	: room backfilled with muck	.327
3:1	muck around waste package	: no room backfill	.326
4:1	sand around waste package	: no room backfill	.326
2:1	concrete around waste package	: no room backfill	.322
1:1	no backfill around waste package	: no room backfill	.295

NOTE: The apparent effectiveness of each backfill scheme (see Table E.6) entails inherent uncertainty due to the subjective nature of the assessments made and should thus be used only as an approximate indication of the extent to which the generic backfill design basis used in this study might be achieved by that scheme. The apparent effectiveness can range from 0.0 (no effectiveness at all) to 1.0 (total effectiveness or complete achievement of the backfill design basis used in this study).

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14 ABSTRACT (200 words or less)

This report includes the identification and subjective evaluation of alternative schemes for backfilling around waste packages and within emplacement rooms. The aspects of backfilling specifically considered in this study include construction and testing; costs have not been considered. However, because construction and testing are simply implementation and verification of design, a design basis for backfill is required. A generic basis has been developed for this study by first identifying qualitative performance objectives for backfill and then weighting each with respect to its potential influence on achieving the repository system performance objectives. Alternative backfill materials and additives have been identified and evaluated with respect to the perceived extent to which each combination can be expected to achieve the backfill design basis. Several distinctly different combinations of materials and additives which are perceived to have the highest potential for achieving the backfill design basis have been selected for further study. These combinations include zeolite/clinoptilolite, bentonite, muck, and muck mixed with bentonite. Feasible alternative construction and testing procedures for each selected combination have been discussed. Recommendations have been made regarding appropriate backfill schemes for hard rock (i.e., basalt at Hanford, Washington, tuff at Nevada Test Site, and generic granite) and salt (i.e., domal salt on the Gulf Coast and generic bedded salt).

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