EEG-1

A COMPILATION OF SITE SELECTION CRITERIA, CONSIDERATIONS AND CONCERNS APPEARING IN THE LITERATURE ON THE DEEP GEOLOGIC DISPOSAL OF RADIOACTIVE WASTES

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FOREWORD

The purpose of the New Mexico Environmental Evaluation Group (EEG) is to conduct an independent technical evaluation of the potential radiation exposure to people from the proposed Federal radioactive Waste Isolation Pilot Plant (WIPP) near Carlsbad in order to protect the public health and safety and insure there is no environmental degradation. The EEG is part of the Environmental Improvement Division, a component of the New Mexico Health and Environment Department - the agency charged with the primary responsibility to protect the public health of the citizenry of New Mexico.

The Group is neither a proponent nor an opponent of WIPP.

Analyses are conducted of the reports issued by the Department of Energy and its contractors, other Federal agencies and other organizations as they relate to the potential health, safety and environmental impacts from WIPP.

This report titled, "A Compilation of Site Selection Criteria, Considerations and Concerns Appearing in the Literature on the Deep Geologic Disposal of Radioactive Waste" by Donna Goad, EEG, EID, HED, June, 1979, has been developed to assist the EEG in evaluating the reasonableness and adequacy of the WIPP site selection criteria. It is being made available to others for this purpose as well.

Robert H. Neill
Director

INTRODUCTION

This report is a compilation of information from a variety of sources (fifty-nine to be exact) about the selection and evaluation of a site for the deep geologic disposal of radioactive wastes: the criteria that should be used, the factors that must be considered and the concerns expressed by various authors on this issue. No attempt was made in this report to analyze or to judge the criteria and factors cited here. Rather the purpose of the report is to set forth the criteria that have been suggested in a form which provides for easy reference and which delineates the degree of agreement and disagreement present in the field of waste repository site selection.

A word of explanation is therefore needed on the format of this report. The criteria suggested are listed in Parts I through IV: Part I the general framework criteria, Part II the criteria for the host rock itself, Part III the criteria on the waste form and canister, and Part IV other criteria. Part V contains general considerations and concerns voiced in the sources. Within each part, the criteria are grouped according to subject; for example what each source says about volcanic activity in the site region is listed in the chapter Geothermal Gradient/Volcanic Activity. In order to avoid unnecessary repetition, within each chapter I have listed statements which summarize a given position and following each statement is the list of sources in which it can be found. If certain sources elaborate on this position, this is included (when informative) immediately preceding the source's listing. The criteria are organized in each chapter from general to specific.

Forward

Introduction

CONTENTS

EXPANDED TABLE OF CONTENTS

PART I: GENERAL FRAMEWORK CRITERIA

Part I: No. 2

1. TOPOGRAPHY

1. Should be taken into account/information useful for site selection/evaluation:
   - i. AECL, Canada, 1976, p. 12-13, (E2)
   - ii. USGS 4339-1, 1972, p. 7-9, (B2)
   - iii. ES of WM of LWR Cycle, NRC 1973, p. 4-73, (C8)

2. Low relief and gently sloping terrain is desirable for site:
   - i. preliminary site selection criteria, GCR, p. 1:3, (D10)
   - ii. USGS 74-158, 1974, p. 27, (B8)
   - iii. ERDA/BNWL Alternatives, App C, 1976, p. C-1, (D18)
   - iv. IAEA S.S. Factors 1977, p31, (E11)
   - v. avoid areas with slopes steeper than 500 ft./mile, Kehnemuyi, Battelle M, 1979, (D23)

Reasons for preference:

a. accessibility
   - i. GCR, p. 2:16-17, (D10)
   - ii. ERDA/BNWL Alternatives, App C, 1976, p. C-1, (D18)
   - iii. Kehnemuyi, Battelle M, 1979, (D23)
   - iv. IAEA S.S. Factors, 1977, p. 31, (E11)

b. avoid areas where high relief coincides with high frequency of faults:
   - i. USGS 74-158, 1974, p. 3, (B8)
   - ii. HLWM Alternatives, BNWL-1900, 1974, p. 4.4, (D16)

c. complex surface indication of complex subsurface; gentle relief indication of undisturbed rocks at depth:
   - i. ERDA/BNWL Alternatives, App C, 1976, p. C-1, (D18)
   - ii. IAEA 1977, p. 31, (E11)

d. questioned stability, hydrology in rugged relief:
   - i. Kehnemuyi, Battelle M., 1979, (D23)
   - ii. HLWM Alternatives, BNWL-1900, 1974, p. 4.4, (D16)
   - iii. USGS 74-158, p. 3, (B8)

e. avoid steep surface water drainage gradients that would allow rapid distribution of contaminants in case of accident:
   - i. USGS 74-158, p. 2, (B8)
   - ii. HLWM Alternatives, BNWL-1900, 1974, p. 4.13, (D16)

f. minimize accelerated erosion:
   - i. GCR, p. 2:16-17, avoid features that would tend to localize and/or accelerate erosion, (D10)
   - ii. HLWM Alternatives, BNWL-1900, 1974, p. 4.5 - in case of change of climate, (D16)
   - iii. Considerations for HLWM, Gera and Jacobs, ORNL, 1972, p. 97, (D5)

g. lower cost of development:
   - i. Kehnemuyi, Battelle M., 1979, (D23)

h. avoid conditions triggering diapirism:
   - i. consider effect of relief, GCR p. 2:16-17, (D10)
   - ii. S.S. Criteria - diapirism should not be a reasonable possibility; factors that militate against salt flow - low relief, minimal differential loading, NAS/NRC Bedded Salt 1970, p. 4-5, (A2)
   - iii. risk of containment failure due to diapirism negligible if rep located where surface relief, differential loading is minimal
     - Gera, ORNL, Salt Tectonics, GSA 1972, (D4)
     - Considerations for HLWM, Gera and Jacobs, ORNL 1972, p. 115-116, (D5)
   - iv. for thick bodies of salt, limit site to those with low to moderate relief to avoid differential loading, ERDA/BNWL Alternatives, App C, p. C-1, (D18)

3. Drainage pattern - area unsuitable for rep where change in pattern could inundate site, HLWM Alternatives, BNWL-1900, 1974, p. 4.4, (D16)

4. Elevation:

a. for site in coastal region, site should be above the highest level to which marine incursions are likely to extend during operation of rep. (Some off-shore islands may be suitable if this requirement is met). IAEA 1977, p. 31, (E11)

b. areas unsuitable for rep where sea level rise could inundate site

i. HLWM Alternatives, BNWL-1900, 1974, p. 4.4, (D16)

ii. USGS 74-158, p. 3, (B8)

c. if site is in area of low elevation with disposal formation perhaps below sea level, greatly reduce risk of excessive erosion, Considerations for HLWM Gera and Jacobs, ORNL 1972, p. 97, (D5)

2. Climate

1. Should be taken into account/ information useful for site selection/evaluation:

   i. p. 11, USGS 4339-1, 1972, (B2)
   ii. factors affecting long term stability/site suitability: rain and snow, temperature, tornados and winds, p. 25-45, AEC, Lyons E.S. 1971, (D6)
   iii. criteria should include meteorological problems, p. 46, NRC, State Review/Analysis, Nureg 0354, 1978, (C5)
   iv. climatic setting is one of more critical factors (for salt it is necessary to establish the nature and rate of dissolutioning)
      - p. 26-27, USGS 74-158, 1974. (B8)
      - p. 4.63, HLWM Alternatives, BNWL-1900, 1974, (D16)

2. Possible climatic change should be considered:

   i. consider changes like ice ages and sea level rises in making criteria, p. 12-13, Canada AECL, 1976, (E2)
   ii. waste should be safe from climatic changes; criteria must be met, p. 13-14, Deep Rock, Klett, Sandia, 1974, (D8)
   iii. Glaciation must be considered in site selection
      - p. C12-13, ERDA/BNWL, Alternatives App C 1976, (D18)
      - p. 44, IAEA SS Factors, 1977, (E11)
   iv. area unsuitable where return to glacial/pluvial climate causes undesirable changes, p. 4.4, HLWM Alternatives, BNWL-1900, 1974, (D16)
   v. most important general and basic considerations - possible climatic change, p. 9, USGS 74-158, 1974, (B8)
   vi. has to be shown that effects of future glaciation are acceptable, p. 15, Canada AECL 1975, (E1)
   vii. glaciation and associated climatic changes (differing effects on all waste rep sites) or warming/sea level rise - should be taken into consideration, p. 36-40, EPA, State of Geologic Knowledge, 1978, (C7)
   viii. in site selection - consideration of probability and consequences of glaciation, climatic change, p. 9, NAS/NRC Implementation of Standards, 1979, (A3)

Should be considered because:

a.) effect on hydrological factors/changes in groundwater regime (because of glaciation, return to pluvial climate, warming trend):
   i. p. 2:17-18, GCR, 1978, (D10)
   ii. p. 2, 155-157, USGS 74-158, 1974, (B8)
   iii. p. 9-12, USGS ES Perspectives, 1978, (B10)
   iv. low permeability of aquifers limits flow even if hydraulic heads changed due to future pluvial cycles, Letter from Beckner to Schueler, 1978, (D13)
   v. events taken into account in risk assessment - climatic change leading to an influx of groundwater, p. 162, AD Little, Assessment, 1978, (C3)
   vi. p. 20, NAS/NRC Implementation of Standards, 1979, (A3)

b.) effect on rate of erosion by streams, surface water:
   i. p. 2; for salt need careful studies, p. 26-27; by streams, drainage associated with glaciers, p. 155-7; waste must be placed where it will not be exhumed by erosion, p. 165-168, USGS 74-158, 1974, (B8)
   ii. select site with low rate of erosion and all available information must indicate that no significant increase in rate is likely in the future, p. 93, Considerations for HLWM, Gera and Jacobs, ORNL 1972, (D5)

iii. events taken into account in risk assessment - increased erosion, p. 162, A.D. Little, Assessment 1978, (C3)

c.) effect on rate of erosion - glaciers:
   i. areas covered by past glacial epochs should either be avoided or considered only in terms of concepts requiring several thousand feet of burial, p. 158-160, USGS 74-158, 1974, (B8)
   ii. glacial erosion differs considerably from stream erosion and deserves careful consideration - high rates possible, can extend erosive action below sea level p. 69-76; most prudent to select site that has not been affected by any of the Pleistocene glaciations, p. 93, Considerations for HLWM, Gera and Jacobs, ORNL 1972, (D5)

d.) effect on rate of erosion - sea level rise, isostatic uplift:
   i. can drastically effect the rate of erosion, p. 69-76, Considerations for HLWM, Gera and Jacobs, ORNL, 1972, (D5)

e.) possibility of inundation by creation of new lakes, streams, rivers:
   i. glacial lakes, p. 158-160; new lakes from the return of pluvial climate, p. 165, USGS 74-158, 1974, (B8)

f.) possibility of inundation by sea level rise:
   i. unsuitable areas for rep - where sea level rise could inundate site, p. 2-3; if all ice in polar caps melted, would rise 200 ft - all sites within coastal area, especially those below 200 ft level, should be reviewed critically as site, p. 163, USGS 74-158, 1974, (B8)
   ii. areas unsuitable for rep - where sea level rise could inundate site, p. 4.4, HLWM Alternatives, BNWL-1900, 1974, (D16)
   iii. should be taken into consideration, p. 36-40, EPA State of Knowledge, 1978, (C7)

g.) effect on rate of dissolutioning of salt formations:
   i. p. 26-27, USGS 74-158, 1974, (B8)
   ii. p. 4.63, HLWM Alternatives, BNWL-1900, 1974, (D16)

h.) effect on rates of sedimentation:
   i. p. 158-160, USGS 74-158, 1974, (B8)

i.) glaciation - effect of isostatic loading : faulting and fracturing:
   i. p. 158=160, USGS 74-158, 1974, (B8)
   ii. peak rates of glacial isostacy linked to extensive faulting, fracturing, seismic activity - should be factored into analysis, p. 122, Johansson and Steen, Ringhals-3, 1978, (E10)

3. So should an area which could be glaciated be considered for a rep?
   i. no or only for concept requiring several thousand feet of burial, p. 158-160, USGS 74-158, 1974, (B8)
   ii. no - most prudent to select a site in an area that has not been affected by any of the Pleistocene glaciations, p. 93, Considerations for HLWM, Gera and Jacobs, ORNL 1972, (D5)
   iii. sure - there may be certain advantages to selecting a site in areas likely to be reglaciated - effectively seals them from intrusion several thousand years hence, p. 36-40, EPA State of Knowledge, 1978, (C7)

4. Can we predict climatic changes and its effects?
   i. yes - general location and maximum effects of glaciation can be predicted,
      - p. C12-13, ERDA/BNWL, Alternatives App C 1976, (D18)
      - p. 44, IAEA SS Factors, 1977, (E11)

ii. no - at present we don't have the capability to predict future climate so select a site not affected by past glaciations, p. 93, Considerations for HLWM, Gera and Jacobs, ORNL 1972, (D5)

iii. Can we estimate the long term effects of climatic change? current state of knowledge: moderate understanding of principles, developing models, p. 44, ESTP, USGS and DOE, 1979, (D24)

5. So far as practicable, design and construction of rep should provide for the possible onset of conditions resulting from gross climatic change, p. 44, IAEA SS Factors, 1977, (E11)

3. Hydrology - surface water

1. Should be taken into account/information useful for site selection/evaluation:
   - i. p. 6-7, USGS 4339-1, 1972, (B2)
   - ii. p. 2-3, Supplemental areas, Kansas GS, 1972, (B11)
   - iii. p. 2:16-17, GCR 1978, (D10)
   - iv. p. 25-45, AEC Lyons ES, 1971, (D6)
   - v. determine that present surface water will not interfere with short term or compromise long term containment,
     - p. 5-6, OWI/DOE, Salt Dep of US 1978, (D21)
     - p. C10-12, ERDA/BNWL, Alternatives App C 1976, (D18)
     - p. 41, IAEA SS Factors 1977, (E11)
   - vi. future behavior of streams must be predicted in order to assure containment,
     - p. C10-12, ERDA/BNWL, Alternatives App C 1976, (D18)
     - p. 41, IAEA SS Factors 1977, (E11)

Because:

a.) erosion:
   - i. avoid features that tend to localize and/or accelerate erosion, p. 2:16-17, GCR 1978, (D10)
   - ii. Los Medaños site suitable - has escaped almost completely undamaged long periods of erosion, p. 34, USGS 4339-7, 1973, (B5)
   - iii. potential hazard to rep in SENM - erosion by streams, p. 6 USGS 74-194, 1974, (B7)
   - iv. site should be where danger of exhumation by erosion is nil, p. 2; most important general and basic considerations - effects of erosion and rates of denudation, p. 9; studies must be made to predict accurately denudation and erosion rates that will prevail during the lifetime of the rep, p. 26-27; USGS 74-158, 1974, (B8)
   - v. long term considerations - stream erosion, p. 25-45, AEC Lyons ES 1971, (D6)
   - vi. recommendation for Lyons - long term R&D needed to estimate future rate of erosion, p. 14-15, NAS/NRC, Bedded Salt, 1970, (A2)
   - vii. range of tasks includes study of erosion and denudation, p. 32, OWI/ERDA Program Plan for NWTSP, 1976 (D19)
   - viii. areas of rapid uplift/deformation are less desirable - effect on denudation, p. 3-4, OWI/DOE, Salt Dep of US 1978, (D21)
   - ix. site selection - need evaluation of erosion and denudation, p. 3 ORNL - Program Plan for BSPP 1973, (D1)
   - x. evaluation of site suitability must include investigation/evaluation of surface erosion and denudation, ORNL, McClain and Boch, 1974, (D3)
   - xi. depth - must be sufficient to protect rep from erosion, Kehnemuyi, Battelle M, 1979, (D23)
   - xii. rates of erosion - should be considered, p. 9-10, BSPP SS Factors, 1973, D2
   - xiii. areas unsuitable for rep - where there is danger of exhumation by erosion, p. 4.4, HLWM Alternatives, BNWL-1900. 1974, (D16)
   - xiv. consider stream erosion, p. 61-69; necessary to select site in area with low rate of erosion, p. 93; site selection criteria that should be used - depth of burial should not be reduced excessively by erosion and the possibility of future increase in erosion rates due to uplift, climatic changes, people should be considered, p. 131, Considerations for HLWM, Gera and Jacobs, ORNL 1972, (D5)
   - xv. erosion considered - can expose wastes or alter conditions of groundwater flow, p. 9-12, USGS, ES Perspectives 1978, (B10)
   - xvi. geologic hazard to be taken into account - denudation and erosion, p. 36-40, EPA State of Knowledge, 1978, (C7)

xvii. events taken into account in risk assessment - erosion, change in erosion rates due to climatic change, p. 162, AD Little, Assessment, 1978, (C3)

xviii. ES aspects of long term risk analysis - need knowledge of processes affecting containment capability like erosion, p. 16-17, ESTP, USGS and DOE, 1979, (D24)

xix. erosion to be evaluated for changes in hydrologic regime, p. 20, NAS/NRC Implementation of Standards, 1979, (A3)

b.) Inundation/flooding:

i. evaluate possibility, p. 2:16-17; surface water should not endanger penetrations while these are still unplugged, p. 2:17-18, GCR 1978, (D10)

ii. possibility considered for SENM, p. 6, USGS 74-194, 1974, (B7)

iii. waste should not be placed in natural hazard areas where there are frequent floods (criteria must be met), p. 13-14, Deep Rock, Klett Sandia 1974 (D8)

iv. flood plains- not suitable for site unless unique design precautions are utilized.

- p. C10-12, ERDA/BNWL Alternatives App C 1976, (D18)
- p. p. 41, IAEA SS Factors, 1977, (E11)

v. special problems with using flood plains for site, p. 5-6, OWI/DOE, Salt Dep of US, 1978, (D21)

vi. avoid flood plains and if area has been known to have been flooded within the recent past, its suitability needs careful consideration, Kehnemuyi, Battelle M, 1979, (D23)

vii. areas unsuitable for rep - where changes in drainage patterns could inundate site, p. 4.4, HLWM Alternatives BNWL-1900, 1974, (D16)

c.) rapid dispersal in case of an accident:

i. avoid steep surface water gradients, p. 2, USGS 74-158, 1974, (B8)

ii. so site should be remote from large surface water supplies, p. 9-10, BSPP SS Factors, ORNL 1973, (D2)

iii. as far removed from oceans, major lakes, streams as practicable, p. 4.63, HLWM Alternatives, BNWL-1900, 1974, (D16)

d.) conflict with surface water usage:

i. no area adjacent to actual or potential dam site should be considered, (due to disruption of hydrologic system by presence of lake), p. 13-15, NAS/NRC, 1978, (A1)

ii. consideration - possible conflict with recreational, scenic, industrial interest in large lakes and streams

- p. C10-12, ERDA/BNWL Alternatives App C 1976, (D18)
- p. 41, IAEA SS Factors, 1977, (E11)

iii. areas potentiallly attractive for development of surface water resources shall be avoided as much as possible, p. 6, Brunton and McClain, OWI/ERDA 1977, (D20)

e.) sedimentation:

i. events taken into account in risk assessment - sedimentation, p. 162, AD Little, Assessment, 1978, (C3)

f.) stream capture:

i. to be evaluated/considered for changes in hydrologic regime, p. 20, NAS/NRC Implementation of Standards, 1979, (A3)

g.) ES aspects of long term risk analysis - need knowledge of regional movement of surface water supplied by groundwater, p. 16-17, ESTP, USGS and DOE, 1979, (D24)

2. So site selection criteria with regard to surface water are:

a. mere presence of streams, lakes , ponds above an otherwise suitable site should not necessarily rule it out - determine it will not interfere with operation or jeopardize containment

i. p. 5-6, OWI/DOE, Salt Dep of US, 1978, (D21)
ii. p. CI0-12, ERDA/BNWL Alternatives App C 1976, (D18)
iii. p. 41, IAEA SS Factors, 1977 , (E11)

b.) promising area - Shafer Dome which is crossed by a bend of the Colorado River (this does not seem to bother the authors), p. 62-66, USGS 4339-6, 1973 , (B4)

c.) site should be far removed from oceans, major drainages, major lakes:

i. p. 2, USGS 74-158, 1974, (B8)
ii. Kehnemuyi, Battelle M, 1979, (D23)
iii. surface water should be remote, Summary of SS Factors, BSPP SS Factors, ORNL 1973, (D2)
iv. p. 4.5; as far as practicable, p. 4.63, HLWM Alternatives, BNWL-1900, 1974 ,(D16)

3. Can we predict future erosion? There is a finite but very low probability that a rep buried at depth will reappear at the earth's surface. How one can make an order of magnitude conjecture concerning the probability is beyond the Panel's ability to resolve. p. 36-40, EPA, State of Knowledge, 1978 , (C7)

4. Tectonic Stability/Seismicity/Faulting

1. Should be taken into account/information useful for site selection/evaluation:
   i. take into account location, frequency and intensity of seismic activity, p. 5, USGS 4339-5, 1973, B3
   ii. should be considered in making criteria - seismicity, faulting, p. 12-13, Canada AECL 1976, E2
   iii. consider complexity of internal structure/faulting, p. 45, USGS 4339-6, 1973, B4
   iv. features of interest - seismicity, p. 1, faulting, p. 20, USGS 74-60, 1974, B6
   v. features of interest - deformation due to compressional forces or tectonic stresses, p. 17, USGS 74-190, 1974, B9
   vi. tectonics, p. 25-45, AEC Lyons ES, 1971, D6
   vii. future occurence of faulting and earthquakes must be considered in site selection,
   - p. C12-13, ERDA/BNWL Alternatives App C 1976, D18
   - p. 44, IAEA SS Factors, 1977, E11
   viii. range of tasks - evaluation of structural stability, seismicity, and tectonics for long periods into the future, p. 32, OWI/ERDA Program Plan for NWTSP, 1976, D19
   ix. must investigate tectonism, especially faulting, diapirism, and microseismicity (can indicate deeply buried faults), ORNL, McClain and Boch, 1974, D3
   x. consider tectonism and seismicity - can transport waste to surface, alter initial conditions of groundwater flow, p. 9-12, USGS, ES Perspectives, 1978, B10
   xi. site selection criteria must include consideration of seismicity and tectonics, p. 4-73, ES of WM of LWR Cycle, NRC 1976, C8
   xii. events taken into account in risk assessment - faulting, seismicity, p. 95-103; tectonic activity, folding and faulting, resulting in direct exumation, p. 162, AD Little Assessment 1978, C3
   - prediction of faulting, p. 16-17, ESTP, USGS and DOE, 1979, D24
   xiii. site selection - suitability of broad regions in terms of geologic stability, of local regions in terms of structural integrity, i.e. occurence of faults, p. 13; site characterization - need detailed definition of tectonic and geomorphic processes acting at or near site, p. 14, ESTP, USGS and DOE, 1979, D24
   xiv. factors that determine the suitability of the site - risk of rock movements/stability, Appendix, p. 5, Johansson and Steen, Ringhals-3, 1978, E10
   xv. for site selection, consideration of probability and consequences of earthquakes, p. 9; tectonism/tilting of ground surface - consider for changes in hydrologic regime, p. 20; information needed - document historical record of earthquakes in region, stress determinations, geologic record, p. 14, NAS/NRC Implementation of Standards, 1979, A3
   xvi. most important general and basic considerations - long term tectonic effects and seismic risk, p. 9, USGS 74-158, 1974, B8
   xvii. site selection factors - all aspects of regional geologic structure should be examined for any features which would suggest that site might be located where future deformations would be concentrated, i.e. look for zones of weakness, folding trends, p. 9; tectonic stability - details of historical earthquakes should be examined for large area surrounding site and correlated with regional structure if possible, p. 9, BSPP SS Factors, ORNL 1973, D2

2. Site preferably located in an area of tectonic stability/low seismicity, low seismic risk:

i. in structurally stable block far from tectonic boundary
- p. 6-9, NAS/NRC Aug 1978, A1
- Kehnemuyi, Battelle M, 1979, D23

ii. p. 2:18-19, GCR, 1978, D10

iii. p. 4, p. 15, Canada AECL 1975, E1

iv. information useful in evaluating suitability of Carlsbad area - tectonically stable since the Tertiary, p. 28-32, USGS 4339-1, 1972, B2

v. Los Medaños suitable because has long history of tectonic stability, only slightly structurally deformed, p. 34, USGS 4339-7, 1973, B5

vi. area suitable - prerequisites of catastrophic events like earthquakes and mountain building not known to exist in SENM, p. 6, USGS 74-194, 1974, B7

vii. p. 2; areas unsuitable - where seismic risk is high, p. 3; rep should not be located in seismic risk zone 3, yes in zones 2 or less if zones of active faulting are avoided, p. 187-189; not in S. California, p. 173, USGS 74-158, 1974, B8

viii. areas considered unsuitable - where seismic risk is high, p. 4.4; rep should not be located in seismic risk zone 3, yes in zones 2 or less if zones of active faulting are avoided, p. 4.62, HLWM Alternatives, BNWL-1900, 1974, D16

ix. site selection criteria, p. 21, AEC Lyons ES 1971, D6

x. p. 5, USGS 4339-5, 1973, B3

xi. waste should not be placed in natural hazard areas where there are frequent earthquakes, waste should be safe from geologic change, i.e. media must be stable (criteria must be met), p. 13-14, Deep Rock, Klett Sandia, 1974, D8

xii. criteria for bedded salt, p. 4-5, NAS/NRC Bedded Salt 1970, A2

xiii. site shall not have experienced events in past 10^7 (10,000,000) years of type and magnitude that would compromise integrity of rep in future, p. 4-5, NRC State Review, Nureg 0353, 1977, C4

xiv. siting should be based on geological investigation and predictions of future stability in entire region, p. 30, NRC State Review/Analysis, Nureg 0354, 1978, C5

xv. dominating factor - geological stability, p. 23.15-17, ERDA/BNWL Alternatives Vol. 4, 1976, D17

xvi. p. C1, C2, ERDA/BNWL Alternatives App C 1976, D18

xvii. p. 31-32, IAEA SS Factors 1977, E11

xviii. p. 5; regional characteristics important for disposal - regions that have been tectonically stable over the past tens of millions of years are likely to remain so for a while, p. 3-4, OWI/DOE, Salt Dep of US 1978, D21

xix. p. 2, ORNL Program Plan for BSPP, 1973, D1

xx. avoid areas of high relief - may indicate questionable stability, Kehnemuyi, Battelle M, 1979, D23

xxi. Summary of SS Factors - tectonic stability, low historic seismicity, BSPP SS Factors, ORNL 1973, D2

xxii. one of principal reasons for considering a formation - has existed undisturbed for up to many millions of years, p. 19, IAEA SS Factors, 1977, E11

xxiii. Criteria must be met - predicted seismic activity of region shall be low enough so as not to pose a threat to operation or integrity of rep, p. 5, Brunton and McClain, OWI/ERDA 1977, D20

xxiv. site selection criteria that should be used - site distant from orogenic belts, tectonically stable in last few million years, p. 131, Considerations for HLWM, Gera and Jacobs, ORNL 1972, D5

xxv. to make rep inaccessible and inviolable, de Marsily et al, Guarantee Isolation? 1977, E5

xxvi. one of most important technical aspects - geological stability, rep should not be jeopardized by earthquakes, p. III-6-9, KBS Rydberg and Winchester, 1978, E9

xxvii. p. 2-9, p. 4-73, ES of WM of LWR Cycle, NRC 1976, C8
xxviii. assumption for safe rep - in an area not subject to high energy earthquakes, in stable geological environment, p. 1, EPA State of Knowledge, 1978, C7
xxix. U. of Uppsala - site should be far from earthquake center in Sweden, p. 168, Johansson and Steen, Ringhals-3, 1978, E10
xxx. select site not prone to seismic activity, p. 15; it must be demonstrated quantitatively that the proposed location of the rep is tectonically very stable, p. 26, NAS/NRC, Implementation of Standards, 1979, A3

Reasons for prefering an area of low seismicity/tectonic stability:

a.) earthquake induced faulting through rep - a major concern:
i. p. 6-9, NAS/NRC 1978, A1
ii. p. 2, USGS 74-158, 1974, B8
iii. p. C1-2, ERDA/BNWL Alternatives App C 1976, D18
iv. p. 5, OWI/DOE Salt Dep of US 1978, D21
v. p. 31-32, IAEA SS Factors 1977, E11
vi. p. 79, p. 92, Considerations for HLWM, Gera and Jacobs, ORNL 1972, D5
vii. p. III 6-9, KBS Rydberg and Winchester, 1978, E9
viii. taken into account in risk assessment, p. 162, AD Little Assessment, 1978, C3

b.) changes in hydrologic regime:
i. p. 9-12, USGS ES Perspectives 1978, B10
ii. p. 20, NAS/NRC Implementation of Standards, 1979, A3

c.) Trigger diapirism:
i. tectonic stability is a factor that militates against salt flow, p. 4-5, NAS/NRC Bedded Salt 1970, A2
ii. ORNL, McClain and Boch, 1974, D3
iii. risk of containment failure due to diapirism is negligible if, among other things, the formation is located in a tectonically stable area
- Gera, Salt Tectonics, ORNL, GSA 1972, D4
- p. 115-116, Considerations for HLWM, Gera and Jacobs, ORNL 1972, D5
iv. p. 3, Brunton and McClain, OWI/ERDA 1977, D20

d.) problems with areas of pronounced uplift/subsidence:
i. avoid such areas as it makes prediction of future dissolution, erosion and salt flow uncertain, p. 2:18-19, GCR 1978, D10
ii. avoid areas of rapid uplift - accelerated erosion, p. 3-4, OWI/DOE Salt Dep of US 1978, D21
iii. uplift/subsidence shall not pose a threat to integrity of rep, criteria must be met, p. 3, Brunton and McClain, OWI/ERDA 1977, D20
iv. uplift - accelerated erosion, p. 69; subsidence - deep burial and subsequent change in temperature and pressure conditions, p. 76-78; uplift can be fast enough to affect the rates of erosion in a way relevant to waste disposal and therefore site should be located in an area where the earth's crust is in isostatic equilibrium and where no uplifting is occuring. Subsidence on the other hand might be a desirable feature, p. 93-4, Considerations for HLWM, Gera and Jacobs, ORNL 1972, D5

v. of concern - accelerated erosion, p. 36-40, EPA State of knowledge, 1978 , C7

e.) increased risk of volcanic activity in tectonically unstable area or in area near the mobile belts of the earth, p. 89-91, Considerations for HLWM, Gera and Jacobs, ORNL 1972, D5

f.) seismic shaking of closed rep in not of great concern; more of concern is the affect on operating facility:

i. p. 6-9, NAS/NRC 1978 , A1

ii. low seismicity is prefered but facility design can accomodate higher levels, p. 2:18-19, GCR 1978 , D10

iii. short term risk of seismicity to shafts, mine workings, i.e. flooding due to shaft failure where it passes through an aquifer

- p. C1-2, ERDA/BNWL Alternatives App C 1976, D18
- p. 31-32, IAEA SS Factors, 1977 , E11

iv. p. 5, OWI/DOE, Salt Dep of US, 1978, D21

v. salt is self sealing, p. 2, ORNL Program Plan for BSPP, 1973, D1

vi. earthquake resistance is a factor in design of surface facilities, p. 9, BSPP SS Factors, ORNL 1973, D2

vii. hazards of earthquakes may be overly exagerated - there is little damage to underground workings if they are not dissected by seismogenic fault (in site selection avoid such faults). Once the rep has been sealed, effects of large scale earthquakes are likely to be negligible. p. 36-40, EPA State of Knowledge 1978, C7

g.) Though areas of low seismicity are prefered in site selection, sites may be located in areas of higher seismicity if greater care and discrimination is used in their selection:

i. p. 5, USGS 4339-5, 1973, B3

ii. site must not be in seismic risk zone 3 but may be in zones 2 or less if it is assured that fault systems are avoided through careful mapping and seismic monitoring

- p. 26, p. 187-189, USGS 74-158, 1974, B8
- p. 4.62, HLWM Alternatives, BNWL-1900,1974, D16

3. Existing Faults - should be considered/information useful in site selection:

i. to be considered in making criteria - occurence of major faults, existence of faults, p. 12-13, Canada AECL 1976 , E2

ii. consider abundance of fractures, p. 5; presence of Quaternary faults, p. 12, USGS 4339-5, 1973 , B3

iii. generally deleterious - some flexuring occurs in most rock though and its significance has to be evaluated for each site (adversely affects brittle more than plastic rocks)

- p. C4-5, ERDA/BNWL Alternatives App C 1976, D18
- p. 35, IAEA SS Factors 1977, E11

iv. must be investigated, ORNL, McClain and Boch, 1974, D3

v. should examine site for features that would suggest future deformations, i.e. subsurface faults, p. 9, BSPP SS Factors, ORNL 1973 , D2

vi. shall not compromise rep operations, design or containment capability, p. 3, Brunton and McClain, OWI/ERDA 1977 , D20

vii. uncertainties introduced into transport model making - presence of fractures which increases flow rate and decreases sorption capacity, p. 8, USGS, ES Perspectives 1978, B10

viii. determination of suitability on local level, p. 13, ESTP, USGS and DOE, 1979, D24

ix. information needed - need detailed high quality maps, 3 dimensional data needed for design. Look at geologic record of fault displacements of region (also for prediction of earthquakes.), p. 15, NAS/NRC Implementation of Standards, 1979, A3

4. Existing faults - should be avoided in site selection:
   i. avoid thaose seismically active or that have been in last million years, p. 6-9, NAS/NRC, 1978, A1
   ii. avoid major faults, pronounced linear trends, p. 2:16-17, GCR 1978, D10
   iii. formation should have high integrity with minimum of faults, p. 15, Canada AECL 1975, E1
   iv. should not have abundance of fractures, p. 12, USGS 4339-5, 1973, B3
   v. important consideration - site must be virtually free of faults, p.1; unsuitable area - where high relief coincides with high frequency of faults, p. 3; site must be hydrologically isolated from permeable fault systems, p. 145; faults, active or not,must be checked for in area, p. 26; thermal springs can be surface expression of faults - check it out, p. 147; area in seismic risk zone 2 or less suitable for rep if zones of active faulting are avoided, p. 187-189, USGS 74-158, 1974, B8
   vi. faults - generally deleterious effect - major faults should be avoided entirely; choose area with no or few faults - if faults are present they should be locatable
      - p. C4-5, ERDA/BNWL Alternatives App C 1976, D18
      - p. 35, IAEA SS Factors, 1977, E11
   vii. generally undesirable, p. 3-4, OWI/DOE Salt Dep of US 1978, D21
   viii. faults along which rupture could occur must be avoided; avoid faults that are active or have been within last million years, Kehnemuyi, Battelle M, 1979, D23
   ix. assure that active fault systems are avoided, p. 4.62, HLWM Alternatives, BNWL-1900, 1974, D16
   x. faulting most likely to occur along existing faults or zones of weakness - rep in a fault free block surrounded by faults at some distance (a few km) has a good chance to remain undisturbed until a new ice age, p. III-10, KBS Rydberg and Winchester, 1978, E9
   xi. p. 36-40, EPA State of Knowledge, 1978, C7

Reasons for avoiding existing faults:

a.) can enhance dissolutioning of salt at that point:
   i. p. 2:18-19, GCR 1978, D10
   ii. p. 5, OWI/DOE Salt Dep of US 1978, D21

b.) affects permeability of rock:
   i. p. 1, USGS 74-158, 1974, B8
   ii. p. C4-5, ERDA/BNWL Alternatives App C 1976, D18
   iii. p. 3-4, OWI/DOE Salt Dep of US 1978, D21
   iv. p. 35, IAEA SS Factors, 1977, E11
   v. p. 79, Considerations for HLWM, Gera and Jacobs, ORNL 1972, D5
   vi. p. 12, USGS 4339-5, 1973, B3

c.) complicated mining:
   i. p. 3-4, OWI/DOE Salt Dep of US 1978, D21
   ii. p. 35, IAEA SS Factors, 1977, E11
   iii. decreases rock strength, p. 12, USGS 4339-5, 1973, B3

5. State of current knowledge: Do we adequately understand the effects of seismic

events on an operational rep? Moderate amount of data, developing models, p. 42, ESTP, USGS and DOE 1979 , D24

6. Can we make predictions of future seismicity/faulting?
   i. regions with frequent earthquakes or Quaternary faults are more likely to be subjected to significant diastrophism during the next several hundred thousand years, p. 5, USGS 4339-5, 1973 , B3
   ii. based on geologic history, the general location and maximum effects of these events (faulting and earthquakes) can be predicted
      - p. C12 - 13, ERDA/BNWL Alternatives App C 1976 , D18
      - p. 44, IAEA SS Factors, 1977, E11
   iii. range of tasks needed to be done in geological study of areas - evaluation of structural stability of formation for long periods into the future, p. 32, OWI/ERDA Program Plan for NWTSP, 1976, D19
   iv. "At the present stage of geological knowledge, there is no area of the earth for which the possibility of faulting can be absolutely excluded." Faulting is most intense along mobile belts of the earth, but even in stable mid-continental areas without records of seismic activity, the probability of faulting cannot be considered to be zero. p. 79, Considerations for HLWM, Gera and Jacobs, ORNL 1972 , D5
   v. rep in Sweden in fault free block surrounded by faults at some distance (a few km) has a good chance to remain undisturbed until a new ice age, p. III-10, KBS Rydberg and Winchester, 1978, E9
   vi. prediction of stability - basis for safe rep - future seismicity is predicted on the basis of present day instrumental records, p. 121; uncertainty regarding the probability of new faults - mere existence of rep "makes it totally unreasonable to cite present fracture distribution in bedrock of Sweden as evidence for future effects in vicinity of a waste rep." (Dames and Moore); "If indeed the weakest link in the chain breaks during a seismic event, then the rep may be that weakest link", (E10) (California Energy Commission), p. 123; Johansson and Steen, Ringhals-3, 1978
   vii. sites stable in the past and currently are not expected to change significantly during rep lifetime so the effectiveness of barriers is expected to continue, p. 9, NAS/NRC, Implementation of Standards, 1979, A3
   viii. We cannot claim that the probability of an earthquake is zero anywhere in the world since the origens of earthquakes in the interior of the continent (New Madrid, 1811) or at its passive margins (Charleston, 1886) remain pretty much a mystery. About all we can confidently say is that the risk is much less in some regions. There is a lack of systematic data so there is little reason for confidence in forward predictions covering a million years. As to uplift, it is unpredictable where it will happen. There is a finite but very low probability that a rep buried at depth will reappear thus at the earth's surface. How one can make an orders of magnitude conjecture concerning these probabilities is beyond the Panel's ability to resolve. p. 36-40, EPA State of Knowledge, 1978, C7

5. Geothermal Gradient/Volcanic Activity

1. Should be taken into account/information useful for site selection/evaluation:
   i. p. 79, Considerations for HLWM, Gera and Jacobs, ORNL 1972, D5
   ii. p. 9-12, USGS, ES Perspectives, 1978, B10
   iii. probability and consequences should be considered, p. 9, NAS/NRC, Implementation of standards, 1979, A3
   iv. future occurence of volcanic activity should be considered in site selection
      - p. C12-13, ERDA/BNWL Alternatives App C 1976, D18
      - p. 44, IAEA SS Factors 1977, E11
   v. expected igneous activity shall not compromise containment (criteria must be met), p. 3, Brunton and McClain, OWI/ERDA, 1977, D20
   vi. event taken into account in risk assessment, p. 95-103, AD Little, Assessment 1978, C3

2. Site should be located to avoid areas of active or recent volcanic/igneous activity:
   i. p. 6-9, NAS/NRC, 1978, A1
   ii. p. 2:18-19, GCR 1978, D10
   iii. Kehnemuyi, Battelle M, 1979, D23
   iv. within last few million years; also the area should be distant from the mobile belts of the earth and tectonically very stable to decrease the risk from volcanic activity, p. 89-91, Considerations for HLWM, Gera and Jacobs, ORNL 1972, D5
   v. assumption for safe rep, p. 1, EPA State of Knowledge, 1978, C7
   vi. currently active regions not suitably stable for site, p. 14-15; select site not prone to volcanic activity, p. 15, NAS/NRC Implementation of Standards, 1979, A3
   vii. prerequisites for catastrophic events, i.e. volcanic, not known to be present in SENM - area promising, p. 6, USGS 74-194, 1974, B7

3. Select site to avoid areas of abnormally high geothermal gradient (may indicate igneous or tectonic activity):
   i. p. 6-9, NAS/NRC, 1978, A1
   ii. p. 2:18-19. GCR, 1978, D10
   iii. Kehnemuyi, Battelle M, 1979, D23
   iv. p. 32, IAEA SS Factors, 1977, E11
   v. p. C2-4, ERDA/BNWL Alternatives App C 1976, D18

4. ES aspects of long term risk analysis - need knowledge of processes that effect containment capability: for prediction of disruptive events like volcanism that could breach rep . p. 16-17, ESTP, USGS and DOE, 1979, D24

5. Can we predict future volcanic activity?
   i. examine the geologic record of history and frequency of volcanic activity over region to determine the probability of future activity, p. 14-15, NAS/NRC, Implementation of Standards, 1979, A3
   ii. based on geologic history the general location and maximum effects can be predicted
      - p. C12-13, ERDA/BNWL Alternatives App C 1976, D18
      - p. 44, IAEA SS Factors 1977, E11
   iii. within different specified regions, we may estimate the relative order of danger, but for very few areas can we have confidence in orders of magnitude estimates of risk probability. Of all the world's volcanoes under observation, only a few exist whose short term behavior is remotely predictable, p. 36-40, EPA State of Knowledge, 1978, C7

Part: I No. 6

6. Aquifers

1. Their presence (above, below, interbedded) detracts from suitability/absence preferred:
   i) questions regarding suitability of salt as host media - sedimentary basins can contain prolific aquifers both above and below salt horizons. p 9 AECL 1976, E2

   ii) Most shales in U S probably not suitable because they are underlain or overlain by important aquifers. p 39-40 USGS 4339-5, 1973, B3

   iii) Preferred salt environment - where there are no important aquifers above rep, p3, USGS 74-158, 1974, B8

   iv) interbedding known to contain circulating groundwater detracts from suitability - C2-C4, ERDA/BNWL Alternatives App C 1976; p.3, IAEA SS Factors 1977, least desirable surrounding rocks those containing large quantities of circulating groundwater, esp over rep: potential for flooding rep in case of unexpected fracturing p C2-4 ERDA/BNWL Alternatives App C 1976 (D18); p 34 IAEA SS Factors, E11

   v) least desirable adjacent strata - those containing large quantities of circulating water that is unsaturated with respect to salt, p 3-4, OWI/DOE, Salt Dep of US 1978, D21

2. Aquifers as resource:

   i) In many areas, esp arid, groundwater is an important commodity - extensive deposits of fresh water above or below rep could adversely affect availability of site for rep, due to public opinion - p C10-12, ERDA/BNWL Alternatives, (D18) App C 1976; p 41, IAEA SS Factors 1977, E11

   ii) special care needed in site evaluation if water is used by municipalities, industry, agriculture, p 5-6, OWI/DOE Salt Dep of U S 1978, D21

   iii) Avoid as much as possible locations where there are deep extensively used groundwater resources or aquifer systems with usable volumes of water having a potential for future development - Kehnemuyi Battelle M 1979, D23

   iv) Considered by Beckner in letter to Schueler - aquifers at WIPP do not produce potable water - contains too many salts and could not be used. p 5, Dec. 1978, D13

3. Overlying and underlying formations may contain water bearing zones:
   a. Work must be done to ensure that the aquifers will remain isolated from disposal area. p 9 AECL Canada 1976, E2
   b. VErtical isolation from overlying aquifers:
   i) by 300 m or more of impervious rock to minimize potential hazard (i.e. from flooding) p C2-4 ERDA/BNWL Alternatives App C 1976, D18; p 34, IAEA SS Factors, E11
   ii) for brittle rocks, over-/underlying aquifers should be separated from host rock by thick bodies of impermeable shales or other aquiludes. p C10-12 ERDA/BNWL Alternatives App C 1976, D18; p 42, IAEA SS Factors 1977, E11
   iii) Necessary to assure that wastes are protected from aquifers by showing salt formation is separated and isolated from flowing aquifers by suitable impermeable formations in such a way that water could not contact the salt; or showing that although aquifer is in contact with salt, the available thickness of salt between wastes and aquifers is more than adequate to assure confinement at maximum potential dissolution rate p 6-7; So vertical isolation must be adequate to assure confinement., BSPP SS Factors ORNL 1973 (See also Dissolutioning)., D2 *

iv) barriers between rep and closest aquifer should be adequate to withstand possible geologic processes, such as faulting, p 131, Considerations for HLWM, Gera and Jacobs ORNL 1972, D5

c. Adequate sealing of shafts:
   i) Mine specifications for Lyons: outer surface casing to a depth below the lowest aquifer which will isolate the casing and its cement from known aquifers; aquifers will be pressure sealed and/or lined with concrete poured in place - to effectively prevent water from entering the mine through the shaft. p 23-25, NAS/NRC Bedded Salt 1970, A2
   ii) Considered in Beckner letter to Schueler Dec. 1978, D13
   iii) See Also - People-Made Penetrations

d. For WIPP, over and underlying aquifers represent a secondary barrier if salt is breached so low permeability and transmissivity are desired by not mandatory. p 2:17-18, GCR 1978, D10

e. Thermal effects of waste on aquifers considered, p 3, Letter from Beckner to Schueler 1978, D13

f: Information needed:

   i) need accurate knowledge of aquifer parameters. p 2-17-18 GCR 1978, D10

   ii) Need comprehensive geohydrologic study of entire region to establish spatial relationships, interconnections and fluid characteristics of all aquifers above and below salt and to identify recharge and discharge areas. Need to determine nature and characteristics of aquifers near disposal zone since they are critical elements of establishing suitability - direction, velocity and volume of flow. p 5-6, OWI/DOE Salt Dep of U S 1978, D21

7. Nature of Overlying, Underlying, Surrounding Rocks

1. Though primary reliance for containment is on host rock body itself, additional protection can be attained/ an additional barrier can be found in over-, underlying and surrounding rocks.
   i) pC2-4, ERDA/BNWL Alternatives, App C 1976, D18
   ii) p 3-4, OWI/DOE, Salt Dep of US 1978, D21
   iii) p 34, IAEA SS Factors 1977, E11
   iv) if salt as barrier failed, confinement would be up to over-and underlying formations - de Marsily, et al, Guarantee isolation? 1977, E5
   v) stages of containment include surrounding geological formations, p 5 EPA State of Knowledge 1978, C7
   vi) Criteria must be met: hydrological properties of rep rock together with those of surrounding rocks shall not permit the transport of hazardous amounts of nuclides to biosphere, p 3 Brunton & McClain, OWI/ERDA 1977, D20
   vii) p 92, 98, Considerations for HLWM, Gera & Jacobs ORNL 1972, D5

2. Least desirable surrounding rocks: those containing large quantities of circulating groundwater: (see also aquifers)
   i) pC2-4 ERDA/BNWL Alternatives App C 1976, D18
   ii) Unsaturated with respect to salt, p 3-4, OWI/DOE Salt Dep of U S 1978, D21
   iii) p 34, IAEA SS Factors 1977, E11

3. Preferred surrounding rocks - Impervious beds:
   i) thick beds of shale or other plastic impervious rocks, can deform without fracturing - p C2-4, ERDA/BNWL Alternatives App C 1976, D18
   - p 3-4, OWI/DOE Salt Dep of US, 1978, D21
   - p 34, IAEA SS Factors, 1977, E11
   ii) Safety of disposal would be improved if surrounding aquiludes were very thick, in case of slippage along faults, p 92; for salt, to assure that dissolutioning is negligible, shale beds above and below salt must be continuous over a large area and shale bed over salt must be deep enough so no erosion could reasonably affect its integrity in a time span of several 100,000 years, p 98, considerations for HLWM, Gera & Jacobs, ORNL 1972, D5

4. Information needed/ analyses to be made:
   a. on effect of slow subsidence on integrity of overlying rock (as part of SS procedure), p 4-82 ES of WM of LWR Cycle, NRC 1976, C8

   b. On groundwater:
      i) nature and characteristics of water bearing strata near disposal zone are critical elements in establishing suitability p 5-6, OWI/DOE Salt Dep of U S 1978, D21

      ii) essential to determine hydrological characteristics of rocks close to salt formation - p 5, ORNL Program Plan for BSPP 1973, D1

      iii) for risk analysis need knowledge of features that affect containment capability and nuclide migration like the regional distribution of rock types and structural features as they affect groundwater flow. p 16-17, ESTP USGS & DOE 1979, D24

      iv) need to know if there are permeable zones below rep - p 118 Johansson & Steen, Ringhals - 3, 1978, E10

8. Conflict with Natural Resources

1. Should be taken into account/information useful for site selection/evaluation:
    - i. to be considered in making criteria - petrographical and mineralogical composition and economic value, p. 12-13; questions regarding salt as host media: often associated with potash and oil and may be an attractive target for exploratory boreholes, p. 9, AECL Canada 1976, E2
    - ii. for salt formation, occurences of petroleum, potash mines, oil and gas production, USGS 4339-1, 1972, B2
    - iii. Criteria - future value of potash deposits should be considered, p. 70-71; economic development - potash, ranches, oil and gas fields, p. 45, USGS 4339-6, 1973, B4
    - iv. study considered oil and gas deposits, potash, p. 20, USGS 74-190, 1974, B9
    - v. criteria considered - oil, gas and recreational potential development, p. 2-3, Supplemental Areas, Kn GS 1972, B11
    - vi. in geologic study of areas, range of tasks includes natural resource evaluation, including those items relating to people's activities in the subsurface which would alter the natural geologic conditions, p. 22, OWI/ERDA Program Plan for NWTSP 1976, D19
    - vii. petroleum, potash, sulfur - may be present near a salt deposit. Necessary to weigh need for rep and the availability of other sites against present and potential need for mineral resources at site,
      - p. 6, OWI/DOE Salt Dep of US 1978, D21
      - p. 48, IAEA SS Factors 1977, E11
    - viii. potential for oil and gas - considered since it might attract drilling, ORNL McClain and Boch 1974, D3
    - ix. potential sites in salt should be evaluated for potential exploitation and/or contamination of oil, gas, and water resevoirs, and of salt, potash and other valuable or potentially valuable commodities, p. 4.63, HLWM Alternatives, BNWL-1900, 1974, D16
    - x. site selection - determine suitability of broad regions in terms of potential for denial of natural resources, p. 13; site evaluation - need detailed definition of distribution of physical properties throughout site (i.e. petrologic and mineralogic features), p. 14; ES aspects of long term risk analysis - need knowledge of processes that affect containment capability: identification of mineral resources that might serve to cause people to penetrate rep, p. 16-17, ESTP USGS and DOE 1979, D24
    - xi. events taken into account in risk analysis - human intrusion: gas/oil exploration, mineral exploration, p. 95-103, AD Little, Assessment 1978, C3

2. Formation should not be associated with or be in the immediate vicinity of potentially valuable mineral resources:
    - i. no area with present or past history of resource extraction except by surface quarrying should be considered, p. 13-15, NAS/NRC 1978, A1
    - ii. to the extent possible, p. 2:10; unavoidable conflict with resources should be minimized to the extent possible (large scale site selection criteria), p. 2:20-21, GCR 1978, D10

iii) p15, Canada AECL 1975, E1

iv) tract considered is most promising since it is 5 miles or more from any center of industrial activity, i.e. gas or oil wells or mines, p 34-35, USGS 4339-7, 1973, B5

v) preferred salt environment -where oil and gas potential is low; unsuitable area - where strata have high oil or gas potential, p 3 USGS 74-158, (B8) 1974; p 4.4, HLWM Alternatives, BWNL - 1900, 1974, (D16)

vi) p 21 AEC, Lyons E. S. 1971, D6

vii) Criteria must be met: waste must not be placed in potentially useful mineral deposits, p 13-14, Deep Rock, Klett/Sandia 1974, D8

viii) SS criteria p 12-13, SS WIPP/Sandia 1977, D9

ix) Site should not offer an attractive resource target p 5; actual or potential resource of site should be such that it will not unduly deprive this or future generations of necessary and valuable resources, p 5-6, Nureg 0353, NRC-State Review 1977, C4

x) Would make site more favorable, p 6, OWI/DOE Salt Dep of US 1978, D21

xi) p 3-4, ORNL, Program Plan for BSPP 1973, D1

xii) Avoid areas where mineral resources are "known to abound" and where resources were "worked out" in formation below rep, Kehnemuyi, Battelle M, 1979, D23

xiii) avoid areas of existing production or extensive exploration as much as possible, p 10, mineral potential should be minimal to minimize probability of future operations. p 11, summary, BSPPSS Factors ORNL 1973, D2

xiv) presence of potentially mineable minerals detract from usefulness of host rock for disposal, p 33, IAEA SS Factors 1977, E11

xv) as much as possible - p 5, Brunton & McClain, OWI/ERDA 1977, D20

xvi) de Marsily, etal, Guarantee Isolation? 1977, E5

xvii) p 2-9, 4-73, ES of WM of LWR Cycle, NRC 1976, C8

Reasons:

a. potential source of raw materials that would be denied:

i) p 13-15, NAS/NRC 1978, A1

ii) proposed criteria: actual or potential resource value of site should be such that it will not unduly deprive this or future generations of necessary and valuable resources, p 5-6 NRC State Review, Nureg-0353 1977, C4

iii) p 36-40, EPA State of Geologic Knowledge 1978, C7

iv) waste disposal facilities shall be sited and operated to avoid as much as possible the foreclosure of future options. p 13, NRC - Proposed Goals for RWM, 1978, C9

b. disturbance of hydrological/geological system by boreholes, shafts, fractures, cavities;

i) p 13-15, NAS/NRC 78 , A1

ii) p 32 OWI/ERDA, Program Plan for NWTSP 1976, D19

iii) avoidance of areas over "worked out" mineral deposits because of danger of subsidence, Kenhemuyi, Battelle M, 1979 , D23

iv) site should be located so that existing subsurface operations would be outside buffer zone and to minimize probability of future operations since current technology makes it difficult to predict what the eventual effects of mechanical or solution mining on rep might be. p 11, BSPPSS Factors ORNL 1973 , D2 +

v) people are now one of the major driving forces for geologic change (erosion, solid movement and water movement for example) p-13, NRC Proposed Goals for RWM 1978, C9

vi) site should be where intrusion of people in a manner that will change conditions is minimal. p 4.5 HLWM Alternatives, BNWL-1900 1974, D16

c. Attract propspection - exploration that might penetrate rep:

i) p 13-15, NAS/NRC 1978, A1

ii) danger of reexploitation of already mined resources; Kehnemuyi, Batelle, M, 1979, D23

iii) minimize probability of future operations within buffer zone, p 11, BSPP SS Factors, ORNL 1973, D2

iv) Must have no natural resources in area that would attract prospection deMarsily, et al, Guarantee Isolation? 1977, E5

v) site should not offer attractive resource target, p 5, NRC, State Review, Nureg 0353, 1977, C4

vi) Recommendations have been presented p IV-57, KBS Rydberg & Winchester 1978, E9

vii) People will seek anything of value and are now one of the major driving forces of geologic change - to the extent predictable, we should design and locate facilities so as to avoid motivation for penetrating disposal volume, p 13 NRC-Proposed Goals for RWM 1978, C9

viii) p 35-40, EPA State of Geologic Knowledge 1978

3. Avoid conflicts with water as a natural resource:

i) esp in arid areas, groundwater is an important commodity - extensive deposits of fresh water above or below site could adversely affect its availability due to public opinion, p c 10-12, ERDA/BNWL, App c 1976, D18
p 41, IAEASS Factors 1977 , E11

ii) special care needed if water near site is used by municipalities, industry, agriculture, p 5-6 OWI/DOE Salt Dep of US 1978 , D21

iii) avoid areas where groundwater resources are extensively used and/or have potential for significant future development -Kehnemuyi, Battelle M, 1979, D23
-SS Factor, BSPPSS Factors, ORNL 1973, D2
-p 6 Brunton & McClain, OWI/ERDA 1977, D20
-p 4.4.H L WM Alternatives, BNWL-1900 1974, D16

iv) there may be conflict with industrial, recreational, scenic interest in large lakes and streams - p C 10-12, ERDA/BNWL, Alternatives App c 1976, D18
- p 41 IAEA SS Factors 1977, E11
- p 6 Brunton & McClain, OWI/ERDA 1977, D20

4. Waste placed in rep as a natural resource:

i) operation of the rep should not create a potential future source of valuable material; unreprocessed spent fuel elements, potentially highly valuable to future people, should not be placed in non-retrievable storage (temptation to penetrate rep), p 13-15, NAS/NRC 1978, A1

ii) consideration: since uranium ore is limited, it may become desirable to recover unreprocessed fuel rods, so a breach in the rep to recover them could be a serious problem in the future. p 3, p 35-36 State of Geologic Knowledge 1978 EPA, C7

iii) goals for RWM: to the extent predictable, we should design and locate facilities so as to avoid motivation for penetrating the disposal volume. p 13, NRC-Proposed goals for RWM 1978, C9

5. If the rep is located where there are natural resources present or near-by:

i) If possibility exists that some valuable resource is present, it will be necessary to show that credible attempts to recover the resources will not have adverse effects on the effectiveness of the rep, p 5; Proposed criteria: site should have characteristics such that the consequences of unplanned intrusions will be ALARA p 5-6, Nureg 0353, NRC State Review 1977, C4

ii) accidental penetrations should not result in undue hazard. p 2:17 GCR 1978, D10

iii) Resources could be extracted from adjacent regions with proper evaluation and precautions. To be considered in evaluations: compatibility of operations, impact on rep from extraction operations, possibility of contamination of resource by waste. p 48, IAEA SS Factors 1977, E11

iv) "The expectation, but one that cannot yet be guaranteed is that these minerals (at WIPP site in Zone III) may be recovered in decades ahead should they be economically attractive. Certainly the time frame for their development would be within the next century while the rep site is still under administrative control. The small amounts of either resource within zone III would not be of significant interest in the absence of other production in the area." p 10, Letter from Beckner to Schueler, Dec. 1978, D13

v) Rydberg -Though recommendations have been presented that rep be placed in area with no valuable minerals, "it seems probably that a future person, who is capable of mining and drilling to a depth of 500m, also will use instruments capable of detecting radioactivity." p IV-57- KBS Rydberg & Winchester 1978, E9

6. Can we predict the likelihood of intrusion of people into rep in search of resources?

i) Uncertainities are introduced into risk assessments because of uncertainities of probabilities and consequences of human intrusion. p 4-94, ES of WM of LWR Cycle, NRC 1976, C8

ii) Another risk for which no trustworthy probability estimates can be applied-intrusion at some future date by people in search of minerals (including the uranium and TRU buried in rep) or to satisfy archeological or other curiosity. People's unpredictability far outstrips that of most of the imagined geologic hazards, p. 35-36; as raw materials dwindle there will be an increasingly desperate exploitation of them. What mineral resource exploitation might be like a thousand years from now is impossible to predict - should be considered, p. 36-40, EPA State of Knowledge, 1978, C7

iii. Do we adequately understand how to evaluate current resource conflicts? models tested, applying to specific site (including WIPP), p. 38; Can we estimate the long term effects of future resource conflicts? moderate understanding of principles, developing models, p. 44, ESTP USGS and DOE 1979, D24

9. People-Made Penetrations: drillholes, excavations, etc. (see also Conflict with Natural Resources, for discussion of future penetrations)

1. Their effect should be considered/evaluated in site selection:
   i. drillholes considered in study, p. 45, USGS 4339-6, 1973, B4
   ii. oil/gas holes drilled, abandoned considered, p. 2-3, Supplemental Areas, Kn GS 1972 , B11
   iii. re:dissolutioning (long term consideration for rep in salt).
      - p. 2:17-18, GCR 1978, D10
      - p. 25-45, AEC Lyons ES 1971;(in the four known cases where penetration solutioning has occured: shallow prolific aquifer, possible casing break in salt zone, and highly permeable deeper zone having low hydrostatic head were all present.), D6
      - needs to be studied in situ, but the necessary conditions (the above) not believed to exist in SENM, p. 9 ORNL Program Plan for BSPP 1972, D1
      - study the possibility, ORNL, McClain and Boch, 1974, D3
   iv. consider abundance of drillholes or mines in area in determining potential for disposal, p. 12, USGS 4339-5, 1973, B3
   v. consequence of plugged and unplugged boreholes in the vicinity of the rep should be evaluated in a consequence/sensitivity study. Leakage should be varied over a reasonable range. p. 48, ESTP USGS and DOE 1979, D24
   vi. range of tasks includes resource evaluation including those items relating to people's activities in the subsurface which could alter natural geologic conditions, p. 32, OWI/ERDA Program Plan for NWTSP 1976, D19
   vii. since boreholes may serve as hydraulic connection between all rock units penetrated, their occurence and control is of special concern, p. 10, ORNL Program Plan for BSPP 1973, D1
   viii. in site suitability study, need to consider/evaluate the prevention of adverse conditions from penetrations, ORNL McClain and Boch 1974, D3
   ix. factor to be considered for various criteria: the quantity and spacial distribution of boreholes, mineshafts, and other excavations that may be potential subsurface pathways for water around rep, Glossary, p. 7, Brunton and McClain, OWI/ERDA 1977, D20
   x. method by which nuclides could escape (to be considered) - accidental drilling through formation, p. 86, Considerations for HLWM, Gera and Jacobs ORNL 1972, D5
   xi. uncertainties introduced into model-making of nuclide transport: presence of boreholes - must be considered as potential short circuit in containment, p. 8, USGS ES Perspectives 1978, B10
   xii. events taken into account in risk analysis: rep stresses cause shaft seal failure, abandoned borehole, mine, not properly plugged, p. 95-103, AD Little, Assessment 1978, C3

2. In site selection it is desirable to avoid areas with existing penetrations:
   i. no area with present or past history of resource extraction except by surface quarrying should be considered, p. 13-15, NAS/NRC 1978, A1
   ii. large scale site selection criteria first used for WIPP: 2 mile radius from deep boreholes, no active mining within 5 miles, p. 2:10; changed preliminary site selection criteria: at least one mile from deep borehole, existing mining not present within two miles of rep, future controlled mining allowable within one mile or closer if future studies permit, p. 1:3, p. 2:20-21, GCR 1978, D10
   iii. study area near Carlsbad promising since it has lowest density of drillholes for potash, oil and gas, p. 78, USGS 4339-1, 1972, B2
   iv. shales in extensively developed oil and gas fields are probably poor risks for rep; many shale bodies in US are unsuitable because they are locally penetrated by oil or gas wells, p. 12, USGS 4339-5, 1973, B3
   v. site should be at least 4.5 miles from the nearest underground workings

of flooded solution mining operation, p. 70-71, USGS 4339-6, 1973, B4

vi. Los Medaños area is promising because - all places within tract are five miles or more from oil or gas wells or mines and there is a low density of boreholes that completely penetrate the salt deposit, p. 34-35, USGS 4339-7, 1973, B5

vii. site selection criteria for WIPP - two mile radius from deep boreholes, later reduced to one mile, p. 12, SS WIPP, Sandia 1977, D9

viii. site should be as remote as possible from existing boreholes and there should be a restriction of drilling in buffer zone, ORNL McClain and Boch, 1974, D3

ix. avoid areas over "worked out" mineral deposits - danger of subsidence. If only minor disturbance has occured - surface mining or unfruitful drilling - area can be considered, Kehnemuyi, Battelle M, 1979, D23

x. areas of existing mineral production or extensive exploration should be avoided as much as possible, p. 10; existing subsurface operations should be outside the buffer zone (which is designated to protect rep from their effects), p. 11; Summary of site selection factors: mineral production history should be minimal, current mining operations should be remote, existing boreholes - minimum number. BSPP SS Factors, ORNL 1973, D2

xi. where there are large scale cavities, safety distances will have to be defined, p. 46, IAEA SS Factors 1977, E11

xii. Winchester: one of the requirements of site suitability - freedom from disturbance of previous human activities.
- p. IV 27-28, KBS Rydberg and Winchester 1978, E9
- p. 170, Johansson and Steen, Ringhals-3, 1978, E10

Reasons for concern/avoidance of areas with existing boreholes:

a. disturbance of geo-hydrologic system by the penetrations:
   i. p. 13-15, NAS/NRC 1978, A1
   ii. p. 12, USGS 4339-5, 1973, B3
   iii. danger of subsidence, Kehnemuyi, Battelle M, 1979, D23
   iv. current technology makes it difficult to predict what the eventual effects of mechanical or solution mining might be on rep, p. 11, BSPP SS Factors ORNL 1973, D2

b. penetration dissolutioning for rep in salt:
   i. we will probably never know the required conditions for borehole solutioning well enough to preclude the possibility over the very long term, so the site should be as remote as possible from existing boreholes. ORNL McClain and Boch 1974, D3

c. creation of convective hydrologic system due to heating and access by water - few bases for judgement on this. p. 35-36, EPA State of Knowledge 1978, C7

3. All existing boreholes, mine shafts, cavities, in the area must be identified and properly plugged:
   i. Los Medaños area most promising because the complete history of drilling in the area is known from federal and state records, p. 34-35, USGS 4339-7 1973, B5
   ii. essential that they are identified and sealed effectively, p. 6, OWI/DOE Salt Dep of US 1978, D21
   iii. p. 10, ORNL, Program Plan for BSPP 1973, D1
   iv. Kehnemuyi, Battelle M, 1979, D23
   v. all existing boreholes have to be located, evaluated as to their potential to form a hydraulic connection between salt and higher and lower aquifer

systems, re-entered, cleaned out and replugged in as permanent a manner as possible. The advantage of selecting a site with a minimum number of existing holes is apparent. p. 11, BSPP SS Factors, ORNL 1973 , D2

vi. this is essential, p. 46, IAEA SS Factors 1977, E11

vii. in site selection, premium on sites where precise locations of all abandoned drillholes and mines are known. Any old drillholes may disqualify site if they cannot be properly plugged and sealed. p. 18-19, EPA State of Knowledge 1978 , C7

viii. at WIPP, p. 6, SS WIPP Sandia 1977 , D9

ix. assumption: all communications with surface will have been sealed, p. 86, Considerations for HLWM, Gera and Jacobs, ORNL 1972 , D5

Reasons:

a. potential short path for nuclide migration
   i. p. 46, IAEA SS Factors 1977, E11
   ii. Letter from Beckner to Schueler, Dec. 1978 , D13
b. flooding by surface water, p. 46, IAEA SS Factors 1977, E11

4. A geologic system should be selected that can be satisfactorily plugged and sealed when rep is closed:
   i. p. 9-11, NAS/NRC 1978 , A1
   ii. assumption for safe rep - host rock is sealable, p. 1, EPA State of Knowledge, 1978 , C7
   iii. proposed criterion: state-of-the-art techniques for site exploration, construction and D&D should not compromise site effectiveness, p. 4-5; site must be able to maintain integrity notwithstanding impacts due to exploration, excavation and D&D, p. 6, NRC State Review, Nureg 0353 1977, C4

5. Shaft/Borehole Plugging and Sealing :

   a. Quality: the ability of the seal to preserve the integrity of containment should equal or surpass that of the protective rock formation surrounding the rep.
      i. p. 23.26-27, ERDA/BNWL Alternatives Vol. 4, 1976, D17
      ii. p. 53, OWI/ERDA Program Plan for NWTSP 1976, D19
      iii. p. III 13-14, p. IV 30-31, KBS Rydberg and Winchester 1978 , E9
      iv. p. 16, ESTP USGS and DOE 1979, D24
      v. seal should present both hydraulic and chemical barriers of this quality, p. 29, NAS/NRC Implementation of Standards 1979 , A3

   b. Sealing techniques suggested:
      i. mine specification for Lyons - shafts lined with heavy-wall metal casing and fully cemented; outer casing to depth below lowest aquifer which will isolate casing and its cement from known aquifers; aquifers will be pressure sealed and/or lined with concrete poured in place (to effectively prevent water from entering the mine through the shaft), p. 23-25, NAS/NRC Bedded Salt 1970 , A2
      ii. KBS suggestion - filling shaft with quartz/bentonite clay (plasticity when wet, low permeability, high sorption capacity).
         - p. III 13-14, KBS Rydberg and Winchester 1978, E9
         - p. 12-15, Johansson and Steen, Ringhals-3 1978, E10
      iii. promising new technique for sealing - compaction of natural materials, p. 2-3; boreholes should be sealed over entire length and carefully engineered plugs should be placed at critical points, i.e. bottom of the shaft and

above and below aquifers; backfill in the remainder, p. 2-7,8, NRC Info Base for Rep Design 1979, C10

iv. for WIPP, shaft will be lined with concrete from suface to and including the first fifteen feet of Salado; there will be a water ring at this level to collect any seepage; shaft will be unlined for the rest of the way, p. 83, WIPP Conceptual Design Report 1977, D12

v. WIPP - shaft will be lined to provide adequate water seal below the lowest potential aquifer penetrated; aquifers penetrated will be pressure grouted using formation-compatible grouts. Chapter 5, p. 9, WIPP Design Criteria 1978, D11

vi. KBS plan - leave shaft open for 30 years - there may be problems with this that could make sealing more difficult, p. IV 30-31, KBS Rydberg and Winchester 1978, E9

c. Studies needed:

i. sealing technology must be demonstrated.
- p. 10, Letter from Beckner to Schueler, 1978, D13
- p. IV 8-9; "The shaft sealing problem is one of the most important technologies to be demonstrated before the KBS design can be considered absolutely safe." p. IV 30-31, KBS Rydberg and Winchester 1978, E9
- set aside test area so concepts planned for seals and backfills can be tested to assure that proper designs have been selected, p.2-7, NRC Info Base for Rep Design 1979, C10
- concern with KBS proposed scheme: neither small nor large scale experimental simulations have been made to verify its properties. KBS staff said they are not needed - their reasoning: lab measurement of basic material properties and the laws of nature preclude the failure of the approach. "This is an example of technological optimism in the extreme." p. 124-5, Johansson and Steen, Ringhals-3, 1978, E10
- p. 10-11; confirmation of engineering design: demonstration of stability must include the following - sealing of shafts, boreholes and tunnels, p. 25; must demonstrate that openings when sealed do not significantly reduce overall integrity, p. 29; in situ testing of seals - representative lengths of shafts and excavations should be sealed in exactly the same manner as proposed for final sealing. Leave space so can pump gas and fluid behind the seals to measure their responses to fluid and rock stresses (seals fitted with measureing equipment). This is to demonstrate the practicability and effectiveness of seals to be used. p. 30, NAS/NRC Implementation of Standards 1979, A3

ii. research is needed to develop sealing materials and techniques for their emplacement:
- p. 10, p. 53, OWI/ERDA Program Plan for NWTSP 1976, D19
- matched to host rock, p. 46, IAEA SS Factors 1977, E11
- ORNL, McClain and Boch 1974, D3
- final solution of problem is essential for a successful rep, p. III 13-14, KBS Rydberg and Winchester 1978, E9
- metal casing cannot be guaranteed against corrosion over the required time span, so some impermeable chemically-inert cement to grout and plug holes must be developed. p. 18-19, EPA State of Knowledge 1978, C7
- p. 16, ESTP USGS and DOE 1979, D24

iii. predictions of seal performance:
- uncertainty about long term effectiveness of shaft seals - few bases for judgement on this, p. 35-36, EPA State of Knowledge 1978, C7
- critical technology needing development - shaft seals: deterioration is likely but there is limited, insufficient historical data on seal

performance to allow prediction, p. 2-3; critical information needs to be better able to evaluate rep design: long term risk analysis is needed specific to shaft and borehole sealing techniques, p. 2-6, NRC Info Base for Rep Design 1979, C10

- consequence of plugged and unplugged boreholes in vicinity of rep should be evaluated. Leakage should be varied over a reasonable range, flow rates through and around plug under normal conditions should be simulated using realistic geologic and hydrologic conditions, p. 48, ESTP USGS and DOE 1979, D24

d. State of Current Knowledge:

- Do we adequately understand how to seal shafts and boreholes? moderate amount of data, developing models.
- Do we adequately understand sealing material-media compatibility? limited data, currently expanding data base.
- Can we adequately demonstrate the long term stability of sealing materials? limited data, currently expanding data base.
- Can we adequately measure/evaluate the in situ permeability of seals? approach unknown, developing techniques
- Do we adequately understand the mechanical and chemical stability of sealing materials? moderate amount of data, developing models.

p. 42, ESTP USGS and DOE, 1979, D24

PART II: HOST ROCK BODY CRITERIA

Part II: No.1

1. Depth of disposal formation

1. Should be considered in site selection:
    - i. study looked at depth of salt formations in US, Pierce and Rich, USGS Bulletin 1148, 1962, B1
    - ii. area studied has formation at reasonable depth below surface, p. 78, USGS 4339-1, 1972, B2
    - iii. study looked at minimum depth to salt, p. 45, USGS 4339-6, 1973, B4
    - iv. Los Medaños suitable - thick seams of salt at moderate depths, p. 34, USGS 4339-7, 1973, B5
    - v. feature of interest of Mescalero Plains - minimum depth to salt ranges from 200 to 1,500 ft., p. 20, USGS 74-190, 1974, B9
    - vi. p. 4, ORNL Program Plan for BSPP 1973, D1
    - vii. site selection - determine suitability on local level in terms of probable volume of host rock at usable depths, p. 13,; site evaluation - determine depth of host and associated units, p. 14, ESTP, USGS and DOE, 1979, D24

2. Minimum Depth:
    - i. Large scale site selection criteria: depth to suitable salt of at least 1,000 ft, p. 2:10, GCR, 1978, D10
    - ii. 300m, p. 2, Canada AECL 1976, E2
    - iii. 500 ft, p. 5-7, USGS 4339-5, 1973, B3
    - iv. Los Medaños promising because depth to Salado varies from 750 to no more than 1,500 ft, p. 34-35, USGS 4339-7, 1973, B5
    - v. site selection criteria - 500 ft, p. 21, AEC Lyons ES 1971, D6
    - vi. large scale site selection criteria - 1,000 ft, p. 12, SS WIPP, Sandia 1977
    - vii. 200 to 300 m, p. C2-4, ERDA/BNWL Alternatives App C 1976, D18
    - viii. 300 m, p. 4-5, OWI/DOE, Salt Dep of US 1978, D21
    - ix. 300 to 400m desirable, Gera, ORNL Salt Tectonics, GSA 1972, D4
    - x. 1000 ft, p. 7, BSPP SS Factors, ORNL 1973, D2
    - xi. 200 to 300 m, p. 32, IAEA SS Factors 1977, E11
    - xii. assume minimum depth of about 300 m, p. 86; at least 300 to 400 m, p. 115-116, Considerations for HLWM, Gera and Jacobs, ORNL 1972, D5
    - xiii. site selection criteria - 1,000 ft, p. 4-73, ES of WM of LWR Cycle, NRC 1976, C8

Reason for/determination of minimum depth:

a.) depth should be sufficient to separate rep from any surficial process that might cause a breach, i.e. erosion, meteor impact, bombs, etc:
- i. p. 4-5, NAS/NRC 1978, A1
- ii. (minimum depth must include consideration of probable penetration distances of these processes/events plus a margin for uncertainties), Kehnemuyi, Battelle M, 1979, D23
- iii. p. 7, BSPP SS Factors, ORNL, 1973, D2

b.) insure against disinterment by erosion
- i. p. 2:10, GCR, 1978, D10
- ii. p. C2-4, ERDA/BNWL Alternatives App C 1976, D18
- iii. p. 4-5, OWI/DOE Salt Dep of US 1978, D21
- iv. Gera, Salt Tectonics, ORNL, GSA 1972, D4
- v. stream erosion is the most damaging, p. 7, BSPP SS Factors, ORNL 1973, D2
- vi. p. 32, IAEA SS Factors, 1977, E11
- vii. p. 2, Brunton and McClain, OWI/ERDA 1977, D20
- viii. p. 115-116, Considerations for HLWM, Gera and Jacobs, ORNL 1972, D5

c.) numerous open fractures near surface:

i. p. C2-4, ERDA/BNWL Alternatives App C 1976 , D18

ii. p. 32, IAEA SS Factors 1977 , E11

d.) avoid dissolution of salt by shallow aquifers:

i. p. 4-5, OWI/DOE Salt Dep of US 1978 , D21

ii. p. 98, Considerations for HLWM, Gera and Jacobs, ORNL 1972 , D5

e.) protection against accidental and criminal encounters, de Marsily et al, Guarantee Isolation? 1977, E5

f.) factor tending to lengthen transport time - long flow path, p. 8, USGS, ES Perspectives, 1978 , B10

3. Maximum depth:

i. salt - less than 3,000 ft, p. 2:10, GCR, 1978 , D10

ii. all rocks - 2,000 m, p. 2, Canada AECL, 1976 , E2

iii. shale - 2,000 ft, p. 5-7, USGS 4339-5, 1973 , B3

iv. salt - 2,500 ft, p. 44, USGS 4339-6, 1973 , B4

v. salt - 3,000 ft, p. 34-35, USGS 4339-7, 1973, B5

vi. salt - 2,000 ft, p. 2-3, Kansas Supplemental Areas, Kn GS, 1972 , B11

vii. salt - 3,000 ft, p. 3; other media - 10,000 ft, p. 23, USGS 74-158, 1974 , B8

viii. salt - 2,000 ft, p. 21 , AEC Lyons ES 1971, D6

ix. salt - 3,000 ft., p12, SS WIPP, Sandia 1977, D9

x. mechanical mining in salt and shale - 1,500 m; for solution mining in salt - 3,000 m; other rocks - deeper; most common depths - 1,500 m
- p. C2-4, ERDA/BNWL Alternatives App C 1976 , D18
- p. 32, IAEA SS Factors, 1977 , E11

xi. salt - 1,500 m, preferably less than 900 to 1,000 m, p. 4-5, OWI/DOE Salt Dep of US 1978 , D21

xii. salt - 700 m, Gera, Salt Tectonics, ORNL, GSA 1972, D4

xiii. salt - 2,500 ft. , p. 7, BSPP SS Factors, ORNL 1973, D2

xiv. all rocks - 3,000 m, p. 4.61, HLWM Alternatives, BNWL-1900, 1974 , D16

xv. all - 4,000 ft, p. 4-73, ES of WM of LWR Cycle, NRC 1976 , C8

Reason for maximum depth:

a. in salt - mining criteria because of increasing plasticity of salt with depth:

i. p. 2:10, GCR 1978 , D10

ii. p. 44, USGS 4339-6, 1973, B4

iii. p. 3, USGS 74-158, 1974 , B8

iv. p. 21, AEC Lyons ES 1971 , D6

v. p. C2-4, ERDA/BNWL Alternatives App C 1976, D18

vi. p. 4-5, OWI/DOE Salt Dep of US, 1978 , D21

vii. Gera, ORNL, Salt Tectonics, GSA 1972, D4

viii. p. 7, BSPP SS Factors, ORNL 1973 , D2

ix. p. 32, IAEA SS Factors, 1977 , E11

b. increased cost of exploration, development and operation at depth:

i. p. 21, AEC Lyons ES 1971 , D6

ii. p. C2-4, ERDA/BNWL Alternatives App C 1976 , D18

iii. p. 32, IAEA SS Factors 1977, E11

c. in salt risk of containment failure due to diapirism negligible if rep is not located at great depth:

i. Gera, ORNL, Salt Tectonics, GSA 1972 , D4

ii. p. 115-116, Considerations for HLWM, Gera and Jacobs, ORNL 1972 , D5

4. Assumed depth of rep:
   i. 500 m in granite, KBS plan, Rydberg and Winchester, 1978, p. II-9-10, E9
   ii. for risk assessment, baseline rep assumed to be at 460 m depth, p.66, AD Little, Assessment, 1978, C3
   iii. W. German plan - Asse mine - 775 m depth to disposal horizon, p. 10, Krause and Randl, WM in West Germany, 1972, E7
   iv. introduction to KBS report - geological factors that will determine the suitability of a site - 500 m depth, p. 5 Appendix, Johansson and Steen, Ringhals - 3, 1978, E10

5. Effect of changing the depth:
   i. in risk assessment, affects the failure probabilities caused by technological imperfections; alters meteorite and human induced failure probabilities, p. 206, AD Little, Assessment 1978, C3
   ii. reconcentration phenomenon - increasing the depth at first increases and then decreases the magnitude of the effect, (reconcentration phenomenon - maximum discharge rates to biosphere for deep geological rep greater than the corresponding level for surface storage), p. 1.13-1.15, Burkholder, Reconcentration Phenomenon, BNWL, 1976, D15
   iii. increasing depth from zero to 10 miles decreases the highest incremental dose by a factor of 12,000, Incentives for Partitioning, Burkholder, 1976, D14

2. Dimensions of Host Rock Body

1. Should be considered/information useful for SS:

i. in making criteria, p. 12-13 AECL Canada 1976, E2
ii. gross thicknesses, USGS 4339-1, 1972, B2
iii. p. 5, 7, USGS 4339-5, 1973, B3
iv. looked at in study - thickness of salt, thickness of target bed and areal extent, p. 45, USGS 4339-6, 1973, B4
v. factor affecting long term safety/suitability of site-salt thickness, p. 25 - 45, AEC-Lyons ES 1971, D6
vi. must be assessed prior to SS-thickness and continuities, p. 4 Program Plan for BSPP, 1973, D1
vii. assumptions for a safe rep: a volume of rock in stable geological environment, p. 1, EPA State of Knowledge, 1978, C7
viii. SS - determine suitability of local regions in terms of probable volume of acceptable lithology at usable depths, p. 13; site evaluation - detailed definition needed of thickness and size of host and associated units. p. 14, ESTP - USGS and DOE 1979, D24
ix. study looked at thicknesses of formations in U.S. Pierce & Rich, USGS Bulletin 1148, 1962, B1

2. Minimum size:

a. The size and shape (lateral and vertical) of body should be sufficient for rep and a sufficiently large buffer zone:

i. p. 4-5, NAS/NRC Aug. 1978, A1
ii. buffer zone of "significant" size - p. 15 AECL Canada 1975, E1
iii. p. C2-4, ERDA/BNWL Alternatives App. C 1976, D18
iv. Kehnemuyi, Battelle M, 1979, D23
v. p. 33, IAEA SS Factors 1977, E11
vi. p. 2, Brunton & McClain, OWI/ERDA 1977 (geological criteria--must be met), D20

b. host rock formation should be thick:

i. p. 1, Pierce and Rich, Bulletin 1148 USGS 1962, B1
ii. Los Medaños suitable - thick seams of salt at usable depths, p. 34, USGS 4339-7, 1973, B5
iii. Mescalero Plains features of interest - thick beds of salt p. 20, USGS - 74 - 190, 1974, B9
iv. great lateral and vertical extent of salt make SE New Mexico area prime location, p. 2, ORNL Program Plan for BSPP 1973, D1
v. one of 2 principal reasons for considering certain formations--have large volumes p. 19, IAEA SS Factors 1977, E11
vi. rep. rock shall have sufficient vertical extent-- p. 2, Brunton & McClain, OWI/ERDA 1977, D20
vii. p. 95, p. 98, Considerations for HLWM, Gera & Jacobs ORNL 1972, D5

c. exact minimum thickness:

i. total of salt deposits - several 100 ft.; for rep. bed, 20 ft. or more, - p. 1:3, p. 2:16-17, GCR 1978, D10
ii. Los Medaños tract promising because there is as much as 1,500 to 2,000 ft. of salt above maximum depth - p. 34-35, USGS 4339-7, 1973, B5
iii. 150 to 200 ft., p. 2-3, Supplemental Areas, KnGS 1972, B11
iv. several 100 ft. of very low permeability both above and below disposal horizon, p. 23, USGS 74-158, 1974., B8
v. 200 ft., p. 21, AEC-Lyons ES 1971, D6
vi. at least 60m prefered for salt bearing strata; minable salt should be at least 6m thick - p. 4-5, OWI/DOE Salt Dep of US 1978, D21
vii. 100m, Gera, Salt Tect., ORNL, GSA 1972, D4
viii. 200 ft. p, 3-4; 150 ft. above disposal horizon, p. 4-5, BSPP SS Factors, ORNL 1973, D2
ix. 100m of low permeability above and below disposal horizon, p. 4.61, HLWM Alternatives, BNWL - 1900, 1974, D16
x. criteria for disposal horizon selection: minimum of 50 ft. uniform salt, p. 26 SS WIPP, Sandia 1977, D9

d. reasons for setting minimum thickness:

i. adequate heat dissipation/mitigate thermal effects on non-host rock units:

- p. 2:16-17, GCR 1978, D10
- p. 21, AEC, Lyons ES 1971, D6
- p. C2-C4, ERDA/BNWL Alternatives App. C. 1976, D18
- p. 4-5. OWI/DOE Salt Dep. of US 1978, D21
- to take full advantage of salt's desirable properties of high thermal conductivity, - p. 3-5, BSPP SS Factors, ORNL 1973, D2
- p. 33 IAEA SS Factors 1977, E11
- p. 2, Brunton & McClain, OWI/ERDA 1977, D20

ii. buffering of mechanical effects/in case of fractures originating in disposal zone:

- p. 2:16-17, GCR 1978, D10
- p. C2-4, ERDA/BNWL, Alternatives, App. C 1976, D18
  (For plastic rocks, need smaller buffer zone to absorb fractures-self healing.)
- p. 4-5, OWI/DOE Salt Dep. of U.S. 1978, D21
- to take full advantage of salt's desirable properties (plasticity) to prevent excessive deformation of more brittle rocks above salt, p. 3-5, BSPP SS Factors, ORNL 1973, D2
- p.33, IAEA, SS Factors 1977 (For plastic rocks need smaller buffer zone to absorb fractures - self heaing.), E11
- p. 2, Brunton & McClain, OWI/ERDA 1977, D20

iii. combination of options can be exercised in selecting potential disposal horizon - p. 34-35, USGS - 4339-7-1973, B5

iv. to ensure that chamber can be effectively sealed - (for all rocks)

- p. 23, USGS 74-158, 1974, B8
- p. 4.61, HLWM Alternatives, BNWL 1900, 1974, D16

v. in case of slippage along faults - p. 92, considerations for HLWM, Gera & Jacobs, ORNL 1972, D5

vi. the thickness of the layer is not a governing parameter since doubling it only doubles the time it takes the nuclides to reach the environment. De Marsily et al, Guarantee Isolation? 1977, E5

e. lateral extent, distance to structural boundaries, should be adequate to provide for future integrity:

i. i.e. to protect from dissolutioning - at least 5 miles to Capitan Reef, at least 1 mile to dissolution front- p.2:16-17, GCR Sandia 1978, D10

ii. at least several tens of miles, p. 21, AEC Lyons ES 1971, D6

iii. protection from boundary dissolutioning, (required distance depends on an analysis of total thickness and shape of formation; thickness of salt overlying wastes, structure of salt between rep & formation boundary) p. 10 BSPP SS Factors 1973 ORNL, D2

iv. to protect rep from dissolutioning, p. 22 IAEA SS Factors, 1977, E11

v. to protect rep from dissolutioning, p. 98, considerations for HLWM, Gera & Jacobs ORNL 1972, D5

vi. for rep, in granite - in fault free block surrounded by faults at some distance, i.e. a few Km, (has a good chance to remain undisturbed until next ice age) p. III-10; Winchester - may need fault free block as big as 100 Km^2; Rydberg - size needed that meets the hydrological requirements, - a few Km^2, P. III-53; -KBS - Rydberg & Winchester 1978, E9

vii. for rep. in granite, need block with area of 1 Km^2 with small frequency of non-continuous tight cracks. p. 168; Winchester - required size of block - perhaps 3 Km in each direction desirable, 50-100 Km^2 p. 168 - Johanson & Steen, Ringhals - 3, 1978, E10

f. formation should be of great lateral extent:

i. great lateral extent of salt in SENM makes it a prime area - p. 2, ORNL Program Plan for BSPP 1973, D1

ii. one of 2 principal reasons for considering certain formations- their large volumetric masses - p. 19, IAEA SS Factors 1977, E11

3. Maximum Size: Risk of containment failure due to diapirism in salt is negligible if formation is thick enough to furnish safe containment but less than the 300 to 400 m necessary to produce sizable salt structures.

- Gera, Salt Tect, ORNL GSA 1972, D4
- p. 115-116, Considerations for HLWM, Gera & Jacobs, ORNL 1972, D5

3. Structure of Host Rock Body

1. Subsurface structure should be considered/information useful for site selection/ evaluation:
    - i. p. 2-3, Supplemental areas, Kansas GS, 1972, B11
    - ii. factors affecting long term safety - structure and stratigraphy, p. 25-45, AEC Lyons ES 1971, D6
    - iii. in geologic study of areas, range of tasks includes definition of rock structure and stratigraphy, p. 32, OWI/ERDA Program Plan for NWTSP, 1976, D19
    - iv. between rep and dissolution boundary for prediction of dissolution/ determination of adequate lateral extent, p. 10, BSPP SS Factors, ORNL 1973, D2
    - v. structure shall not compromise rep operations, engineering design or containment (criteria must be met) - consider homogeneity, isotropy, etc., p. 3, Brunton and McClain, OWI/ERDA 1977, D20
    - vi. site selection criteria must include consideration of structure and stratigraphy, p. 4-73, ES of WM of LWR Cycle, NRC 1976, C8.
    - vii. USGS - information needed on distribution and extent of major heterogeneities, (affect flow pattern), p. 114; confidence in a site - from understanding of structural and lithologic features on scales of a few meters to tens of kilometers, p. 170-1, Johansson and Steen, Ringhals-3, 1978, E10
    - viii. information is needed on geologic structures - detailed high quality maps, 3 dimensional data for design, p. 15, NAS/NRC, Implementation of Standards, 1979, A3

2. Simple structure:
    - i. feature of interest of Clovis-Portales area - fairly simple structure, p. 17, USGS 74-60, 1974, B6
    - ii. feature of interest of Mescalero Plains area - simple structure, p. 17, USGS 74-190, 1974, B9
    - iii. for salt, desired since it is a factor that militates against salt flow, p. 4-5, NAS/NRC Bedded Salt 1970, A2
    - iv. large scale site selection criteria - simple structure, p. 12, SS WIPP, Sandia 1977, D9
    - v. desired since complex geology is an indication of complex hydrology,
        - p. C2-4, ERDA/BNWL Alternatives App C 1976, D18
        - p. 33, IAEA SS Factors 1977, E11
    - vi. Summary of SS Factors - regional structural framework - minimal; structure of mining horizon - easily mineable, BSPP SS Factors, ORNL 1973, D2
    - vii. absence of discontinuities desired, or at least a small number, p. 13, EPA State of Knowledge, 1978, C7

3. Bedding should be close to horizontal (when rep is in bedded strata):
    - i. less than 3 degrees, p. 2:16-17, GCR 1978, D10
    - ii. information useful in evaluating the Carlsbad formation: gentle dip of less than 2 degrees, p 78, USGS 4339-1, 1972, B2
    - iii. p. 21, AEC Lyons ES 1971, D6
    - iv. dip should not exceed a few degrees for ease of mining; steep dips are an indication of tectonic stress and perhaps fractures.
        - p. C4-5, ERDA/BNWL Alternatives, App C 1976, D18
        - p. 3-4, OWI/DOE Salt Dep of the US, 1978, D21
        - p. 34, IAEA SS Factors 1977, E11
    - v. in salt, risk of containment failure due to diapirism in negligible if formation beds are close to horizontal
        - Gera, Salt Tectonics, ORNL, GSA 1972, D4
        - p. 115-116, Gera and Jacobs, Considerations for HLWM, 1972, D5

vi. dips of mining horizon less than 100 ft/mile, for ease of mining, avoidance of appreciable differential loading, p. 8, BSPP SS Factors, ORNL 1973, D2

4. Continuity of Bedding:
   i. consideration for construction and assessment of failure scenarios, p. 2:16-17, GCR, 1978, D10
   ii. looked at/considered in study, p. 45, USGS 4339-6, 1973
   iii. assessed prior to final site selection, p. 4, ORNL, Program Plan for BSPP, 1973, D1

5. Deformation/Folding:
   i. undesirable, p. 2:13, GCR, 1978, D10
   ii. information useful in evaluating Carlsbad formation - little deformed, p. 28-52, USGS 4339-1, 1972, B2
   iii. regions with abundant folding generally less suitable - more fractured rocks, p. 5, USGS 4339-5, 1973, B3
   iv. looked at/ considered in study - folding, p. 45, USGS 4339-6, 1973, B4
   v. Los Medaños area suitable because only slightly deformed, p. 34, USGS 4339-7, 1973, B5
   vi. features of interest of Clovis-Portales area - moderate folding, age of deformation unknown, p. 17, USGS 74-60, 1974, B6
   vii. features of interest of Mescalero Plains area - no evidence of deformation, p. 17, USGS 74-190, 1974, B9
   viii. formation should be relatively undisturbed structurally, p. 21, AEC Lyons ES 1971, D6
   ix. is hazard and should be avoided, p. 12-13, p. 39-41, SS WIPP, Sandia 1977
   x. gentle terrain prefered since it is an indication of undisturbed rocks at depth .
      - p. C1, ERDA/BNWL Alternatives App C 1976, D18
      - p. 31, IAEA SS Factors, 1977, E11

6. character of interbedding/relationships between stratigraphic units should be taken into account:
   i. for construction and assessment of failure scenarios, p. 2:16-17, GCR 1978, D10
   ii. information useful, p. 28-52, USGS 4339-1, 1972, B2
   iii. of critical strata, must be assessed prior to final site selection, p. 4, ORNL, Program Plan for BSPP, 1973, D1
   iv. important to detect weak bands in salt above and below pillars - affects mechanical structures, p. 2-8, NRC, Info Base for Rep Design 1979, C10
   v. factors making bedded salt leading candidate - presence of shale interbeds, p. 63, AD Little, Assessment, 1978, C3

7. Presence of cracks, fractures, faults, joints (see also Tectonic Stability/Faulting)
   i. minimum - formation should have high integrity, p. 15, AECL Canada 1975, E1
   ii. to be considered in making criteria, p. 12-13, AECL Canada 1976, E2
   iii. shale - regions with abundant faults less suitable - greater secondary permeability, p. 5, USGS 4339-5, 1973, B3
   iv. considered/looked at in study, p. 45, USGS 4339-6, 1973, B4
   v. features of interest of Clovis-Portales area - beds locally cut by faults, p. 17, USGS 74-60, 1974, B6
   vi. deleterious effect - principal pathway for water circulation in brittle rock; choose an area with no or few faults and if faults are present they must be locatable; their significance must be evaluated at each site (adversely affects brittle rocks more than plastic ones)
      - p. C4-5, ERDA/BNWL Alternatives App C 1976, D18

- p. 34, IAEA SS Factors 1977, E11

vii. generally undesirable - pathway for groundwater and complicates mining, p. 3-4, OWI/DOE Salt Dep of US 1978, D21

viii. shall not compromise rep operations, engineering design or containment (criteria must be met), p. 3, Brunton and McClain, OWI/ERDA 1977, D20

ix. introduces uncertainties into nuclide transport model-making (increases flow rate and decreases sorption), p. 8, USGS, ES Perspectives, 1978, B10

x. rep in granite should be in fault free block, p. III-10, KBS Rydberg and Winchester 1978, E9

xi. required host rock - absence of discontinuities like jointing or at least a very small number of these, p. 13, EPA State of Knowledge 1978, C7

xii. fracture zones in rock surrounding shafts should be sealed (prudent operating procedure), p. 2-7, NRC, Info Base for Rep Design 1979, C10

xiii. site selection - determine suitability on local level in terms of structural integrity (i.e. occurence of faults and fractures) p. 13; site characterization - detailed definition of stratigraphic discontinuities like faults, p. 14, ESTP, USGS and DOE 1979, D24

xiv. need 3 dimensional data on fractures and flow pattern (site specific)p.113; can strongly affect flow, p. 115; U. of Uppsala - site selection - need area with favorable crack density (not possible to find a big enough crack-free block in granite) p. 168; GS of Canada - need integrated broad overview of fractures and fracture characteristics as they relate to permeability to determine suitability of site, p. 168; USGS - for conficence in site need understanding of structural features, many of which are subtle like small faults and fracture systems (critical features) - the necessary structural integrity cannot be assumed through surface mapping and coring, p.170-1; Royal Technical Institute, Stockholm - with present techniques it is not possible to determine completely safely in detail the crack system in an area or new ones that may be created over the long term, p. 172, Johansson and Steen, Ringhals-3, 1978, E10

xv. information needed on faults - detailed high quality maps, 3 dimensional data, p. 15; need careful investigation of hydraulic properties of any fracture system as prerequisite for predicting rep performance, p. 18; important to obtain data on dilation and contraction of fractures in response to changes in fluid pressures and temperature, p. 43, NAS/NRC Implementation of Standards, 1979, A3

8. Major faults (see also Tectonic Stability/Faulting):

i. to be considered in making criteria, p. 12-13, AECL Canada 1976

ii. should be avoided

- p. C4-5, ERDA/BNWL Alternatives App C 1976, D18
- p. 34, IAEA SS Factors 1977, E11

9. Rock Cover over Rep Formation:

a.) substantial consolidated cover is desirable:

i. p. 78, USGS 4339-1, 1972, B2

ii. Los Medaños suitable, p. 34, USGS 4339-7, 1973, B5

iii. gentle dip prefered since over steep dips, protective covering of impermeable over-lying beds would generally not be present

- p. C4-5, ERDA/BNWL Alternatives App C 1976, D18
- p. 34, IAEA SS Factors, 1977, E11

b.) presence of cap rock over salt:

i. considered/looked at in study, p. 45, USGS 4339-6, 1973, B4

ii. factor making bedded salt leading candidate - cap rock remains more intact than those of salt domes, p. 63, AD Little, Assessment, 1978, C3

c.) differential loading of concern for salt due to danger of diapirism - should be minimal:

i. p. 4-5, NAS/NRC Bedded Salt 1970, A2
ii. Gera, ORNL, Salt Tectonics, GSA 1972, D4
iii. p. 8, BSPP SS Factors, ORNL 1973, D2
iv. p. 115-116, Considerations for HLWM, Gera and Jacobs, ORNL 1972, D5

10. Salt Anticlines, Diapirs, Flowage (see also Salt - Diapirism)

i. avoidance is a prime consideration, p. 2:13; steep anticlines avoided, p. 2:16-17; major anticlines should be avoided or evaluated to check on brine presence and anhydrite fracturing, p. 2:18-19, GCR, 1978, D10
ii. salt formation should be bedded (not dome) p. 21, AEC Lyons ES 1971, D6
iii. expanded site selection criteria - avoidance of anticlinal structures; synclines are unfavorable for oil and gas accumulation and less likely to contain geopressured brine resevoirs, p. 12; potential geologic hazard to be investigated - salt flowage, p. 39-41, SS WIPP, Sandia 1977, D9

11. Other Structures of Concern:

i. breccia pipes, dikes, p. 39-41, SS WIPP, Sandia 1977, D9
ii. dikes, p. 2:13, GCR 1978, D10
iii. taken into account in risk assessment - breccia pipes, p. 95-103, AD Little Assessment 1978, C3
iv. site characterization - need detailed definition of structural and stratigraphic discontinuities like breccia pipes, permeable lenses, p. 14, ESTP, USGS and DOE, 1979, D24

12. State of Geologic Knowledge: Site characterization - can we adequately evaluate the spatial characteristics of the geologic system such as the occurence of fractured rock masses within it?

a. do we have adequate understanding? models tested, applying to specific site
b. can we adequately measure/evaluate it? techniques known, developing equipment or verifying techniques; equipment available or techniques verified, improving sensitivity, range and/or reliability or applying techniques

p. 38, ESTP, USGS and DOE, 1979, D24

4. Homogeneity and Rock Purity

1. Homogeneity should be considered/information useful in site selection/evaluation:
   i. to be considered in making criteria, p. 12-13, AECL Canada 1976, E2
   ii. study looked at the percentage of non-halite beds, p. 45, USGS 4339-6, 1973, B4
   iii. site selection/evaluation/facility design will be based on an understanding of the effects of interbeds on long term containment, p. 4-75, ES of WM of LWR Cycle, NRC 1976, C8
   iv. prudent operating procedures - important to detect weak bands in salt (i.e. shale partings) above and below pillars - affects mechanical structures, p. 2-8, NRC Info Base For Rep Design 1979, C10
   v. factor making bedded salt leading candidate - presence of shale interbeds (shale has low permeability and high sorption capacity), p. 63, AD Little, Assessment 1978, C3
   vi. USGS - confidence in site from understanding of lithologic features on scales of a few meters to tens of kilometers, p. 170-1, Johansson and Steen, Ringhals-3, 1978, E10

2. Formation should be homogenous:
   i. p. 15, Canada AECL 1975, E1
   ii. beds of unusual composition and/or containing minerals with bound water should not occur within 20 ft of waste horizon so as to lessen the uncertainties with thermally driven geochemical reactions, p. 2:19-20, GCR, 1978, D10
   iii. shales of marine origen given more study - more uniform in composition and less likely to contain coarser grained water-bearing beds, p. 4, USGS 4339-5, 1973, B3
   iv. criteria for disposal horizon - those with fewest non-halite interbeds, p. 26, SS WIPP, Sandia 1977, D9
   v. rocks with high degree of homogeneity are considered superior but limits of acceptibility of non-homogeneity cannot be stated unequivocally. Heat dissipation can be adversely affected by discrete interbeds of impurities; interbeds known to contain circulating groundwater also detract from formation suitability.
      - p. C2-4, ERDA/BNWL Alternatives App C 1976, D18
      - p. 33, IAEA SS Factors 1977, E11
   vi. high degree desired for uncomplicated mining operations and heat dissipation, p. 4-5, OWI/DOE Salt Dep of the US, 1978, D21
   vii. a degree of lithologic homogeneity is necessary but cannot be assured through surface mapping and coring (especially if the number of boreholes is limited), p. 170-1, Johansson and Steen, Ringhals-3, 1978, E10

3. Purity in general:
   i. quality of salt should be considered in making criteria, p. 2-3, Supplemental areas, Kn GS 1972, B11
   ii. factor affecting long term safety/suitability - salt quality, p. 25-45, AEC Lyons ES 1971, D6
   iii. preliminary site selection criteria - relatively pure salt beds, p. 1:3; purity desirable, p. 2:16-17, GCR 1978, D10
   iv. features pertaining to storage of radwastes - pure salt or salt with only a small percentage of impurities required, p. 69, USGS, Bulletin 1148, Pierce and Rich, 1962, B1
   v. study only considered deposits that were at least 80 % shale, mudstone or claystone, p. 7, USGS 4339-5, 1973, B3
   vi. features of interest of Mescalero Plains - relatively high purity salt beds present, p. 20, USGS 74-190, 1974, B9

vii. criteria - good quality salt, p. 45, NAS/NRC Bedded Salt 1970, A2

viii. large scale site selection criteria - salt of high purity, p. 12; criteria for disposal horizon - those of highest purity, p. 26, SS WIPP, Sandia 1977, D9

ix. high degree desirable but limits of acceptability of non-homogeneity / presence of impurities cannot be stated unequivocally; heat dissipation can be adversely affected by significant amounts of certain impurities.
- p. C2-4, ERDA/BNWL Alternatives App C 1976, D18
- p. 33, IAEA SS Factors 1977, E11

x. not possible to specify acceptable quantitative limit of impurities (which dilute the desirable properties of salt) - depends on salt thickness and the type, locations, dimensions and distributions of impurities. In general, overall formations should be largely halite over at least the required minimum thickness and the amount and nature of the impurities should not be such that the pertinent properties of the formation are seriously degraded, p. 5; Summary of SS factors - purity of salt - largely halite, BSPP SS Factors, ORNL 1973, D2

4. Impurities Present:

a. water/brine:

i. undesirable - brine flow, p. 2:13; currently desirable upper limit - 3% brine for the heat producing horizon, limit for TRU horizon has not been established but same value as for HLW is acceptable, p. 2:16-17, p. 2:19-20, GCR 1978, D10

ii. "As storage or disposal of radioactive materials in salt envisions placement within a bed or mass of salt, there is no need to be concerned here with salt brines,.." p. 4, Pierce and Rich, USGS Bulletin 1148, 1962, B1

iii. consideration - maximum amount of brine accumulation in any disposal hole would be 2 to 10 liters and migration should cease in about 20 to 30 years, p. 55, AEC Lyons, ES 1971, D6

iv. recommendations for Lyons - proper design and spacing of canisters such that the problem of minute quantities of water in salt (gradually released at temperatures over 250 degrees) is reduced to an acceptable level, p. 7-8, NAS/NRC Bedded Salt 1970, A2

v. potential geologic hazard to be investigated - brine accumulations, p. 39-41, SS WIPP, Sandia 1977, D9

vi. brine migration - when less than 1% of salt volume, the maximum inflow of brine would be expected to be small; other than its effect on radiolysis and canister corrosion, this moisture's impact should be insignificant; for other rock types, fluid migration is probably inconsequential,
- p. C6-10, ERDA/BNWL Alternatives App C 1976, D18
- p. 37, IAEA SS Factors 1977, E11

vii. short term effects to be evaluated for site suitability - brine inclusions and migration (apparently present in all bedded salt deposits); can have significant effect on corrosion rate, will stop in 30 to 50 years because thermal gradient decreases, ORNL, McClain and Boch, 1974, D3

viii. water is a factor to be guarded against no matter what its source - nuclide transport, alters rock fractures, cavities created, etc., Kehnemuyi, Battelle M, 1979, D23

ix. desirable to limit the quantity of moisture available in disposal horizon as much as possible - water from brine inclusions <u>and</u>

hydrated minerals should not exceed 2% by volume (to limit corrosion and gas generation rates to acceptable values) p. 5-6; Summary of site selection factors of disposal horizon - less than 2% available water, BSPP SS Factors, ORNL 1973, D2

x. occurence of brine streams rare but requires careful investigation; brine inclusions may not be a problem if present in limited amounts, p. 22, IAEA SS Factors 1977, E11

xi. water content of rep rock shall be sufficiently low that water liberated by heat will not compromise containment by chemical reactions with waste or rep rock, p. 4, Brunton and McClain, OWI/ERDA 1977, D20

xii. site selection/evaluation/design will be based on an understanding of long term effects of water presence, p. 4-75; brine cavities - about .5% of many salt deposits - will move up thermal gradient but if contain gas, can move down gradient, p. 4-76, ES of WM of LWR Cycle, NRC 1976, C8

xiii. salt crystals contain significant amounts of water as fluid inclusions, along intergranular boundaries - a significant amount of water may be available from decrepitation where water is in excess of 1% of rock, p. 8; realistic estimates of water and brine content is critical to proper estimation of the fate of canisters and rate of creep, p. 18; at 200 degrees C water can contain 70% (by weight) of dissolved salts - so one weight percent of water in salt may yield 3 weight % of fluid due to the high concentration, which can also be highly acidic, pH as low as 2, p. 18, EPA State of Knowledge 1978, C7

xiv. critical information needs to be better able to evaluate rep design - physical chemistry of dense brines in contact with canisters, sleeves, waste; possibility of formation of volatile chemical compounds from combination of fission products and brine, p. 2-5, NRC Info Base for Rep Design 1979, C10

xv. need information on waste-rock interactions caused by fluid release and migration, p. 15, ESTP, USGS and DOE, 1979, D24

xvi. assumed rep environment - 98% NaCl and ½% H_2O; for HLW - potential for localized intrusion of NaCl-$MgCl_2$ brine - migration rate is function of thermal gradient and would cease in less than 20 years; calculated inflow/canister -.4 liters/yr. Techniques should be developed for eliminating any potential consequences of inflow (for example venting, sorption, preheating, etc), p. 6-7, Braithwaite and Mollecke, Canisters, Sandia 1978, D7

xvii. information needed on water content, hydrous phases and chemical properties of water - important for calculating the potential for leaching of canister and waste and subsequent chemical reactions, p. 19, NAS/NRC Implementation of Standards 1979, A3

b. Water-Bearing Minerals:

i. unacceptable constituent in shale since releases water on heating, p. 3; constituents relevant for determining disposal potential of a body of shale: montmorillonitic (a water-bearing mineral) p. 7; most shale is unacceptable because contains water-bearing minerals, p. 39-40, USGS 4339-5, 1973, B3

ii. presence can be detrimental - reacts adversely with waste.
- p. C2-4, ERDA/BNWL Alternatives App C 1976, D18
- p. 33, IAEA SS Factors 1977, E11

iii. presence of significant quantities may create undesirable conditions on heating. Includes - gypsum, polyhalite, carnallite, epsomite (often found in evaporites); also clay. When these minerals occur near the disposal zone, they must be considered as potential sources of water -

rate of dewatering, mechanisms and pathways by which freed water might escape or be recombined must be evaluated.

- p. C6-10, ERDA/BNWL Alternatives App C 1976, D18
- p. 39-40, IAEA SS Factors 1977, E11

iv. small quantities occur in most evaporites - studies to be done: on conditions under which water is released or recombined, to determine their quantities, distributions and dewatering characteristics at the disposal level, p. 11, ORNL Program Plan for BSPP 1973, D1

v. especially Ca and Mg sulfates - even small quantities can significantly affect geological and structural characteristics of formation - a horizon should be selected with no appreciable quantities of these within the heated zone; careful mineralogical analysis is needed, ORNL, McClain and Boch, 1974, D3

vi. water is a factor to be guarded against whatever its source, Kehnemuyi, Battelle M, 1979, D23

vii. desirable to limit as much as possible the amount of moisture available in disposal horizon - water from brine inclusions and hydrated minerals should not exceed 2% by volume (to limit corrosion and gas generation rates to acceptable values), p. 5-6, BSPP SS Factors, ORNL 1973, D2

viii. water content of rep rock shall be sufficiently low that water liberated by heat will not compromise containment by chemical reactions with waste or rock, p. 4, Brunton and McClain, OWI/ERDA 1977, D20

ix. site selection/evaluation/facility design will be based on an understanding of the effects of impurities of Ca sulfate, Mg chloride (water bearing minerals) on long term containment, p. 4-75, ES of WM of LWR Cycle, NRC 1976, C8

x. information needed on water content, hydrous phases and chemical properties of water - important for calculating the potential for leaching of waste and canister and subsequent reactions, p. 19, NAS/NRC Implementation of Standards, 1979, A3

xi. information needed on waste-rock interactions caused by fluid release and migration, p. 15, ESTP, USGS and DOE, 1979, D24

c. Gases:

i. potential geologic hazard to be investigated - gas accumulations, p. 39-41, SS WIPP, Sandia 1977, D9

ii. mainly a problem for mine working

- p. C6-10, ERDA/BNWL Alternatives App C 1976, D18
- p. 37, IAEA SS Factors 1977, E11
- p. 2, USGS 4339-6, 1973, B4

d. Organic Material:

i. shales - potentially relevant to determining site suitability: presence of petroliferous, carbonaceous compounds, p. 7; unacceptable - shales that contain a lot of organic matter - may yield combustible carbon compounds when heated, p. 3, USGS 4339-5, 1973, B3

5. Mechanical/Geophysical Properties and State of Stress

1. Should be such as to ensure the stability of the rep during its operational period:

i. p. 6-9, NAS/NRC 1978, A1
ii. even while thermally loaded (avoid clay seams, zones of unusual structural weakness in horizon selection), p. 2:19-20, GCR 1978, D10
iii. collapse during operational period could be disasterous, Kehnemuyi, Battelle M, 1979, D23
iv. p. 4,5, Brunton and McClain , OWI/ERDA 1977, D20
v. p. 13, EPA State of Knowledge 1978, C7
vi. stability must be demonstrated for a period significantly longer than that required for retrievability, p. 15-16, p. 26, NAS/NRC Implementation of Standards 1979, A3

2. Should be such as to ensure that the site is able to maintain its long term structural/mechanical integrity despite stresses imposed by excavation/presence of the rep (thermal, etc.):

i. must be established that transient and permanent deformations (displacement, strains and stresses) induced will not produce conditions leading to a breach in integrity
- p. C6-10, ERDA/BNWL Alternatives App C 1976, D18
- p. 37-8, IAEA SS Factors 1977, E11

ii. has to be shown that emplacement of waste could not have a significant effect on macroscopic stability of the formation, p. 15, AECL Canada 1975, E1
iii. p. 4,5, Brunton and McClain, OWI/ERDA 1977, D20
iv. p. IV-8,9, KBS Rydberg and Winchester 1978, E9
v. p. 13, EPA State of Knowledge, 1978, C7
vi. Concept, p. 6, NRC State Review, Nureg 0353 1977, C4
vii. p. 15-16; variation of stability throughout lifetime of the rep must be calculated and shown to be acceptable under the most adverse thermal conditions generated, p. 28, NAS/NRC Implementation of Standards, 1979, A3

3. Mechanical properties/state of stress should be considered/information useful for site selection/evaluation:

i. such as strength and elastic moduli, in making criteria, p. 12-13, AECL Canada 1976, E2
ii. looked at in study of rock types - strength
- p. 190 on, USGS 74-158, 1974, B8
- Section 4.0.3, HLWM Alternatives, BNWL-1900, 1974, D16

iii. generic technical studies to be done on rock mechanics, p. 10, OWI/ERDA Program Plan for NWTSP 1976, D19
iv. host rock characteristics pertinent to waste disposal - plasticity (salt), strength/structural stability (granite, etc), p. 3-4, USGS ES Perspectives 1978, B10
v. in site evaluation, need detailed definition of mechanical properties of host rock and confining media, p. 15; need information on state of natural stress and bulk and mechanical properties, p. 15, ESTP USGS and DOE, 1979, D24
vi. experimental determination of state of stress/rock mass stability at site is of primary importance, p. 15-16, NAS/NRC Implementation of Standards 1979, A3
vii. presence of faults/joints affects stability, p. 35, IAEA SS Factors 1977, E11

4. Strength is desirable:

i. sufficient to allow safe excavation, p. 13, EPA State of Knowledge 1978, C7

ii. factor that will determine suitability of site - rock strength, p. 5 Appendix (Intro to KBS Report), Johansson and Steen, Ringhals-3, 1978, D10

iii. three factors of rep that lie outside mining experience: containment, required lifetime and thermal stress - imposes stringent requirements on stability of rock mass and on the two principal factors that determine this stability: state of stress and strength of rock mass, p. 37-8, NAS/NRC Implementation of Standards 1979, A3

5. Plasticity is desirable:

i. contributes to reliability of containment, p. 2, IAEA SS Factors, 1977, E11

ii. to determine potential of shale body for disposal: need to know estimated plasticity, p. 7, USGS 4339-5, 1973, B3

iii. hard brittle rocks are unsuitable for disposal - fractures don't heal p. 92; formation must be characterized by plasticity because the sealing of fractures represents "the main safeguard against sudden loss of containment and release of radionuclides to groundwater"; but there are negative consequences of too much plasticity - diapirism; so rate of deformation required must be defined, p. 100-101; so in site selection, use the following criteria: formation should be plastic enough to cause the sealing of fractures but not so plastic as to permit the occurence of diapiritic processes in a time period of several hundred thousand years, p. 131, Considerations for HLWM, Gera and Jacobs, ORNL 1972, D5

iv. factor making bedded salt leading candidate - its plasticity, p. 63, AD Little, Assessment 1978, C3

6. Desired State of Stress:

i. site selected should in past have been mechanically stable, p. 2-9, ES of WM of LWR Cycle, NRC 1976, C8

ii. so that existing or future planes of weakness will not be mobilized - state of stress should be such that: the resistance to slip is appreciably greater than the shear stress across all planes of orientation within the rock mass; normal minimum stress should exceed the pressure of the hydrostatic head to ensure that existing fractures are not fully opened; to obviate the likelihood of faulting, especially in the presence of hydrostatic pressure, the difference between the values of the maximum and minimum components of the principal stresses should be small, p. 15-16; geoengineering - three factors that lie outside mining experience: containment, required lifetime and thermal stress - imposes stringent requirements on the stability of the rock mass and on the two principal factors that determine this stability - state of stress and strength, p. 37-8, NAS/NRC Implementation of Standards, 1979, A3

7. Rock should have mechanical properties such that mining it is not too difficult:

i. especially drillability in disposal zone - should be equivalent to commercial grade rock salt for convenience, p. 5-6, BSPP SS Factors, ORNL 1973, D2

ii. faults and joints affect ease of mining, p. 35, IAEA SS Factors 1977, E11

iii. factor making bedded salt a leading candidate - ease of mining, p. 63, AD Little, Assessment 1978, C3

8. Effect of rep induced stresses/deformations should be considered/information useful in site selection/evaluation:

i. studies should be performed on deformational behavior of rocks - operation of rep will induce transient and permanent deformations in surrounding and overlying rock, p. 11-12, ORNL Program Plan for BSPP 1973, D1

ii. in evaluating site suitability, must consider deformations expected around mine openings, long term deformations over rep, creep and their effect on the long term integrity of containment, ORNL, McClain and Boch 1974, D3

iii. as part of site selection, site specific analyses will be made of the effect of slow subsidence on the integrity of overlying rock, p. 4-82, ES of WM of LWR Cycle, NRC 1976, C8

iv. critical technology needing development: analytical techniques for predicting fractures (rep induces stresses and risk analysis would be facilitated if fractures and resulting permeabilities could be predicted); volumes of concern - around excavation and over rep (subsidence), p. 2-3,4; critical information needs: structural behavior of salt under stress, p. 2-5,6; risk analysis specific to excavation techniques needed to address issues like fracturing, p. 2-6, NRC Info Base for Rep Design 1979, C10

v. earth science capabilities needed for PSAR and ER: near and far field thermomechanical analysis and improved understanding of mine stability, p. 9,11; in evaluation of site, need detailed definition of the effects of heat and radiation on mechanical properties of host rock and confining media, p. 15; information is needed on the effects of stresses caused by thermal loading and mechanical effects of backfilling and subsidence, p. 15, ESTP USGS and DOE 1979, D24

vi. there is concern with faulting in granite - fracture forecast should include mining and temperature effects, p. 124, Johansson and Steen, Ringhals-3, 1978, E10

vii. geohydrologic information needed - changes in regime induced by rep, i.e. fracturing from excavation, p. 19-20; considerations in site selection - uncertainties and additional variables introduced into predictions by the disturbance of inherent integrity of host rock caused by excavations, waste - factors must be taken into account, p. 9, ; demonstration of stability must include consideration of stresses induced by excavation, p. 25, NAS/NRC Implementation 1979, A3

9. Induced State of Stress:

i. maximum stresses resulting from cavities, thermal stresses and inherent state of stress in wall rock must be well below the critical value for the uniaxial compressive strength of the host rock, Kehnemuyi, Battelle M, 1979, D23

ii. to ensure stable openings, a limit should be placed on the value of maximum stress and stress differences at positions of excavations - values related to the strength and plasticity of rock, and the layout of the excavations, p. 15-16, NAS/NRC Implementation of Standards, 1979, A3

10. Rep Design and Construction Procedures:

a. their effects should be considered/information useful:

i. terrestrial disposal option attractive since can use existing technology of mining, p. IV-8, KBS Rydberg and Winchester, 1978, E9

ii. critical information needs, to be better able to evaluate rep design: detailed operational risk analysis should be performed on the importance of design of equipment and procedures peculiar to waste handling and emplacement, p. 2-4,5; long term risk analyses are needed specific to D&D procedures, excavation techniques, p. 2-6; design option studies needed on structural design parameters, i.e. ventilation, extraction rates, thermal loading (how they interact is important), p. 3-1,2, NRC Info Base for Rep Design, 1979, C10

b. should limit adverse effects on formation:
   i. p. 2-3; rep should be designed to achieve maximum stability consistent with practicable operational design of rep, p. 25, NAS/NRC Implementation of Standards 1979, A3
   ii. as well as testing and exploration techniques - potential effects on long term integrity should be insignificant, p. 6, NRC State Review, Nureg 0353, 1977, C4

c. dimensions of rooms/extraction rate:
   i. those consistent with safe operation, p. 23-25, NAS/NRC Bedded Salt, 1970, A2
   ii. extraction rate will be at conservative 30% (potash mining rate is usually 60%), p. 39-41, SS WIPP Sandia 1977, D9
   iii. currently available equipement is capable of extracting rock at necessary rates, p. 2-1; to keep deformation at a minimum, 20% or less extraction rate in salt at depth of 2,000 ft for waste thermal loading of 100 kW/acre is recommended. If rooms are ventilated, up to 30% may be feasible, p. 2-8, NRC Info Base for Rep Design 1979, C10
   iv. from general data, extraction rates of less than 40% in CH area and less than 30% in RH area, WIPP Conceptual Design, Sandia 1977, D12

d. design/layout of excavations:
   i. information is needed on engineering design of openings for maximum stability, p. 15, ESTP, USGS and DOE, 1979, D24
   ii. demonstration of stability must include consideration of location and arrangement of excavation, p. 25, Implementation of Standards, 1979, NAS/NRC, A3
   iii. detailed stratigraphy of mining horizon should be such that pillars perform as planned - exact requirements depend on mine design, methods, local situation, p. 6, BSPP SS Factors, ORNL 1973, D2
   iv. earth science technology will be applied to design in at least the following areas: mine stability and mining impacts, p. 9, ESTP, USGS and DOE, 1979, D24

e. rock reinforcement methods:
   i. confirmation of adequate engineering design - demonstration of of stability must include consideration of support design, p. 25; in situ tests are needed for confirmation - on mechanical and hydrological effects of rock reinforcement methods, p. 31, NAS/NRC Implementation of Standards, 1979, A3

f. excavation methods:
   i. current technology/equipment in use is satisfactory, p. 2-2; long term risk analysis specific to excavation techniques is needed, p. 2-6, NRC Info Base for Rep Design, 1979, C10
   ii. mining methods utilizing explosives shall not be used to develop mine openings outside of shaft pillar, p. 10-11, WIPP Design Criteria, 1978, D11
   iii. every effort should be made to ensure that isolation remains adequate in original design of penetrations, p. 29; in situ tests needed for confirmation of adequate design - on mechanical and hydrological effects on rock of excavation methods, p. 31, NAS/NRC Implementation of Standards, 1979, A3

g. backfilling (see also Design):
   i. to minimize subsidence and deformation, p. 23.26-27, ERDA/BNWL Alternatives Vol. 4, 1976, D17

ii. information is needed on mechanical effects of backfilling, p. 15, ESTP, USGS and DOE, 1979 , D24

iii. backfilling and sealing of each segment should be done as soon as waste is in place and final checking has been completed, so as to prevent roof collapse that could result in fracture propagation, p. 6-9, NAS/NRC, 1978 , A1

h. equipment/design - current technology is adequate for the following: hoisting equipment, shaft lining (for operational phase), waste storage holes, earthquake protection, mine safety, p. 2-1,2, NRC Info Base for Rep Design 1979, C10

11. Current State of Knowledge:

i. additional R&D is needed to allow reliable determination of both state of stress and rock strength for any site - there is much uncertainty in current methods, p. 37-8, NAS/NRC Implementation of Standards, 1979, A3

ii. site characterization: can we adequately evaluate the physical/chemical properties of a geologic system? Salt - techniques and sensitivity are adequate, applying to site; Anhydrite, granite, shale, basalt, tuff - equipment available and techniques verified, improving sensitivity, range and/or reliability or applying techniques, p. 39; Do we adequately understand mine stability? Salt, granite, basalt - models tested, applying to specific site; Anhydrite - limited data, currently expanding data base; Shale - moderate amount of data, developing models; Tuff - models developed, assessing applicability, p. 40; Do we adequately understand mining induced fracturing? Salt - models tested, applying to specific site; Anhydrite shale - limited data, currently expanding data base; Granite, basalt, tuff - moderate amount of data, developing models, p. 41; Can we estimate the long term thermomechanical impacts of the rep on the geologic environment? moderate understanding of principles, developing models, p. 45, ESTP, USGS and DOE, 1979, D24

6. Radiation and Thermal Effects

1. Radiation and heat generated should not cause physical/chemical reactions in the host rock that would compromise containment:

i. p. 11-13, NAS/NRC 1978 , A1
ii. site and wastes should be compatible - effects do not compromise long term effectiveness of rep, p. 4-5, NRC State Review, Nureg 0353, 1977, C4
iii. Kehnemuyi, Battelle M, 1979 , D23
iv. (radiation), p. 4, Brunton and McClain, OWI/ERDA 1977 , D20
v. (thermal), p. IV 8-9, KBS Rydberg and Winchester 1978, E9
vi. p. 4-73, ES of WM of LWR Cycle, NRC 1976 , C8

2. Thermal Properties:

i. no major thermal barriers should exist closer than 20 ft to avoid undesirable temperature rises, p. 2:19-20, GCR 1978 , D10
ii. to be considered in making criteria, such as conductivity and expansion, p. 12-13, AECL Canada 1976 , E2
iii. should promote rapid dissipation of decay heat; salt - high thermal conductivity (desirable feature); to determine the effects of thermal loading on host rock, must define and determine the appropriate thermal transport and mechanical strength related properties - i.e. thermal conductivity, specific heat, coefficient of expansion, rupture stress and creep rate
- p. C6-10, ERDA/BNWL Alternatives App C 1976, D18
- p. 38-9, IAEA SS Factors 1977, E11
iv. high degree of homogeneity is desired for uncomplicated heat dissipation, p. 4-5, OWI/DOE Salt Dep of US, 1978 , D21
v. lithological considerations - study looked at thermal conductivity of rock types, Section 4.0.3, HLWM Alternatives BNWL-1900, 1974 , D16
vi. characteristics pertinent to waste disposal - high thermal conductivity of salt, p. 3-4, USGS ES Perspectives 1978, B10
vii. one of suitability requirements of site: temperature, p. IV 27-28, KBS Rydberg and Winchester 1978 , E9
viii. much more needs to be known about thermo-elastic expansion, thermal conductivity, particularly as they are affected by thermal cracking, p. 14, EPA State of Knowledge 1978 , C7
ix. factors making bedded salt a leading candidate - high thermal conductivity, p. 63, AD Little, Assessment 1978 , C3
x. in evaluation of site, need detailed definition of thermal properties of host rock and confining media, p. 15, ESTP, USGS and DOE, 1979, D24
xi. current analytical techniques are adequate for predicting temperature distribution. Many of the data for models are site specific and it should be possible to measure most of the parameters during exploration and early stages, p. 2-2, NRC Info Base for Rep Design 1979, C10
xii. need detailed data on: thermal conductivity, heat capacity, geothermal gradients, p. 16-17, NAS/NRC Implementation of Standards, 1979, A3

3. Effects of Thermal Stresses imposed by Rep:

i. should be considered in additional criteria: problems of geothermal impacts, p. 30, NRC State Review/Analysis, Nureg 0354, 1978, C5
ii. generic technical support studies to be done: on heat transfer/thermal analysis, p. 10, OWI/ERDA Program Plan for NWTSP, 1976 , D19

iii. evaluation of site - evaluation of effects of rep on site over short term - thermal transient, ORNL, McClain and Boch, 1974 , D3

iv. must be considered in rep design and operation, p. 4-76, ES of WM of LWR Cycle, NRC 1976 , C8

v. for PSAR and ER preparation , types of ES capabilities needed: near and far field thermomechanical analysis, p. 11; ES technology will be applied to design in at least the following areas: thermo-mechanical effects, p. 9; evaluation of site - need detailed definition of effects of heat on mechanical, thermal and geochemical properties of host rock and confining media and on the containment capability of host rock, p. 15, ESTP, USGS and DOE 1979 , D24

vi. information needed - need to determine if thermal stress is at an acceptable level, p. 15-16, NAS/NRC Implementation of Standards, 1979, A3

a. effect on mechanical stability:

i. take into account temperature and thermal stress transfer effects on the stability of mine and overlying strata to determine the maximum desirable temperature, p. 46, AEC Lyons ES 1971, D6

ii. thermal energy released is only of significance in relation to its effect on structural properties of salt, p. 18-22, NAS/NRC Bedded Salt 1970, A2

iii. host rock stability should not be adversely affected in presence of elevated temperature. Salt - accelerated creep - promotes healing of excavated cavities; brittle rocks - accelerated deformation - detrimental as it may cause fracturing; argillaceous rocks - may cause significant physical changes.

- p. C6-10, ERDA/BNWL Alternatives App C 1976 , D18
- p. 38-9, IAEA SS Factors 1977 , E11

iv. limits themal loading, p. 4-76, ES of WM of LWR Cycle, NRC 1976 , C8

v. required of host rock - mechanical integrity despite high temperature, p. 13; long term stability can be achieved by increasing support but the problem remains of the effect of elevated temperature - only the long term behavior of salt for high temperature and pressure has been investigated. We are far from the capability to predict with accuracy the behavior of other rocks - data on mechanical properties under relevant conditions is lacking; this area needs much work to develop lab procedures, testing machines, etc, to get this data, p. 13-14, EPA State of Knowledge 1978 , C7

vi. fracture forecast should include temperature effects, p. 124, Johansson and Steen, Ringhals-3, 1978, E10

vii. confirmation of adequate engineering design - demonstration of stability must include consideration of the following: temperature fields around rep, thermomechanical stresses, p. 25; variation of stability throughout the lifetime of the rep must be calculated and shown to be acceptable under the most adverse thermal conditions generated, p. 28; geoengineering - factor outside mining experience - effect of thermal stress, p. 37-8, NAS/NRC Implementation of Standards 1979, A3

viii. need information on the effects of stresses on rock mechanics; evaluation of site - need detailed definition of effect of heat on mechanical properties of host rock and confining media, p. 15, ESTP, USGS and DOE, 1979, D24

b. Temperature rise in aquifer and at ground surface:

i. considered in determining maximum thermal load, p. 46, AEC Lyons ES, 1971, D6

ii. considered, p. 3, Letter from Beckner to Schueler Dec. 1978(aquifer), D13

iii. at ground surface , considered as it limits thermal loading, p. 4-76, p. 4-81, ES of WM of LWR Cycle, NRC 1976, C8

c. effect on permeability/groundwater regime:

i. permeability may be altered - minimize complications by design with low heat generation rate, p. III-16, KBS Rydberg and Winchester 1978, E9

ii. may cause stress/thermal gradients which are potential driving forces for radionuclide migration - must be understood and characterized before operational safety can be evaluated, p. 4-76, ES of WM of LWR Cycle, NRC 1976, C8

iii. much more must be known about how permeability is affected by thermal cracking, p. 14, EPA State of Knowledge 1978, C7

iv. consider fractures, thermal effects in creating a convective cell, p. 19-20; confirmation of adequate engineering design - demonstration of stability must include consideration of the effects of temperature fields on hydrology, p. 25, NAS/NRC Implementation of Standards 1979, A3

d. geochemical effects:

i. dehydration of water-bearing minerals - consider it in evaluation of site suitability, ORNL McClain and Boch, 1974, D3

ii. during elevated temperature period, geochemical conditions may differ and may cause alteration of mineral precipitates or coatings on fracture surfaces, retardation capabilities. Lab data on retardation may not be applicable unless done at elevated temperature. Minimize complications by design with low heat generation rate, p. IV-16, KBS Rydberg and Winchester 1978, E9

iii. need firm data on thermal reaction products around canister from in situ experiments, p. 4-76, ES of WM of LWR Cycle, NRC 1976, C8

iv. evaluation of site - need detailed definition of effects of heat on geochemical properties, p. 15, ESTP, USGS and DOE, 1979, D24

v. hydrothermal solutions would be expected to transport species and a process similar to contact metamorphism would occur, producing a zone around the waste container, a contact aureole, in which new minerals could be formed, McCarthy et al, Waste-Rock Interactions, Nature, 1978, E3

vi. important geochemical information to be determined: influence of temperature on geochemical processes p. 21 ; chemical characteristics of solid surfaces near waste and their susceptibility to chemical and physical alteration caused by waste, p. 23; chemical characteristics of solid and fluid media on a large scale around rep including the potential for large scale change under imposed thermal gradients, p. 24; confirmation of adequate engineering design - demonstration of stability must include consideration of thermochemical stresses, p. 25, NAS/NRC Implementation of Standards, 1979, A3

e. effect on canister corrosion and leaching of wastes:

i. considered, p. III-23, KBS Rydberg and Winchester 1978, E9

ii. critical information needs - on limiting processes in corrosion rate, p. 2-5, NRC Info Base for Rep Design 1979, C10

iii. under conditions of high temperature and pressure, poorly crystalline and non-crystalline solids react readily with water, i.e. glass - should be considered, McCarthy et al, Waste-Rock Interactions, Nature 1978, E3

iv. if canister survives and remains a barrier during the major heat generation period - provides significant retarding action against thermally driven interactions (i.e. hydrothermal leaching). Hydrothermal conditions should be avoided for HLW forms if possible since they are effective in leaching out Cs, Rb and Mo, p. 3, Braithwaite and Mollecke, Canister, Sandia 1978, D7

f. effect on brine migration in salt (see also Homogeneity and Rock Purity):

i. considered in evaluation of site suitability, ORNL McClain and Boch 1974, D3

ii. limits thermal loading, p. 4-76, ES of WM of LWR Cycle, NRC 1976, C8

4. Thermal Loading Should Be Limited:

i. upper operating temperature should be prescribed for the combination of the host rock type, waste composition and form to ensure that thermally and radiation induced geophysical processes remain within predictable limits, p. 11-13, NAS/NRC 1978, A1

ii. in salt beds at 300m, about .032 kW/square meter is an acceptable heat generation rate. Same order of magnitude will probably apply to other media, p. 6, AECL Canada 1976, E2

iii. bulk temperature of salt should not exceed 392 degrees F; not an upper limit - operating experience may indicate higher temperature is allowable and thus provide a possible avenue for improving the economy of the operation, p. 46, AEC Lyons ES, 1971, D6

iv. HLW: temperature in salt should not exceed 200 degrees C; limit total power in any one ten ft canister to 7,500 W; space containers so that the centerline temperature is not over 900 degrees C and the temperature of salt at distance of 8 inches is less than 250 degrees; TRU - initial heat generation will be limited to about 0.1 W/cubic ft, p. 18-22; NAS/NRC Bedded Salt, 1970, A2

v. limit peak temperature safely below the waste's solidification or processing temperature and in salt to 200 degrees C except immediately adjacent to canister; spacing such that 65 kW/hectare heat generation rate, ORNL McClain and Boch, 1974, D3

vi. for rep in salt, reasonable limitation is that temperature should not exceed 200 degrees C, p. 76-78, Considerations for HLWM, Gera and Jacobs, ORNL 1972, D5

vii. conservative limits need to be set initially on thermal load until problems are resolved, i.e. of the effects of thermal output on the whole system. The uncertainties associated with hot wastes that interact chemically and mechanically with rock and fluid system appear very high. General rule - restrain the maximum permissible temperature to a level lower than that which will cause gas phase to appear, p. 6; uncertainties involved with all media, at least initially, are greatly reduced if used only for relatively cool waste (surface temperature of less than 100 degrees C), p. 12-13, USGS, ES Perspectives 1978, B10

viii. minimize complications of elevated temperature by design of low heat generation rate /canister, p. III-16; for clay buffer to keep plasticity (KBS plan), maximum temperature in range of 100 to 200 degrees, p. III-26, KBS Rydberg and Winchester 1978, E9

ix. limit thermal loading of HLW to about 150 kW/acre, p. 4-76, ES of WM of LWR Cycle, NRC 1976, C8

x. prudent operating procedure - 20% extraction rate at 2,000 ft depth and thermal loading of 100 kW/acre, to keep deformation at a minimum, p. 2-8, NRC Info Base for Rep Design 1979, C10

xi. heat load affects failure probabilities caused by technological imperfections, p. 206, AD Little, Assessment 1978, C3

xii. ES technology will be applied to design in at least the following areas; thermal loading, p. 9, ESTP USGS and DOE 1979, D24

xiii. requirements dictating design of RH area: thermal loading will be less than 75 kW/acre, p. 125, WIPP Conceptual Design Report, Sandia 1977, D12

xiv. calculations of temperature and thermally induced stress field will provide the information necessary to make critical decisions concerning maximum temperature, maximum canister power, location and arrangement of canisters, p. 27; in situ tests of effects of thermal loading - data is vital for deciding on, for example, maximum acceptable thermal output of waste, p. 31, NAS/NRC Implementation of Standards, 1979, A3

5. Radiation Effects:

i. best quantified in halite so purer rock salt desired for HLW horizon, p. 2:19-20, GCR 1978, D10

ii. to be considered in making criteria, p. 12-13, AECL Canada 1976, E2

iii. should study the possibility of metamict (Wigner) effect due to the high level of radiation, p. 10, NAS/NRC Bedded Salt 1970, A2

iv. problem does not occur for alpha wastes, only considered for HLW. It is essential to establish the identity and magnitude of radiation effects on various types of rocks,

- p. C6-10, ERDA/BNWL Alternatives App C 1976, D18
- p. 40, IAEA SS Factors 1977, E11

v. studies to be done: on radiation effects in salt, p. 15, ORNL Program Plan for BSPP 1973, D1

vi. consider the possibility and consequences of radiation induced energy storage in the evaluation of site suitability, ORNL, McClain and Boch, 1974, D3

vii. considered re: effect on clay, radiolysis and its effect on canister corrosion - KBS plan to encapsulate wastes in lead to minimize radiolysis effect, p. III-23, KBS Rydberg and Winchester 1978, E9

viii. must be considered in rep design and operation, p. 4-76; firm information on identities and amounts of radiolytic reaction products around the waste container will be furnished by site specific in situ experiments to help establish suitable procedures, p. 4-76, ES of WM of LWR Cycle, NRC 1976, C8

ix. current techniques are adequate for predicting radiation intensity (gamma), p. 2-2; waste-rock interactions - preliminary understanding of these in salt appears adequate and of minor consideration: role of radiolysis in corrosion relative to other corrosion considerations, energy stored when annealing effects are insignificant (at temperature of less than 150 degrees C), p. 2-3; Critical information needs for salt: explosive potential of unstable species formed by radiolysis, release of stored energy when salt is below annealing temperature, p. 2-5, NRC Info Base for Rep Design, 1979, C10

x. evaluation of site - need detailed definition of effects of radiation on thermal, mechanical and geochemical properties of host rock, p. 15; need information on waste-media interactions caused by radiation effects - i.e. radiolysis, release of gases, etc, p. 15, ESTP, USGS and DOE, 1979, D24

xi. geochemical information needed - important to determine the chemical characteristics of solid surfaces near wastes and their susceptibility to radiolysis, p. 23; in situ tests are needed on the effects of radioactive loading, p. 31, NAS/NRC Implementation of Standards, 1979, A3

6. State of Geologic Knowledge:

- Can we adequately evaluate the physical / chemical properties of a geologic system? Salt - techniques and sensitivity adequate, applying to rep; Anhydrite, granite, shale, basalt, tuff - equipment available or techniques verified, improving sensitivity, range and/or reliability or applying techniques, p. 39.

- Do we adequately understand thermomechanical effects? Salt - models developed, assessing applicability; Anhydrite and tuff - limited data, currently expanding data base; Granite, shale, basalt - moderate amount of data, developing models, p. 41.

- Do we adequately understand the effects of coupling of thermalhydraulic and thermomechanical phenomena? Moderate amount of data, developing models, p. 45.

- Can we estimate the long term thermomechanical impacts of the rep on the geologic environment? Moderate understanding of principles, developing models, p.45. ESTP, USGS and DOE, 1979, D24

7. Hydrology: Groundwater/Nuclide Transport:

1. Should be taken into account/information useful for site selection/evaluation:

i. hydrological transport - for WIPP a secondary factor; evaluate it to allow quantitative calculations of consequences of failure scenarios; slow transport of isotopes is acceptable if more critical factors have been satisfied, p. 2:17-18, GCR, 1978 , D10

ii. to be considered in making criteria - hydrology, p. 12-13, AECL Canada 1976 , E2

iii. p. 53, USGS 4339-1, 1972, B2

iv. p. 2-3, Supplemental areas, Kn GS, 1972, B11

v. among most important general and basic considerations: hydrology, p. 9, USGS 74-158, 1974 , B8

vi. affects long term safety/suitability of site: groundwater hydrology, p. 25-45, AEC Lyons ES 1971 , D6

vii. criteria should include problems of waste migration in groundwater, p. 30, NRC State Review/Analysis, Nureg 0354, 1978 , C5

viii. critical element in establishing suitability of site
- p. C10-12, ERDA/BNWL Alternatives App C 1976 , D18
- p. 41, IAEA SS Factors 1977, E11
- p. 5-6, OWI/DOE Salt Dep of the US, 1978 , D21

ix. in geologic study of areas, range of tasks includes - hydrology (important), p. 32, OWI/ERDA Program Plan for NWTSP , 1976 , D19

x. groundwater is the principal threat to rep in salt - essential to determine the hydrological characteristics of rocks that lie in close proximity to the salt, p. 5, ORNL, Program Plan for BSPP, 1973, D1

xi. critical consideration, Kehnemuyi, Battelle,M, 1979, D23

xii. diapirs - present much more serious hydrological problems (complexity of circulation) so have to be investigated more carefully in this regard for rep, Gera, ORNL, Salt Tectonics, GSA 1972, D4

xiii. lithological considerations - study looked at rock type's ability to store and transmit water, Section 4.0.3, HLWM Alternatives, BNWL-1900, 1974, D16

xiv. possiblity of groundwater reaching the waste (in salt rep) and transporting it to the biosphere must be evaluated with maximum care, p. 80-81, Considerations for HLWM, Gera and Jacobs, ORNL 1972 , D5

xv. main threat to isolation - movement of groundwater, de Marsily et al, Guarantee Isolation? 1977, E5

xvi. process capable of tranporting waste to biosphere - groundwater, p. 9-12, USGS, ES Perspectives, 1978, B10

xvii. most important technical aspects - groundwater flow; it is an extremely complicated task to evaluate the different processes of groundwater/nuclide/host rock system, which however is fundamental for predicting radionuclide migration, p. III-19, KBS Rydberg and Winchester, 1978 , E9

xviii. site selection criteria must include consideration of hydrology, p. 4-73, ES of WM of LWR Cycle, NRC 1976, C8

xix. events taken into account in risk assessment - hydrology, p. 95-103, AD Little, Assessment 1978 , C3

xx. site selection - determine suitability of broad regions in terms of suitable regional hydrology, p. 13; site characterization - detailed definition needed of distribution of hydrological properties of rock masses of site, p. 14; long term risk analysis - includes knowledge of natural features that influence nuclide migration, p. 16; need information on regional distribution of rock types and structural features as they affect groundwater flow, p. 16-17; information needed on regional movement of groundwater or surface water supplied by groundwater; prediction of nuclide concentrations in system as functions of time and space should be done, p. 17, ESTP USGS and DOE, 1979, D24

xxi. consider transport of "new" waste form (interaction product of waste/canister/rock/water), rather than of original waste form, McCarthy et al, Waste-Rock Interactions, Nature 1978, E3

xxii. a comprehensive set of large scale hydrological tests of existing conditions is imperative - the importance of these data in verifying in situ conditions and in reducing uncertainties in predictions based on modeling cannot be overstated, p. 31, NAS/NRC Implementation of Standards 1979, A3

2. Hydrological system should not permit the transport of radionuclides to the biosphere in amounts/rates above prescribed limits:

i. p. 9-11, NAS/NRC 1978, A1

ii. waste must be immobile unless it can only move to a more desirable location, p. 13-14, Deep Rock, Klett Sandia 1974, D8

iii. must be demonstrated if host rock contains some water
- p. C10-12, ERDA/BNWL Alternatives App C 1976, D18
- p. 42, IAEA SS Factors 1977, E11

iv. Kehnemuyi, Battelle M, 1979, D23

v. criteria must be met, p. 3, Brunton and McClain, OWI/ERDA 1977, D20

vi. p. 17, NAS/NRC Implementation of Standards 1979, A3

3. Water should not react physically/chemically with host rock, especially as the temperature rises, in such a way as to compromise containment, i.e. by altering permeability:

i. p. 11-13, NAS/NRC 1978, A1

4. Characteristics of Hydrological System:

a. formation should be free of / isolated from circulating groundwater (see also Dissolutioning for salt):

i. confinement by salt and isolation from water is the basic isolation premise, p. 2:19-20, GCR, 1978, D10

ii. p. 4, p. 15, AECL Canada 1975, E1

iii. salt - impermeable enclosing beds is a prime requisite to isolate formation from groundwater, p. 69, Pierce and Rich, USGS Bulletin 1148, 1962, B1

iv. dominating factor for deep geologic disposal - potential for groundwater intrusion, p. 23.15-17, ERDA/BNWL Alternatives Vol. 4, 1976, D17

v. for host rocks with low adsorption capacity, it is imperative that the waste remain isolated from groundwater, p. C6-10; generally host rock should be free of circulating groundwater though over- and under-lying formations may contain water-bearing zones if these are separated from rep by aquiludes, p. C10-12, ERDA/BNWL Alternatives App C 1976, D18

vi. salt - by very existence, salt beds attest to being isolated from groundwater, p. 4-5; formation must be free of circulating groundwater and the nature and characteristics of the water-bearing zones near the formation are critical for site suitability, p. 5-6, OWI/DOE Salt Dep of the US, 1978, D21

vii. water - factor to be guarded against whatever its source, Kehnemuyi, Battelle M., 1979, D23

viii. salt site selection factor - groundwater : minimal, to limit the rate of dissolution and, if the waste does escape the salt, to limit widespread dispersal in groundwater, p. 9, BSPP SS Factors, ORNL 1973, D2

ix. or little or no movement of groundwater, (see following factors), p. 2; one of the two principal reasons for considering a formation - no or negligible amounts of migrating groundwater, p. 19, (what is considered negligible must be worked out separately for each site, p. 20); generally host rock should be free of circulating groundwater although over- and under-lying formations may contain water-bearing zones if these are separated from rep by aquiludes, p. 42, IAEA SS Factors 1977, E11

x. salt - at time of disposal, assume there is no circulating groundwater present, 80-81; site selection criteria that should be used - formation must be characterized by an absence of groundwater, p. 100, p. 131, Considerations for HLWM, Gera and Jacobs, ORNL 1972, D5

xi. but water is almost universally present, de Marsily et al, Guarantee Isolation? 1977, E5

xii. p. 2-9, ES of WM of LWR Cycle, NRC 1976, C8

b. permeability:

i. for salt rep, low permeability is desirable in interbeds and surrounding media. Salt permeability to gases may be important in establishing waste acceptance criteria, p. 2:19-20, GCR 1978, D10

ii. formation should be impervious to moving groundwater and/or isolated from it, p. 15, Canada AECL 1975, E1

iii. to be considered in making criteria, a key factor, p. 12-13, AECL Canada 1976, E2

iv. advantage of argillaceous rock - low permeability, p. 3; study considered mainly shales of marine origen - expected to be less permeable, p. 4; assumed that regions with abundant faults/folding less suitable since there are likely to be more fractured rocks and therefore greater secondary permeability, p. 5; to determine suitability of shale body, need information on primary and secondary permeability, p. 7,12, USGS 4339-5, 1973, B3

v. host rock must have very low permeability and be virtually free of faults, p. 1; controls velocity, p. 152; qualities looked at in rock types - permeability, p. 190 on, USGS 74-158, 1974, B8

vi. site selection guidelines - low permeability favored, low or no fracture permeability desired

- p. C6-10, ERDA/BNWL Alternatives App C 1976, D18
- p. 36, IAEA SS Factors 1977, E11

vii. affects velocity but conventional methods of determining hydraulic properties may be ineffective, especially in rocks with low permeabilities, p. C10-12, ERDA/BNWL Alternatives App C 1976, D18

viii. "However low the real values for permeability and for velocity of displacement of fluids in rocks which may be regarded in practice as 'impermeable', the quantities of fluids able to tranverse layers of this rock are almost always significant in the very long term and cannot be considered negligible." p. 43, IAEA SS Factors 1977, E11

ix. prefered geohydrological characteristics: zone of strata with very low permeability, p. 4.61, HLWM Alternatives, BNWL-1900, 1974, D16

x. no rock formation is completely impervious; parameters describing tranport - permeability - affects velocity; extremely excellent formation is defined as having Darcy's permeability of 10^{-10}m/sec; low permeability (very rarely nil in nature)is not a major factor in confining radionuclides with very long ½ lives over time periods on geological scale; de Marsily et al, Guarantee Isolation? 1977, E5

xi. characteristics relevant to waste disposal - salt has low permeability, shale, granite and basalt have low primary permeability, p. 3-4; factors tending to lengthen transport time: low permeability, p. 8; uncertainties introduced into model-making: difficulty in measuring permeability in low permeability strata, p. 8, USGS, ES Perspectives 1978, B10

xii. essential parameter, considered; affects velocity, p. III-11-13; elevated temperature period may cause alteration of fracture permeability - should be considered, p. III-16, KBS Rydberg and Winchester 1978, E9

xiii. assumptions for safe rep - minimal permeability, p. 1; required host rock - low permeability, p. 13; delay in transport can be predicted on the basis of three key factors, one of which is actual permeability, (primary and secondary), p. 25-26, EPA State of Knowledge 1978, C7

xiv. critical technology needing development: analytical techniques for predicting fractures and effective permeabilities, risk analysis would be facilitated; volumes of concern - around excavation and over rep, p. 2-3, 4, NRC Info Base for Rep Design, 1979, C10

xv. factors contributing to slow tranport - small fractures and low permeabilities of media, p. 6-8; factors that make salt leading candidate - low permeability, presence of shale interbeds that have low permeability, p. 63, AD Little Assessment 1978, C3

xvi. site characterization - need detailed definition of permeability, p. 14; ESTP, USGS and DOE, 1979, D24

xvii. points of concern of critics of KBS report - have to consider high permeability of crush zones even at depth; measurements of average permeabilities do not represent flow through cracks, p. 12-15; USGS - information needed on permeability at site, p. 114; need 3 dimensional data on fractures, p. 113; U. of Uppsala - choose an area where the frequency of cracks is small and where cracks are relatively tight and show poor continuity (poor conductivity results), p. 168; GS of Canada - need integrated broad overview of fractures and fracture characteristics as they relate to permeability to determine the suitability of a site, p. 168; KBS - factors determining site suitability - permeability, p. 5 Appendix, Johansson and Steen, Ringhals-3, 1978, E10

xviii. evaluation of the adequacy of rep will require careful measurement of fracture permeability and rock matrix permeability, p. 17; need careful investigation of hydraulic properties of any fracture system to be able to predict rep performance, p. 18; few in situ measurements have been made of permeability at depth in low permeability rock types with realistic temperature and pressure conditions. There is a definite need to develop new field techniques for measuring permeability of low permeability rocks, ideally without impairing integrity of site, p. 40-2; ideal rock for disposal - one with extremely low permeability, p. 42; it is important to obtain data on the dilation and contraction of fractures in response to changes in fluid pressure and temperature, p. 43; NAS/NRC Implementation of Standards 1979, A3

c. porosity:

i. to be considered in making criteria - key factor, p. 12-13, AECL Canada 1976, E2

ii. to determine the suitability of a body of shale, need information on porosity, p. 7,12, USGS 4339-5, 1973, B3

iii. considered as it controls velocity, p. 152; affects sorption, p. 153-155; qualities looked at in rock types - porosity, p. 190 on, USGS 74-158, 1974, B8

iv. low porosity usually goes with low permeability
- p. C6-10, ERDA/BNWL Alternatives App C 1976, D18
- p. 36, IAEA SS Factors 1977, E11

v. affects velocity so must be determined; data representative in 3 dimensions should be sought but conventional methods may be ineffective, especially in rocks with low permeabilities, p. C10-12, ERDA/BNWL Alternatives App C 1976, D18

vi. must be considered in evaluation of fluid bearing rocks - total and effective porosity, p. 8, Brunton and McClain, OWI/ERDA 1977, D20

vii. parameters describing transport - effective porosity - affects pore velocity; extremely excellent formation defined as having 20% porosity, de Marsily et al, Guarantee Isolation? 1977, E5

viii. characteristics relevant to waste disposal - salt - low porosity, p. 3-4; factors tending to lengthen transport time: high effective porosity, p. 8, USGS ES Perspectives 1978, B10

ix. site characterization - detailed definition is needed of total and effective porosities, p. 14, ESTP, USGS and DOE 1979, D24

x. evaluation of adequacy of rep will require careful measurement of rock matrix porosity and fracture porosity, p. 17; few in situ measurements have been made of porosity at depth in low permeability rock types with realistic temperature and pressure conditions, p. 40-2; ideal rock for disposal - one with moderately high porosity, p. 42, NAS/NRC Implementation of Standards 1979, A3

d. sorption/ion-exchange capacity:

i. secondary factor for WIPP since isolation from water is basic confinement premise; ion sorption must be determined to allow quantification of safety analyses and indicate whether engineered barriers (i.e. clay) would be beneficial, p. 2:19-20, GCR 1978, D10

ii. the properties of the geochemical system should be such as to restrict or prevent the mobility of the radionuclides and to delay or prevent their migration to the biosphere; further control can be gained by addition of zeolites, clays and other ion exchange minerals or resins, p. 11-13, NAS/NRC 1978, A1

iii. to be considered in making criteria - key factor, p. 12-13, AECL Canada 1976, E2

iv. advantage of argillaceous rocks - high ion exchange capacity, p. 3, USGS 4339-5, 1973, B3

v. parameters controlling transport - sorption - net effect is reduction of the concentration of nuclides in solution, most is known about cation sorption, p. 152; degree of velocity reduction depends on: chemical nature of the species, concentrations of competing species in solution, and the extent and nature of host rock (bulk density, total surface area, effective porosity). Ideally when selecting a host rock, a match should be made between the waste and the host environment. Movement of cations should be significantly retarded in rocks containing clay and zeolites; anionic and non-ionic wastes should probably be disposed of in water-insoluble forms to minimize leaching since there is little sorption, p. 153-155; qualities looked at in host rock - ion exchange capacity, p. 190 on, USGS 74-158, 1974, B8

vi. dominating factor for deep geologic disposal, p. 23.15-17; sorption is dependent on: acidity, concentration of dissolved salts, temperature, concentration of dissolved nuclides, p. 23.17, 23.22, ERDA/BNWL Alternatives Vol 4, 1976, D17

vii. some water saturated rocks are acceptable if they have high sorption capacity. In case of rocks free of water, sorption capacity could provide secondary barrier should the primary barrier be breached by groundwater. Sorption capacity and the effect of heating on it must be carefully examined for each site.

- p. C6-10, ERDA/BNWL Alternatives App C 1976, D18
- p. 39, IAEA SS Factors 1977, E11

viii. chemical nature of host rock should be such that is is essentially non-reactive or only very slowly reactive with radionuclides. [Does this include sorption?] Kehnemuyi, Battelle M, 1979, D23

ix. for adequate containment - high sorption capacity (especially for long-lived alpha emitters) combined with slow water movement, p. 2; lack of sorption capacity in salt is not a significant disadvantage since such properties are only important if water reaches the waste, (supposedly will not), p. 22, IAEA SS Factors 1977, E11

x. lithological considerations - study looked at ion exchange capacity of the different rock types, Section 4.0.3, HLWM Alternatives BNWL-1900, 1974, D16

xi. one of major mechanisms governing tranport - sorption - it must be noted that sorption phenonena are not well understood; without sorption, (i.e. in case of I, an anion), even an excellent confining formation can only introduce a delay in the return to the waste to the biosphere; it cannot retain it - 100% of it will return and the delay is relatively small. But if the element is adsorbed with a high distribution coefficient, even the worst geological formation from the hydrogeologist's point of view provides enough confinement to retain the nuclide so no significant amount is released to the biosphere. Apparent paradox - the more confining the formation, generally the more concentrated will be the nuclides in the water coming to the biosphere - seems to be an opposition between confinement and dilution. Conclusions: the greater the ion-exchange capacity, the greater the confinement, which may even be total; if there is no sorption, the radioactivity will be released providing a flow of water reaches the waste; no geologic formation can be proved in the very long run to be entirely safe from this danger. Therefore a geologic formation should not be considered to be a confining barrier for radionuclides with very long ½-lives for which it has no sorption capacity, if groundwater can reach the waste or if a hydraulic gradient exists. Neither the thickness of the confining layer nor its low permeability are major factors in confining long lived radionuclides over time periods on geologic scale. Unless there is a total absence of hydraulic gradients during such long periods, the ion exchange capacity vs each toxic element will be the most important factor. de Marsily, et al, Guarantee Isolation? 1977, E5

xii. characteristics that are relevant: clay - sorptive, p. 3-4; serious drawback of salt - low ability to fix or adsorb nuclides in an insoluble form so mechanical integrity is of extreme importance, p. 5; factors to be taken into account in model-making - chemical interactions with rocks along flow path, p. 8; factors tending to lengthen transport time: high adsorption capacity, p. 8, USGS, ES Perspectives 1978, B10

xiii. most important technical aspects: retention; important to know the physicochemical nature of fracture surfaces and their coatings but data is scanty for rocks at depth, p. III-16; during elevated temperature period, the geochemical conditions may differ and cause alteration of mineral coatings on fracture surfaces and retention capabilities - lab data on retardation through sorption may not be applicable unless done at elevated temperature, p. III-16; there is little sorption data for actinides. If water is saline, retention may be inhibited - measuring and modeling the consequences of such a possibility should be carried out, p. III-18; predictions of sorption are also hampered by lack of data on fractured rock with saline water, p. III-19; geochemical properties of rep may be altered significantly by dissolution of canisters, i.e alteration of fracture coatings important in retention or the creation of new chemical gradients, p. III-19; the above limitations of our knowledge introduce uncertainties which could be an obstacle for making predictions with model, p. IV-59; it is necessary to study the field much more carefully and extensively than has been done in the past - measurements should be made specifically for site rock types and under appropriate groundwater and other conditions, p. III-41, KBS Rydberg and Winchester 1978, E9

xiv. delay in transport can be predicted from three key factors, one of which is sorption. Sorption capacity is critical to the operation of the rock as a barrier. There is an abundance of data on sorption but these are useful only in a general way and may be misleading. Experiments have to be done under the same conditions as are expected (high temperature and pressure, strong solutions). Current data - no quantitative basis for estimation of what will really occur in a specific formation at depth and elevated temperature. p. 25-26, EPA State of Knowledge 1978, C7

xv. factors making transport slow - sorption, p. 6-8; factor making bedded salt a leading candidate - presence of shale interbeds that have high sorption capacity, p. 63, AD Little Assessment 1978, C3

xvi. for long term risk analysis - need information on sorption capacity of system, p. 17; recommended sensitivity analysis - analysis varying K_d's should be performed for realistic conditions.Study will determine accuracy requirements and type of K_d measurements required for sorption coefficients, p. 48, ESTP, USGS and DOE, 1979, D24

xvii. geochemical redistribution within rep itself may be important for chemical stability of rep prior to large scale mobilization of waste; chemical interactions could affect ultimate rates of transport; so design should be optimized as a system with respect to important chemical processes occuring near field and at larger distance scales; sortion capacity may be inhibited by dissolving canister materials; conditions that inhibit large scale transport still may allow waste to be redistributed locally, i.e. by ion exchange chromatographic effects, creating zones of concentration within rep (see also Criticality), Winchester, Long term geochem in crystalline, 1978, E6

xviii. reconcentration phenomenon - maximum discharge rates into biosphere from geologic disposal greater than corresponding level for surface storage - function of adsorption properties of medium; phenomenon emphasized the need to perform thorough and comprehensive safey analyses of waste management systems, p. 1.8; phenomenon can only occur when the second member of a decay chain migrates faster than the first, p. 1.13,1.15; phenomenon emphasizes the need to measure sorption equilibrium constants and develop better understanding of actinide migration, p. 1.13,1.15, Burkholder, Reconcentration phenomenon, 1976, BNWL, D15

xix. concerns of reviewers of KBS plan - retention has only been measured in lab - uncertain how well they represent actual conditions, p. 12-15; functioning of rock barrier is dependent on sorption, p. 110; USGS - information is needed on sorptive characteristics along all flow paths, p. 114; retention is a complex phenomenon - current data are a good start but not adequate for conditions to be encountered in rep, i.e. high ionic strength of water. "Because values of K_a are not available for these conditions, inclusion of retardation terms in transport models for rock systems cannot be expected to lead to very useful results." No reliable basis for even making very general estimates of K_a values of fracture systems in granite. All analysis of migration will contain large uncertainties until there is better data. Need field experiments, p. 128-130; sorption depends on water composition, flow rate and other parameters whose interplay is not fully known - uncertainty about retention values is large. p. 132-3; KBS - factors that determine suitability of site - retention, Appendix p. 5; Johansson and Steen, Ringhals-3, 1978, E10

xx. Geochemical information needed: evaluation of processes is essential.

Need sufficient information to predict transport within rep (danger of criticality) and beyond site to biosphere, p. 21. The relevant properties and substances present that should be investigated will differ among different media and in fact are not well understood at present. Once the canister dissolves, the chemical characteristics of the chemical environment depend on both the original composition and added material from canister and overpack, p. 23; information needed on chemical characteristics of solid surfaces near waste and their susceptibility to alteration from thermal and radiation effects of wastes, p. 23; information is needed on chemical characteristics on large scale around rep - retention, potential for large scale change under imposed thermal stress and from dissolved canisters, p. 24; information is also needed on influence of biogenic interactions that may affect nuclide mobilization and transport, p. 24; large scale testing of chemical transport model (based on lab data) is essential - there may be practical difficulty in designing appropriate experiments for these slow processes, p. 32; To date most work has been done on retention - need work on interaction with organic material and micro-organisms, precipitation of new solid phases; there is an urgent need for better geochemical knowledge concerning transport, p. 46-7, NAS/NRC Implementation of Standards, 1977, A3

e. dispersion and diffusion:

i. greater along torturous route; phenomenon may retard or accelerate first arrival of nuclides as compared to groundwater velocity; unpredictable as to generic rock type, p. 151, USGS 74-158, 1974, B8

ii. is important; linked to velocity and is measured by means of tracers, p. 36, IAEA SS Factors 1977, E11

iii. must be considered in evaluation of fluid bearing rocks, p. 8, Brunton and McClain, OWI/ERDA 1977, D20

iv. one of major mechanisms that govern transport; parameters describing transport - dispersion coefficient, which is proportional to pore velocity, de Marsily et al, Guarantee Isolation? 1977, E5

v. factors to be taken into account when constructing transport models, p. 7, USGS, ES Perspectives 1978, B10

vi. diffusion may become the dominant transport process within the dimensions of the rep in the first few hundred years. The process warrants careful consideration in rep design evaluation, (i.e. in models) p. III-17; data base must be sufficiently detailed to determine transport by diffusion, p. III-18, KBS Rydberg and Winchester 1978, E9

vii. site characterization - need detailed definition of hydraulic dispersivity, p. 14, ESTP, USGS and DOE, 1979, D24

viii. during sensitivity analysis it was found that dispersion is an important parameter, especially with short leach times. With dispersion, a short release from rep shows up in recipient during a longer time, having peak activity lower than that of the original release, p. 161, Johansson and Steen, Ringhals-3, 1978, E10

f. velocity and volume of flow:

i. one of the principal factors in the extent of migration; controlled by effective porosity and permeability and hydraulic gradient, p. 152, USGS 74-158, 1974, B8

ii. needs to be determined for water bearing strata near disposal zone in salt, p. 5-6, OWI/DOE Salt Dep of US 1978, D21

iii. one must determine linear velocities and volume rates in host and intervening rocks; data representative in 3 dimensions should be sought in and beyond any zone that could conceivably be invaded by nuclides; velocities cannot be measured directly but can be estimated since they are proportional to porosity, permeability and to gradient; conventional methods to determine hydraulic gradients may be ineffective, especially in rocks with low conductivities, p. C10-12, ERDA/BNWL Alternatives App C, 1976, D18

iv. adequate containment can be provided through extremely slow movement of groundwater and high ion exchange capacity, p. 2; "However low the real values for permeability and for the velocity of displacement of fluids in rocks which may be regarded in practice as 'impermeable', the quantities of fluids able to traverse layers of this rock are almost always significant in the very long term and cannot be considered negligible", p. 43, IAEA SS Factors 1977, E11

v. essential parameter for rep; affected by permeability and gradient, p. III 11-13, KBS Rydberg and Winchester 1978, E9

vi. delay in transport can be predicted from three key factors, one of which is flow rate, p. 25-26, EPA State of Knowledge 1978, C7

vii. site characterization - need detailed definition of groundwater flow and velocities, p. 14, ESTP, USGS and DOE, 1979, D24

viii. functioning of rock barrier depends on slow speed of groundwater, p. 110; sorption depends on flow rate, p. 132-133; KBS - factors that determine suitability of a site - groundwater velocity, Appendix p. 5, Johansson and Steen, Ringhals-3 1978, E10

ix. evaluation of adequacy of rep will require careful measurement of quantities and velocities of regional flow, velocity in rock joints, shears and faults, p. 17; determinations of velocities and quantities of flow become progressively more difficult with decreasing permeability. Adequate models exist for predicting regional but not local flow (especially where fractures or temperature or salinity changes are important), p. 18, NAS/NRC Implementation of Standards 1979, A3

g. direction of flow:

i. must be determined in host and intervening rocks, p. C10-12, ERDA/BNWL Alternatives App C 1976, D18

ii. must be determined for water-bearing rocks near the disposal zone in salt, p. 5-6, OWI/DOE Salt Dep of US, 1978, D21

iii. in deep underground formations with low permeability, movement is essentially vertical - downward in mountains and recharge areas, and upwards in plains and basins. As reps will probably be located in dry plains, transport of nuclides will probably occur vertically upward, de Marsily et al, Guarantee Isolation? 1977, E5

iv. site characterization - need detailed definition of directions of flow and the relationship between surface and groundwaters, p. 14, ESTP, USGS and DOE, 1979, D24

v. need 3 dimensional data on flow pattern - site specific, p. 113; KBS - factors that determine site suitability: flow pattern, Appendix p. 5, Johansson and Steen, Ringhals-3, 1978, E10

vi. for evaluation of adequacy of rep, need careful measurement of directions of flow, p. 17, NAS/NRC Implementation of Standards 1979, A3

h. hydraulic gradient:

i. affects velocity and volume of flow so must be determined for host and intervening rocks, but conventional methods may be ineffective, especially in rocks with low permeabilities, p. C10-12, ERDA/BNWL Alternatives App C 1976, D18

ii. one of parameters describing transport, affects pore velocity of groundwater; extremely excellent formation is defined as having a gradient of 1/50; a formation with no ion-exchange capacity should not be considered a barrier for nuclides with very long ½-lives if a hydraulic gradient exists; unless there is a total absence of gradient for the entire required lifetime of rep, ion exchange capacity will be most important barrier, de Marsily et al, Guarantee Isolation? 1977, E5

iii. factors tending to lengthen transport time: low hydraulic gradient, p. 8; uncertainties introduced into model-making: difficulty in measuring hydraulic head in low-permeability strata, p. 8, USGS, ES Perspectives 1978, B10

iv. essential parameter for rep as it affects velocity and volume of flow - formations with higher gradients should not be chosen, p. III 11-13, KBS Rydberg and Winchester 1978, E9

v. site characterization - need detailed definition of 3 dimensional distribution of hydraulic head, p. 14, ESTP, USGS and DOE, 1979, D24

vi. information needed on hydraulic head gradients in all three dimensions, p. 114, Johansson and Steen, Ringhals-3, 1978, E10

vii. for evaluation of adequacy of rep, need careful measurement of hydraulic gradients, p. 17; measuring hydraulic head must be done over a very long time since test borehole can drastically distort the head and accurate measurement is needed, p. 43, NAS/NRC Implementation of Standards, 1979, A3

i. recharge and discharge points:

i. must be considered in evaluation of fluid-bearing rocks, p. 8, Brunton and McClain, OWI/ERDA 1977, D20

ii. site characterization - need detailed definition of flux across land surface, relationship between surface and groundwaters, p. 14, ESTP, USGS and DOE, 1979, D24

iii. retention time and dilution will generally be greatest if rep is sited in a recharge zone, p. 18, NAS/NRC Implementation of Standards, 1979, A3

j. groundwater composition and temperature:

i. density and temperature of groundwater must be considered in the evaluation of fluid-bearing rocks, p. 8, Brunton and McClain, OWI/ERDA 1977, D20

ii. important to have data on groundwater chemistry but data is scanty for groundwater at depth; also organic constituents may affect transport but not much is known on this, p. III-16; if pore water is saline, retardation may be inhibited due to chemical complexation by anions - modeling on this should be carried out, p. III-18; composition may change with time - dissolution of canister and glass, intrusion of sea water, p. III 30-32; one of the requirements of suitability: groundwater composition, p. IV 27-28, KBS Rydberg and Winchester 1978, E9

iii. site characterization - need detailed definition of chemical characteristics of water, including changes as it moves through various media, and isotopic content, p. 14; need information on changes in water chemistry and mineral solution caused by radiation and thermal effects, p. 15; also taken into account in long term risk analysis, especially as it relates to sorption, p. 17, ESTP, USGS and DOE, 1979, D24

iv. sorption is dependent on acidity, concentration of dissolved salts, sometimes concentration of dissolved nuclides and the temperature of groundwater, p. 23.17-23.22, ERDA/BNWL Alternatives Vol 4, 1976, D17

v. consider the effect of dissolved canister material - may inhibit sorption; loading of other ions (i.e. sodium and calcium cations) also affects sorption - lowers it; dispersion may be enhanced by high ion concentrations, especially of divalent ions from dissolving canisters, Winchester, Long term geochem in Crystalline, 1978, E6

vi. retention depends on water composition, p. 132-133; factors that determine suitability of site - groundwater composition, Winchester p. 170 and KBS Appendix p. 5, Johansson and Steen, Ringhals-3, 1978, E10

vii. chemical properties of water will be important for calculating the potential for leaching canister and waste and the degree to which subsequent chemical reactions may occur, p. 19; changes induced by rep to be considered: thermal effects creating a convective cell, p. 19-20; evaluation of geochemical processes is essential to predict transport - need to carefully evaluate the chemical characteristics of fluid medium in immediate vicinity of waste: concentrations of dissolved organic and inorganic substances, oxidation/reduction and acidity properties, potential for forming chemical complexes, p. 22; consider the effect of dissolving canisters, p. 23, NAS/NRC Implementation of Standards 1979, A3

k. dilution:

i. apparent paradox - the more confining the formation, generally the more concentrated will be the radionuclides in water coming to the biosphere - so use a confining system to delay return and dilution can then be achieved by a favorable setting at the outlet of the confining system, i.e. the seabed, de Marsily et al, Guarantee Isolation? 1977, E5

ii. dilution in groundwater brings the concentration of escaped nuclides to very low levels, p. 6-8, AD Little Assessment 1978, C3

iii. KBS assumed dilution but this may not be justified; in any case it is hard to predict, p. 125-125; KBS - "Dilution in huge volumes of groundwater will take place before entry into the biosphere", p. 6 Appendix, Johansson and Steen, Ringhals-3, 1978, E10

iv. will be greatest for rep located in a recharge zone, p. 18, NAS/NRC Implementation of Standards, 1979, A3

l. flow path: (see also Depth)

i. barrier that people can select or control - path length, a measure of geosphere isolation, p. 23.17-23.22, ERDA/BNWL Alternatives Vol 4 1976, D17

ii. most relevant - on the order of hundreds of meters for nuclide migration from rep to humans, Winchester, Long term geochem in crystalline 1978, E6

m. osmosis: the possible flow of water by osmosis could be a very important consideration if the rep site is in bedded salt because osmotic potentials depend on a salinity contrast on either side to the semipermeable membrane (shale can act as one). To date osmotic potentials have not been measured in the field. p. 43-44, NAS/NRC Implementation of Standards 1979, A3

n. off shore islands, if in hydraulic isolation from mainland, may be an advantageous site, p. 41, IAEA SS Factors 1977, E11

5. Stability of Groundwater System/Changes:

i. it is believed that much greater reliability of containment would exist using host rocks that are virtually impermeable, than exists for water-bearing rock systems which depend predominantly on low velocities (from conductivity and gradient) for limiting the dispersion of nuclides - low velocity can change since geologic processes, climatic change and human activities can drastically alter hydrologic regimes

- p. C10-12, ERDA/BNWL Alternatives App C 1976, D18
- p. 43, IAEA SS Factors 1977, E11

ii. principal criterion - use dry formation or where there is little or no movement of groundwater, with geological indications that this condition will remain relatively stable for not less than an order of 100,000 years, p. 20, IAEA SS Factors 1977, E11

iii. factor to be considered - hydrological history, p. 3, Brunton and McClain, OWI/ERDA 1977, D20

iv. consideration: at time of disposal choose a formation with no circulating groundwater but rapid and slow geologic processes might produce undesirable changes in groundwater regimes, p. 80-81, Considerations for HLWM, Gera and Jacobs, ORNL 1972, D5

v. all natural mechanisms that could generate a release of radioactivity (direct) will probably create a path for water to reach the waste; no geologic formation can be proved, in the very long run, to be entirely safe from the danger of intrusion of groundwater into rep, de Marsily et al, Guarantee Isolation? 1977, E5

vi. process capable of transporting wastes to biosphere - groundwater; tectonism, erosion, seismicity, glaciation and climatic change may alter the initial conditions of groundwater flow, p. 9-12, USGS ES Perspectives, 1978, B10

vii. long term stability and predictability of groundwater flow <u>must</u> be demonstrated over longer period than is customary for conventional mining, p. IV 8-9, KBS Rydberg and Winchester 1978, E9

viii. site should have been in past hydrologically stable, p. 2-9, ES of WM of LWR Cycle, NRC 1976, C8

ix. assumptions for safe rep: variations in hydrological regime must not jeopardize safety, p.1, EPA State of Knowledge, 1978, C7

x. events taken into account in risk assessment - change in hydrology (i.e. influx of groundwater into rep) due to climatic change, p. 95-103, AD Little Assessment 1978, C3

xi. long term risk analysis - includes knowledge of natural features and processes of region that influence radionuclide migration, p. 16, ESTP, USGS and DOE, 1979, D24

xii. evaluation of adequacy of rep will require careful measurement/ evaluation of effects of transient conditions on hydrology, changes in hydrologic pathways, p. 17; transient geologic conditions to be evaluated for changes in hydrologic regime: climatic change, tectonism - tilting of ground surface, erosion - lower level of streams, stream capture, glaciation, osmotic potential developed by changes in water chemistry, p. 20, NAS/NRC Implementation of Standards 1979, A3

6. State of Knowledge:

- Can we adequately evaluate the hydrologic system? (1) do we adequately understand it? models developed, assessing applicability; (2) can we adequately measure/evaluate it? techniques known, developing equipment or verifying techniques, equipment available or techniques verified, improving sensitivity, range and/or reliability or applying techniques. p. 38

- Do we adequately understand waste/water/backfill interactions? limited data, currently expanding data base, p. 40

- Do we adequately understand the effects of coupling thermalhydraulic and thermomechanical phenomena? moderate amount of data, developing models, p. 42.

- Do we adequately understand transport processes? moderate amount of data, developing models, p. 44

- Can we adequately predict and evaluate the effects of changes in the hydrologic system? equipment available or techniques verified, improving sensitivity, range and/or reliability or applying techniques, p. 44.

- Do we adequately understand how to determine the value of data from natural reactors for verifying models of nuclide transport? limited data, currently expanding data base, p. 45

ESTP, USGS and DOE, 1979, D24

8. Chemical Properties of Host Rock/Waste-Rock Interactions other than Sortpion: (see also Radiation/Thermal Effects)

1. Should be taken into account/information useful in site selection/evaluation:
   i. lithological considerations - study looked at chemical stability of rock type, Section 4.0.3, HLWM Alternatives, BNWL-1900, 1974, D16
   ii. generic technical studies to be done: on waste-rock interactions, p. 10, OWI/ERDA Program Plan for NWTSP, 1976, D19
   iii. to prepare PSAR and ER, need improved understanding of waste-rock interactions, p. 9; in evaluation of site, need detailed definition of geochemical properties of host rock and confining media, p. 15; waste-rock interactions to be considered: changes in state and form of media and introduced materials caused by chemical effects, p. 15; ES aspects of long term risk analysis - need knowledge of processes that affect containment capability including waste-rock chemical reactions, p. 17, ESTP USGS and DOE 1979, D24
   iv. chemical interactions between waste and immediately surrounding geologic environment could affect the chemical stability of the rep and the ultimate rates of transport. So design should be optimized as a system with respect to important chemical processes occuring near field and at larger distance scales. Otherwise potentially incompatible behavior of the separate rep components, processes at different times and the many trade offs which must be made in design may not be recognized. Winchester, Long term geochem in Crystalline, 1978, E6
   v. actual substance whose long term stability and non-leachability should be evaluated is the reaction product between the waste form, its containment and the wall rock of the rep, since it is confirmed that these interactions do occur. With hydrothermal solutions a process similar to contact metamorphism would occur to produce a zone around waste, a contact aureole, in which new minerals could be formed. It is this new waste form that should be studied with respect to leaching and transport. McCarthy et al, Rock-Waste Interactions, Nature, 1978, E3
   vi. considerations in site and waste form selection: must take into account the uncertainties and additional variables introduced into predictions by waste-media interactions, p. 9; important geochemical information to be obtained: on waste-media interactions, on chemical characteristics of the solid surfaces in vicinity of waste and their susceptibility to chemical and physical change caused by the wastes, p. 23, NAS/NRC Implementation of Standards, 1979, A3

2. Rep rock shall not react chemically with wastes/canister in such a way as to compromise containment or operational safety (criteria must be met), p. 4, Brunton and McClain, OWI/ERDA 1977, D20

3. Chemical nature of host rock should be such that it is essentially non-reactive or only very slowly reactive with contained radionuclides. Kehnemuyi, Battelle M, 1979, D23

4. State of Knowledge: Do we adequately understand waste-rock interactions over the long term? Moderate amount of data, developing models, p. 44, ESTP USGS and DOE, 1979, D24

9. Criticality

1. There are reconcentration phenomena. One needs sufficient information to predict transport within rep (to know if criticality can occur) and one needs to consider what the consequences would be:

   i. decay chain Am 243 to Pu 239 to U 235: fission conditions shift with time due to decay. The subject is worth careful quantitative analysis. p. III-43, KBS - Rydberg & Winchester, 1978, E9

   ii. p. 21; must consider effects of resulting thermal and pressure pulses on rep rock as well as the transmutation of fissioning actinides to fission products. p. 47-8, NAS/NRC Implementation of Standards, 1979, A3

2. Conditions which inhibit large scale transport of nuclides in groundwater may actually tend to increase the risk of accumulating fissionable isotopes into localized regions, i.e. by ion exchange chromatographic effects. Therefore the rep. design must incorporate barriers to critical mass formation:

   i. i.e. geochemical barriers, to counteract reconcentration tendency, p. IV-37; Westermark suggests adding isotopic U238 to glass mass-- as little as 10-15 Kg per container will isotopically dilute the U235 and U233 so critical mass cannot be formed, App. p. 14; KBS Rydberg & Winchester 1978, E9

   ii. potential for criticality of actinides does not generally decrease in a simple way over geologic time -- decay alone does not render danger negligible, , Winchester, Long term geochem. in Crystalline, 1978, E6

3. Do we adequately understand the potential for reaching criticality as a result of earth science processes? Models tested, applying to specific site (including WIPP) p. 40, ESTP - USGS & DOE 1979, D24

10. Salt - Dissolutioning/Subsidence due to it

1. Should be considered/ information useful in SS/evaluation:
   i) study Carlsbad area looked at - collapse features, p 10. distance from dissolutioning front p 78, USGS-4339-1, 1972, B2

   ii) potential hazard to a rep in salt - subsurface solution of salt, p 6 USGS 74-194, 1974, B7

   iii) features of interest of Mescalero Plains - history of dissolutioning, probably still active, USGS-74-190, 1974, B9

   iv) long term consideration - boundary solutioning, p 25-45, AEC Lyons ES 1971, D6

   v) potential geologic hazard to be investigated - subrosion of salt, p 39-41, SSWIPP, Sandia 1977, D9

   vi) area of low seismicity desired since fault could concentrate dissolutioning at that point, p 5; study of regions - to determine if salt has been or is being dissolved and potential for future dissolution, p 5-6, OWI/DOE, Salt Dep of U S 1978, D21

   vii) evaluation of suitability of site includes evaluation of subsurface dissolutioning, found not to be a problem in SENM. ORNL McClain and Boch, 1974, D3

   viii) careful studies must be made on it - p 26-27, USGS 74-158, 1974, B8

2. Rep should be located where dissolutioning is relatively limited:
   i) Preliminary SS Criteria, p 1:3, GCR 1978, D10

   ii) in area of limited groundwater to limit rate of dissolutioning, if wastes do escape salt, to limit widespread dispersal in groundwater, p 9, BSPPSS Factors ORNL 1973, D2

3. Distance to dissolutional boundaries should be adequate to provide future integrity:
   i) at least 1 mile to dissolution front, p 2:16,-17, GCR 1978, D10

   ii) dissolutioning not considered a problem if sites are located well within the basin margins and at sufficient depths p 38, 42; it is relatively slow process even though presence of thick caprock is evidence of removal of large volumes of halite - site should remain dry for hundreds of 1,000's of years, p 2 - USGS 4339-6 1973, B4

   iii) distant enough to guarantee integrity while wastes still hazardous, p 6 NAS/NRC Bedded Salt 1970, A2

   iv) expanded criteria - 1 mile or more from subsrosion of top of Salado formation, p 12-13, SSWIPP Sandia 1977, D9

   v) disposal level at more than about 100 m depth and/or at such distances from front that dissolution will not uncover wastes during hazardous period-pC10-12, ERDA/BNWL Alternatives App C 1976, D18; p 4-5, OWI/DOE Salt Dep of US 1978, D21; p 22, p 42, IAEA SS Factors 1977, E11

   vi) Vertical, p 6-7, Lateral p 10, BSPP SS Factors ORNL 1973, D2

   vii) p 98, considerations for HLWM, Gera & Jacobs ORNL 1972, D5

4. For rep in salt, the probability must be negligible. This can be assured if the site meets the following conditions: the shale beds above and below salt are continuous over a large area; salt formation is thick and rep is located far from salt boundary; shale bed above salt is so deep that no erosion process can reasonably affect its integrity in a time span of several 100,000 yrs; and region is tectonically stable. p 98, considerations for HLWM, Gera & Jacobs, ORNL 1972, D5

5. Avoid subsidence due to dissolutioning:

   i) will be avoided when it adversely affects rep beds or unduly accelerates rate of dissolutioning, p 2:17-18 GCR 1978, D10

   ii) tract promising - largely free of subrosional debris, deformation due to dissolutioning confined to higher formations, p 34-35, USGS 4339-7 1973, B5

6. Info needed:

   i) that regional and/or local dissolution will not breach rep while waste still hazardous, on the order of 250,000 years should be sufficient, p 2:17-18, GCR 1978, D10

   ii) careful studies must be made on how rates would be affected by changes in climate and in regimes of nearby streams, p 26-27 USGS 74-158, 1974, B8

   iii) recommendations for Lyons: long term research is needed to estimate subsurface leaching, p 14-15, NAS/NRC Bedded Salt 1970, A2

   iv) to determine that at projected rates of dissolution (considering hydrological and climatic changes), wastes will not be uncovered during hazardous lifetime, -C10-12, ERDA/BNWL, Alternatives App C 1976, D18

      - p 4, - OWI/DOE Salt Dep of US 1978, D21
      - p 42 IAEA SS Factors 1977, E11

   v) In investigation to determine site suitability, need to establish nature and rates of salt removal within study area, rate of retreat of salt at dissolution boundaries, p 6,7, ORNL, Program Plan for BSPP 1973, D1.

   vi) total thickness and shape of formation, thickness of salt over wastes; structure of salt between rep and boundary, current rate of dissolutioning and potential rates in future, nature and character of dissolutioning process and the regional hydrologic regime that controls it. p 10 BSPP SS Factors ORNL 1973, D2

   vii) necessary to establish the nature and rates of dissolutioning and how they would be affected by change in climate or in regions of nearby streams-p 4-64, HLWM Alternatives, BNWL 1900, 1974, D16

   viii) for rep in salt, special care is needed - possible dissolution rates should be evaluated, p 80-8, Considerations for HLWM, Gera & Jacob, ORNL 1972, D5

   ix) substantial amounts of additional research on in site salt dissolution must precede waste emplacement in salt rep. Rates must be calculated using scenario that envisions climatic change like more rain. p 44 NAS/NRC Implementation of Standards 1979, A3

11. Salt - Diapirism:

1. Should be considered/information useful for site selection/evaluation:
   i. study of Paradox Basin: one of features looked at is diapirism (one of the most promising areas for rep according to the authors is a diapiritic structure), p. 58-62, USGS 4339-6, 1973, B4
   ii. potential hazard to be investigated - salt flowage, p. 39-41, SS WIPP Sandia 1977, D9
   iii. evaluation of site suitability includes evaluation of possibility of mass flowage, ORNL McClain and Boch, 1974, D3
   iv. process capable of transporting waste to surface - diapirism, p. 9-12, USGS, ES Perspectives 1978, B10
   v. factors that make bedded salt a leading candidate - believed to be less prone to diapiritic movement than salt domes, p. 63, AD Little, Assessment 1978, C3
   vi. rate is critical in realtion to required containment times. To evaluate the possibility of diapiritic processes affecting the long term stability of the waste rep, a thorough understanding of all aspects of diapirism is necessary. Gera, Salt Tectonics, ORNL, GSA 1972, D4

2. Diapiritic Structures are OK for rep if:
   i. rate of diapirism, which may be influenced by the presence of the rep, must be low enough that rep will not reach the edge of the block, where it could be breached by fractures or solution, within the time that waste presents a hazard to people, p. 6-9, NAS/NRC 1978, A1
   ii. integrity of salt body should not be impaired by mass movements of salt during effective lifetime of the waste, p. 11, ORNL Program Plan for BSPP, 1973, D1
   iii. special problems of salt - the possibility of still active diapirism of salt dome can be determined through an investigation and circumvented by choosing and inactive or extremely slow moving structure, p. 22, IAEA SS Factors 1977, E11
   iv. negative consequences of plasticity if too much deformation - so the possibility of deformation must be investigated and possible extent of deformation throughout time period of several hundred thousand years must be evaluated, p. 101, Considerations for HLWM, Gera and Jacobs, ORNL 1972, D5

3. Inactive diapiritic structures only are OK:
   i. such structures (domes, anticlines) may be especially suitable if it can be demonstrated that they are stable and will not begin to flow again during the hazardous lifetime of the wastes.
      - p. C4-5, ERDA/BNWL Alternatives App C 1976, D18
      - p. 35-36, IAEA SS Factors 1977, E11
      - p. 4-5, OWI/DOE Salt Dep of the US, 1978, D21
   ii. although salt diapirs certainly exist for which no future salt uplift is possible because of depletion of salt in source area, nevertheless, the demonstration of safety would require very extensive geologic investigations. Also diapirs present much more serious hydrological problems, due to complexity of circulation and the possibility of temporary permeability of salt in correspondence with shear zones.
      - ORNL, Gera, Salt Tectonics, GSA 1972, D4
      - p. 115-116, Considerations for HLWM, Gera and Jacobs, ORNL, 1972, D5
   iii. problem of possibility of still active diapirism of salt dome can be determined by thorough investigation and circumvented by choosing an inactive structure, p. 22, IAEA SS Factors 1977, E11

4. Diapiritic Structures , active or inactive, should be avoided:
   i. for WIPP siting, p. 2:18-19, GCR 1978 , D10
   ii. should not be a reasonable possibility; factors that militate against salt flow: minimal differential loading, simple structure, low relief, tectonic stability, p. 4-5, NAS/NRC Bedded Salt 1970 , A2
   iii. for sites in thick salt beds, prefer areas with gentle relief since differential loading can trigger diapirism.
      - p. C-1, ERDA/BNWL Alternatives App C 1976 , D18
      - p. 31, IAEA SS Factors 1977 , E11
   iv. for areas with extreme surface relief, examinations must ascertain that diapirism is not incipient and geologic processes during the next few hundred thousand years will not create conditions conducive to such movements.
      - p. C4-5, ERDA/BNWL Alternatives App C 1976 , D18
      - p. 35-36, IAEA SS Factors 1977 , E11
   v. since it is not possible to precisely specify the necessary and sufficient conditions for the initiation of mass salt flow, the problem becomes one of demonstrating that the formation has never experienced even the first stages of diapirism, by the absence of diapiritic structures throughout the region.
      - ORNL McClain and Boch 1974 , D3
      - (there is general agreement that for diapirism to take place you need thick formations at depth with differential loading, as a minimum), p. 8, BSPP SS Factors, ORNL 1973 , D2
   vi. summary of site selection factors - no diapiritic structures in the region, BSPP SS Factors ORNL 1973, D2
   vii. fairly proven that the risk of containment failure due to diapirism is negligible if waste rep is located in salt formation that meets the following conditions: bedded salt showing no evidence of plastic deformation in recent past, located in a tectonically stable area; beds close to horizontal; surface relief/differential loading minimal; thickness of beds adequate for containment but less than the 300 to 400 m necessary to produce sizeable salt structures; not located at great depth where plasticity increased, probably not more than 700 m desirable.
      - ORNL Salt Tectonics Gera, GSA 1972 , D4
      - p. 115-116, Considerations for HLWM, Gera and Jacobs, ORNL 1972, D5

5. Does presence of rep have effect?
   i. may influence the rate of diapirism, p. 6-9, NAS/NRC 1978 , A1
   ii. heat of wastes - affects too small a volume for too short a time to initiate or reactivate diapirism.
      - p. C4-5, ERDA/BNWL Alternatives App C 1976, D18
      - p. 4-5, OWI/DOE, Salt Dep of US, 1978, D21
      - p. 35-36, IAEA SS Factors, 1977, E11

PART III: WASTE AND CONTAINER CRITERIA

1. Waste Form - (see also leaching of waste)

1. Definitions of radioactive wastes:
   a. In general:
      i) have no product or resource value; and require government control if they are human produced by fission or activation, as result of regulations are prohibited from uncontrolled discharge into the environment and/or contain diffuse-naturally occuring radioactive materials that, if discharged into the environment, would increase exposure to humans above background. EPA, Criteria for Radwaste /Rec for Fed Guidance, Fed Reg 1978, C2

   b. specifically:

      i) HLW: legal, normally as the product of reprocessing; one used by workers in trade; quantitative - authors suggest an arbitrary definition: HLW would be that containing total radioactivity exceeding 100 Ci and specific radioactivity exceeding 10^4 Ci / m^3 p II-17, KBS-Rydberg & Winchester, 1978, E9

      ii) CH TRU: more than 10 n Ci long-lived α-emitting radionuclides/gram of waste and less than 200 m rem/hr dose rate at canister surface p 4-9; RH TRU: more than 10 n Ci of TRU elements/gram of waste and between 200 m rem/hr and 100 rem/hr dose rate at canister surface p 9-10; HLW - more than 100 rem/hr dose rate at canister surface, reference form - 1.9 x 10^5 rem/hr for gamma and 45 rem/hr for neutrons; p 13-15; spent fuel - PWR assemblies out of reactor 10 yrs. p 11-12, WIPP - Design Criteria 1978, D11

2. There should be acceptance criteria for wastes:
      i) to be done, p 15 ORNL, Program Plan for BSPP 1973, D1

      ii) remain to be developed for CHTRU, p 4-9, WIPP design Criteria 1978, D11

      iii) exact criteria will differ for different host rock formations, p 11, IAEA SS Factors 1977, E11

3.
   a. Wastes should be in a solid form
      i) p 1-3, NAS/NRC Aug 1978, A1
      ii) p 5, Canada AECL 1975, E1
      iii) assumption - waste form is solid, p 7; there are problems with liquid wastes in permeable strata but even with impermeable host rock it is still tricky, so disposal as a solid is much more appealing. p 147-9, USGS 74-158, 1974, B8
      iv) HLW, TRU - should not be or contain liquid, p 15, 16, AEC Lyons ES 1971, D6
      v) HLW p 18-22, NAS/NRC - Bedded Salt 1970, A2
      vi) in monolithic solid form, p 11, IAEA SS Factors 1977, E11
      vii) study considered both solid and liquid waste forms, HLWM Alternatives BNWL-1900, 1974, D16

   b. Wastes assumed to be in solid form:
      i) de Marsily et al, Guarantee Isolation? 1977, E5
      ii) KBS Rydberg & Winchester 1978, E9
      iii) ES of WM of LWR Cycle, NRC 1976, C8
      iv) EPA State of Knowledge 1978, C7
      v) ESTP, USGS & DOE 1979, D24
      vi) McCarthy etal, Interactions waste-rock, Nature 1978, E3
      vii) Johansson & Steen, Ringhals-3 1978, E10

4. Wastes should be stable:
   i) chemically, p 1-3; wastes should be processed for optimum stability, p 6-9, NAS/NRC Aug 1978, A1
   ii) waste should be incorporated into an inert matrix, p 5 Canada AECL 1975, E1
   iii) chemically, thermally and radiologically - HL waste acceptance criteria. p 15 ;TRU - should not contain potentially explosive chemicals, pyrophoric materials, oxidants other than air, or gas under pressure. p 16; AEC Lyons ES 1971, D6
   iv) radiolyticallyand thermally - criteria must be met ; p 13-14, Deep Rock, Klett Sandia 1974, D8
   v) recommendations for Lyons - TRU - limits be set on integrity and combustibility of waste, p 7-8; HLW must be thermally and radiolytically stable p 18-22 NAS/NRC Bedded Salt 1970, A2
   vi) waste form should be inert with high thermal and radiation stability, p 11; for TRU - combustible and pyrophonic materials should be converted to inert form p 14, IAEA SS Factors 1977, E11
   vii) chemical and radiation stability - important for safety so no gas is generated and the characteristics of solids remain fairly constant. p 20, considerations for HLWM, Gera & Jacobs ORNL 1972, D5
   viii) physically - 1st deterrent against release of HLW, Vol. III, appendix DIV, A D Little Assessment 1978, C3

5. Leach resistance:
   i) wastes should be in a leach resistant form, p. 1-3, NAS/NRC 1978, A1
   ii) should be in insoluble form incorporated into an insoluble matrix, p 5, Canada AECL 1975, E1
   iii) one of barriers that people can choose/control: leach time, a measure of the resistance of the waste form to leaching p 23: 15-17, p 23: 17-22, ERDA/BNWL Alternatives Vol. 4, 1976, D17
   iv) should be highly leach resistant p 11, IAEA SS Factors 1977, E11
   v) characteristics of waste form important for safety - leachability, p 20, considerations for HLWM, Gera & Jacobs, ORNL 1972, D5
   vi) one of stages of containment - resistance to leaching, p 5 EPA State of Knowledge 1978, C7
   vii) factors in slow transport of HLW - low leaching rate of waste form, p 6-8, A D Little Assessment 1978, C3
   viii) 1st deterrent against release of HLW - incorporation into highly insoluble matrix, Vol III, Appendix DIV, A D Little Assessment 1978, C3

6. Waste form should have properties selected to restrict the mobility of the nuclides:
   i) p 1-3 NAS/NRC Aug 1978, A1
   ii) if ionic form of nuclides is favorable, mobility can be restricted, de Marsily, et al Guarantee Isolation? 1977, E5

7. Thermal properties of waste form:
   i) limit thermal power in any single container to 7,500 W, p 18-22, NAS/NRC, Bedded Salt 1970, A2
   ii) should have high thermal conductivity and a high melting point. p 11, IAEA SS Factors 1977, E11
   iii) thermal conductivity is a characteristic that can be of importance for safety, p 20, considerations for HLWM, Gera & Jacobs, ORNL 1972, D5
   iv) thermal generation: CHTRU - about 10 milliwatts/canister, p 4-9; RHTRU - less than 50 watts/canister p 9-10; spent fuel - 600 watts/assembly p 11-12; HLW - reference for 4.3 killowatts/canister, p 13-15, WIPP Design Criteria 1978, D11

8. Waste form should be compatible with host rock:

i) assume wastes can be made chemically compatible with host rock, p 7, USGS 74-158, 1974, B8

ii) should be demonstrated, p 4-5, NRC State Reviews, Nureg 0353 1977, C4

iii) TRU, p 4-30, ES of WM of LWR Cycle, NRC, 1976, C8

iv) p 10, NAS/NRC Implementation of Standards, 1979, A3

9. limit should be placed on amount of fissile material - danger of criticality:

i) criticality safety will be ensured by limiting average fissile concentration to 5 g/ft^3, NAS/NRC Bedded Salt, 1970, A2

ii) CHTRU - max amount of weapon plutonium allowed-200 gm/drum and 350 gm/box. p 4-9, WIPP Design Criteria 1978, D11

10. Forms considered:

i) glasses, rock-like matrices, metallic matrices - more closely meet the desired properties than do calcines. p 14, IAEA SS Factors 1977, E11

ii) assume waste form is glass (in France considered the safest form), de Marsily et al, Guarantee Isolation? 1977, E5

iii) glass presently prefered in which oxides of HLW can be fixed; ceramics or glass ceramics may be found to be better in future. Final glass composition has not been chosen; french process Na/Li borosilicate glass. p III-28, KBS Rydberg & Winchester, 1978, E9

iv) reference system - borosilicate glass, p 4-2, ES of WM of LWR Cycle, NRC 1976, C8

v) no firm decisions have been made yet on this p 5-6; suggestions - calcines, ceramics, glass, p 6-7 EPA State of Knowledge 1978, C7

vi) calcine and glass are 2 forms studied to date. McCarthy et al, Interactions rock-waste, Nature 1978, E3

vii) HLW - borosilicate glass p 13-15, WIPP Design Criteria 1978, D11

viii) borosilicate glass, Johansson & Steen, Ringhals 3 - 1978, E10

ix) safety analysis should be done for rep --useful in identifying those rep designs that can best withstand the effects of transient geological events, i e choice of waste form. p 36, NAS/NRC, Implementation of Standards 1978, A3

11. Studies Needed:

i) on long term behavior of wastes: solid diffusion, grain boundary diffusion, surface diffusion, gas diffusion, ORNL McClain and Boch 1974, D3

ii) there is little info on waste form leachability, thermal conductivity, or chemical/radiation stability though these characteristics can be of importance for safety, p 20 Considerations for HLWM, Gera & Jacobs ORNL 1972, D5

iii) there is little data on whether glass will remain intact; de Marsily etal, Guarantee Isolation? 1977, E5

iv) on ceramics - stability and resistance to leaching under expected conditions; on glasses effect of alpha radiation on devitrification, leaching at T & P expected with likely solutions, ie brines. p 6-7; EPA State of Knowledge 1978, C7

v) recommended: sensitivity analysis varying leach rates (characteristic of waste form), time of beginning of leaching and sorption characteristics of backfill - this study will identify combinations of backfill and overpack, life of canisters and waste form that significantly affect long term release and will provide guidance for future R & D. p 48, ESTP USGS & DOE 1979, D24

vi) tests at 25 degrees and 1 atm are irrelevant for deeply buried waste. The actual substance whose long term stability and nonleachability should be evaluated might not be the original waste form but a reaction product in a contact aureole around the canister between the waste, its containment and the wall rock of the rep (since it has been confirmed that these interactions do occur), McCarthy et al, Interactions Waste-Rock, Nature 1978, E3

vii) glass leaching depends on glass properties, amount and composition of groundwater, T, amount and composition of wastes, radiation. Systematic studies of all variables and actions is very limited. p 12-15, Johanson & Steen, Ringhals-3, 1978, E10

viii) important geochemical information to be determined - on composition of wastes, p 21 NAS/NRC Implementation of Standards 1979, A3

12. Waste form as a containment barrier:

i) one should be very cautious in placing much reliance on such manufactured barriers as waste form for long term containment. p 16, IAEA SS Factors 1977, E11

ii) Conclusions: If the integrity of the glass matrix can be guaranteed indefinitely, the rate of waste release, which depends solely on diffusion within glass, is very slow. The choice of geologic formation is then less difficult. If the integrity of the glass matrix cannot be guaranteed for millions of years, highly absorbed nuclides can be retained if the geologic environment and ionic form of the nuclides is favorable. de Marsily et al, Guarantee Isolation? 1977, E5

iii) at this point there is no evidence that incorporation into glass will ensure resistance to significant leaching over time scales of a decade. Since no evidence suggests long term integrity of glass, assume that glass presents no significant barrier to transport by leaching solutions. The same goes for spent fuel rods. Limiting constraint for both - the degree to which the individual ions or their complexes are soluble p 7; until it is demonstrated otherwise, assume loss of HLW matrix within a very short time of emplacement; in view of isolation time needed, consider the material in the canister primarily from the aspect of what is being dissolved rather than as a barrier of any consequence. p 8 EPA State of Knowledge 1978, C7

iv) It cannot be excluded that the time for the glass to dissolve might be 1/5 or less of values used by KBS (30,000 yrs with unlimited water, 3 million yrs with limited) p 12-15; American Physical Society - our present knowledge of properties of borosilicate glass as a waste form is inadequate to place reliance on the glass as the principal barrier to radionuclide release, p 104, Johanson & Steen Ringhals - 3, 1978, E10

v) a number of recent reports have concluded that present understanding of the stability of canister and waste form is not sufficient to rely on these alone as the principal long term barrier to release. p 45 NAS/NRC Implementation of Standards 1979, A3

13. State of Knowledge:

Do we adequately understand the physical and chemical behavior of the waste form and package? MOderate amount of data, developing models. p 40

Do we adequately understand what the chemical form of the waste will be in the long term? limited data, currently expanding data base. p 44 ESTP USGS & DOE 1979, D24

2. Nuclides of Concern:

1. Tc 99 and I 129 - have combination of high fission yield, long half-life, significant biological uptake and are poorly sorbed - may be most important fission products for long term safety. p. 23.17-23.22, ERDA/BNWL Alternatives Vol 4, 1976, D16

2. Pu 239 - only nuclide that would be brought to the surface in significant amounts in case of total failure of erosion forecast and high erosion rates, p. 97 Considerations for HLWM, Gera and Jacobs, ORNL 1972, D5

3. Study considered I 129, Np 237, Pu 239 - half-lives on order of magnitude of geologic time, present in significant quantities in waste, wide range of physico-chemical properties (behavior indicative of less hazardous elements) , de Marsily et al, Guarantee Isolation? 1977, E5

4. Nd 144, U isotopes - from KBS model with probable parameters only these would arrive at surface (have very long half-lives), p. III-54; model with new representative retention factors - only U would arrive (all others would decay in transit), p. IV 55; KBS report says that the main radiation hazard after canister dissolution is from Np 237, U233, Ra 226, U 234, Th 229, and Th 230, p. IV 13; dose can be calculated for the individual over one year or over a lifetime or for a population over an average lifetime or prolonged periods - for each of these calculations of dose, a different sense of the relative importance of nuclides is apparent. Sumation of cumulative effects over thousands or millions of years for some isotopes will increase their relative importance with respect to short-lived isotopes, p. IV 41; Westermark - if copper encapsulation is used (longer lifetime), simplifies situation to a few main considerations: Np 237 and daughters, U and its daughter Ra 226, Cs 135, p. 16 Appendix, KBS Rydberg and Winchester 1978, E9

5. from study of field "experiments" - Oklo, Nevada Test Site - alkalines and alkali earths were lost completely or in significant quantities, including the major fission products Sr 90 and Cs 137 - so serious concern over the loss of these two, p. 26-27, EPA State of Knowledge 1978 , C7

6. Nuclides significant in LL and HLW or having inhomogeneities in internal dose distribution: H 3, Cr 51, Mn 54, Fe 59, Co 57, Co 59, Co 60, Zn 65, I 131, Cs 134, Cs 137, Pu 239, C 14 Sr 90, Tc 99, I 129, Ra 226, Th 230, Th 232, Np 237, Pu 240, Am 241, Am 243, Desrosiers and Njoku, Risk Limit as Standard, 1978 or 9, D22

7. Np - element that would be responsible for highest global dose commitment, p. 139; contributors to individual dose in well case from KBS model - largest from Np followed by Tc, Ra, U and Ce; largest contributors to collective dose - I, Ce, Np, Th and Te, p. 141, Johansson and Steen , Ringhals-3 1978, E10

8. Because of retardation and decay, each nuclide will have its own concentration profile along transport path - at any point and time, the relative importance of the nuclides will vary. Appropriate evaluation of containment requires detailed and accurate calculation of transport of each, taking into account their chemical properties, radioactive decay and parent-daughter relationships. p. 6-7 NAS/NRC Implementation of Standards 1979, A3

3. Leaching of Waste (see also Waste Form):

1. Considered/information useful:
   i. one of the barriers that people can choose/control - leach time, a measure of the resistance of the waste form to leaching, p. 23.17-23.22, ERDA/BNWL Alternatives Vol. 4, 1976, D17
   ii. leach time - factor to be taken into account when constructing transport model, p. 7, USGS ES Perspectives 1978, B10
   iii. one of important technical aspects: dissolution rate of glass; consider the possibility that glass may be dissolved as polymer containing fission products/actinides (these would have a different migration rate), p. III 30-32, KBS Rydberg and Winchester 1978, E9
   iv. for PSAR and ER, need improved understanding of waste leaching by groundwater, p.9; also need information on radiation and thermal effects on waste leaching, p. 15, ESTP, USGS and DOE, 1979, D24
   v. p. 99; need to take into account the effect of cracks, p. 102, and the amount of groundwater available (leaching is limited by solubility), p. 102-3, Johansson and Steen, Ringhals-3, 1978, E10
   vi. information needed to calculate the potential for leaching of waste, p. 19, NAS/NRC Implementation of Standards, 1979, A3

2. Leachability of waste not considered to be important:
   i. in salt rep, there would be no leaching of waste by water (no water present); if dissolution were to occur, then leaching would follow but this would require a large flow of water, p. 100; leachability is only important when geologic materials surrounding the waste do not provide an effective barrier to movement of nuclides - but this situation should be prevented through the selection of suitable sites, p. 130, Considerations for HLWM, Gera and Jacobs, ORNL 1972, D5
   ii. on longer time scale (beyond first few centuries) dissolution of waste form is assumed so the main barrier is the host rock, p. 45-46, NAS/NRC Implementation of Standards 1979, A3
   iii. since at this point there is no evidence that incorporation into glass will ensure resistance to significant leaching over time scales of a decade, glass should be considered as to what is being dissolved rather than as a barrier of any consequence, p. 7,8, EPA State of Knowledge 1978, C7

3. Possibility/Rate of Leaching of Wastes should be minimized:
   i. interaction of water, rep rock, and waste material should be controlled in such a way as to minimize the rate of dissolution of wastes, p. 11-13, NAS/NRC 1978, A1
   ii. waste form should be insoluble, p. 5, Canada AECL 1975, E1
   iii. anionic and non-ionic wastes should be in water-insoluble forms to minimize leaching, p. 153-155, USGS 74-158, 1974, B8
   iv. factor tending to lengthen transport time: low rate of release of nuclides to groundwater, p. 8, USGS ES Perspectives, 1978, B10

4. Effect of changing the leach rate:
   i. decreasing the leach rate increases the magnitude of the reconcentration phenomenon but at the same time decreases the discharge rates to the biosphere (reconcentration phenomenon - maximum rates of discharge to the biosphere is greater for deep rep than the corresponding rate for surface disposal), p. 1.13,1.15, Burkholder, Reconcentration Phenomenon, BNWL 1976, D15
   ii. reducing the leach rate reduces the incremental dose to a maximum individual but the number of such maximum individuals increases - more individuals get lower doses. However because of radioactive decay, the total integrated doses over all time decrease as leach rate decreases. Incentives for Partitioning, Burkholder, 1972, D14

5. Factors influencing leach rates, to be taken into account:
   i. waste form, container, properties of host rock, composition of available water, temperature and pressure, added materials, equilibrium constants, p. 11-13, NAS/NRC 1978, A1
   ii. chemical characteristics of solid surfaces near canisters - potential for interactions leading to enhanced leaching of wastes, p. 23, NAS/NRC Implementation of Standards, 1979, A3
   iii. chemical composition of glass, properties and availability of glass surface, water temperature, pH, salt content and composition, water flow rate, p. III 28-29, KBS Rydberg and Winchester 1978, E9
   iv. glass composition, groundwater composition and flow, time, radiation, temperature and pressure, p. 100-101, Johansson and Steen, Ringhals-3, 1978, E10
6. Research needed:
   i. whole area of leaching of wastes is a field where much research ought to be done, p. III-30, KBS Rydberg and Winchester 1978, E9
   ii. reconcentration phenomenon emphasizes the need to learn the leaching behavior of wastes. Burkholder, Reconcentration Phenomenon, BNWL 1976, D15
   iii. no systematic experiments have been done covering all parameters or under conditions representative of actual situation - rates reported in the literature can be considered to be very tentative, p. 100-101; also little experimental evidence on the increase of surface area due to cracking, p. 102; experiments done have been limited in time - all extrapolations of glass behavior over thousands of years are done from these limited data, p. 104, Johansson and Steen, Ringhals-3, 1978, E10

4. Canister:

1. criteria for packaging should be developed, p. 15, ORNL, Program Plan for BSPP, 1973, D1

2. The specific canister criteria will have to be based on : required/defined lifetime, adequate mechanical strength for handling and emplacement, material costs, consumption of critically limited resources (may be judged to be worth it). p. 3 Braithwaite and Mollecke, Sandia 1978, D7

3. Required Lifetime/Intended Purpose:

a. Canister optimized for transport requirements and/or for mechanical properties needed for handling and emplacement operations:
   i. rapid corrosion not considered a major impact, lifetime of zero to five years after emplacement. Most desirable from an economic point of view - cheapest container, p. 2, Braithwaite and Mollecke, 1978, D7
   ii. TRU - major health hazard associated with airborne particles so containers must maintain their integrity during handling, p. 18-22, NAS/NRC Bedded Salt 1970, A2
   iii. according to regulations on shielding, containment and heat transfer (transportation regulations), p. 2-16, ER of WM of LWR Cycle, NRC 1976, C8
   iv. current suggestion, p. 5-6; optimum container may be one that is highly effective as container and transport vessel, p. 10, EPA State of Knowledge, 1978, C7
   v. survival of all canisters need not be guaranteed so long as an adequate retrieval method is available and reasonable for corroded canisters, p. 28, WIPP Conceptual Design Report 1977, D12

b. for five to 25 years after emplacement:
   i. in case retrieval becomes necessary during early operational period or waste later viewed as a resource (though you can retrieve waste even if the canisters are corroded), p. 2, Braithwaite and Mollecke, Sandia 1978, D7
   ii. if needed to make retrieval available and reasonable, p. 28, WIPP Conceptual Design Report, 1977, D12

c. Canister considered as a barrier:
   i. canister should survive and remain a barrier at least during the major heat production phase: lifetime of about 300 years provides a significant retarding action against thermally driven interactions (i.e. hydrothermal leaching). Providing this canister lifetime option as part of the overall multibarrier system must be viewed as a desirable goal. p. 3, Braithwaite and Mollecke, Sandia 1978, D7
   ii. p. 25.15-17; one of the barriers that people can select or control: time of initial release - a measure of canister integrity, p. 23.17-22, ERDA/BNWL Alternatives Vol 4, 1976, D17
   iii. de Marsily et al, Guarantee Isolation? 1977, E5
   iv. KBS - most important technical aspects: corrosion resistance of canister, KBS Rydberg and Winchester 1978, E9
   v. p. 5, EPA State of Knowledge 1978, C7
   vi. first physical barrier to release - canister, Vol III, Appendix DIV, AD Little, Assessment 1978, C3
   vii. canister integrity is especially essential for the first 500 years when Sr and Cs decay, p. 105-6, Johansson and Steen, Ringhals-3, 1978, E10

4. Materials suggested:
   i. several methods are availble by which container life can be prolonged:

addition of CaO to backfill to react with water to form stable calcium hydroxide; use stress corrosion resistant alloys for container, perhaps 304L stainless steel on inside and carbon steel or aluminium on outside; bury waste in a ceramic or concrete sleeve, p. 57, AEC, Lyons ES 1971, D6

ii. stainless steel suggested, de Marsily et al, Guarantee Isolation? 1977, E5

iii. KBS plan - titanium layer over lead layer; Westermark suggests copper for long encapsulation - may last 100,000 years, p. 14Appendix, KBS Rydberg and Winchester 1978, E9

iv. reference system - stainless steel, p. 4-2, ES of WM of LWR Cycle, NRC 1976, C8

v. suggestions - steel, stainless steel, molybdenum, p. 5-6; also titanium and copper, p. 10, EPA State of Knowledge 1978, C7

vi. currently under consideration: stainless steels, carbon steel, Iconels, titanium, Vol III, Appendix DIV, AD Little Assessment 1978, C3

vii. from archeological data, lead, copper and copper based alloys have good corrosion resistance, p. 9; conclusion of study: 8 metals chosen for further study because of their corrosion resistance under a variety of conditions, metal cost, metal availability. Prime candidate alloys (by increasing corrosion resistance): 1018 mild steel, Corten A steel, lead, 90-10 cupronickel, SS-Ebrite 26-1, Monel 400, Iconel 600, Ticode 12, p. 19. Certain alloys - copper, lead, cupronickel - must only be considered as overpack because of their low mechanical strength, p. 19; most cost effective material can only be identified after a site specific environment is fully defined and the lifetime is chosen, p. 26, Braithwaite and Mollecke, Sandia 1978, D7

5. Information needed/Research to be done:

i. on likelihood for pinhole corrosion and on what a more rapid pinhole corrosion rate would mean with regard to overall risks, p. III-26; KBS Rydberg and Winchester 1978, E9

ii. studies are underway or planned to establish the corrosion characteristics of canister/waste/medium linkages, p. 4-77, ES of WM of LWR Cycle, NRC 1976, C8

iii. need information on canister corrosion as it is affected by radiation and thermal effects, p. 15; Do we adequately understand the physical and chemical behavior of waste package? Moderate amount of data, developing models, p. 40, ESTP, USGS and DOE, 1979, D24

iv. complete investigation should be done on canister lifetime, based on groundwater flow and composition data. New types of corrosion do occur and it is hard to predict corrosion in a new environment, p. 105-6; there are many uncertainties and lack of knowledge on canister corrosion/lifetime, p. 109, Johansson and Steen, Ringhals-3, 1978, E10

v. information needed ot calculate the potential for leaching of canister p. 19; on chemical characteristics of solid surfaces in vicinity of waste and potential for interaction leading to enhanced corrosion, p. 23; safety analysis of rep should be done - useful in identifying those rep designs that can best withstand the effects of transient geologic events, i.e. choice of canister, p. 36, NAS/NRC Implementation of Standards 1979, A3

vi. more studies are needed to conclusively demonstrate the utility of this engineered metallic barrier - the canister, p. 28, Braithwaite and Mollecke, Sandia 1978, D7

6. Factors affecting corrosion rate to be taken into account:

i. likely solutions/conditions: high ionic concentration of brines in salt (canisters likely to be bathed in it due to brine migration) and high temperature, p. 9; also perhaps low pH, low concentrations of metal ions, p. 10, EPA State of Knowledge, 1978, C7

ii. groundwater flow and composition, p. 105-6, Johansson and Steen, Ringhals-3, 1978, E10

iii. temperature, pressure, solution chemistry (i.e. oxidizing potential, pH, ion concentration), stress, sensitization and welding, radiolysis products, p. 4-6; in geothermal brines, variables making the most significant contribution to corrosion: pH, temperature, and film composition, p. 8; relatively dry salt is not corrosive even to susceptible alloys, p. 16, Braithwaite and Mollecke, Sandia 1978, D7

iv. water content, chemical properties of water, p. 19, NAS/NRC Implementation of Standards 1979, A3

7. Should the canister be considered and optimized as a barrier?

i. sensitivity analysis should be done to evaluate the importance of encapsulation compared to geologic retention. Would the concentrations be acceptably low based on dilution alone (no metallic barrier)? By such analysis, would be better able to evaluate the consequences of unexpectedly short canister lifetime, p. IV 35-36, KBS Rydberg and Winchester, 1978, E9

ii. sensitivity analysis should be done on engineered barriers to identify combinations of backfill and overpack, canisters and waste form that significantly affect long term release and to provide guidance for future R&D, p. 48, ESTP, USGS and DOE, 1979, D24

iii. effect of changing initial release time: increasing cansiter integrity cannot reduce the incremental dose level below background unless containment can be reasonably assured for more than a million years, Incentives for Partitioning, Burkholder 1976, D14

iv. canister as a long lived barrier may be desirable goal but not necessary, especially if site has very low probability for water intrusion during thermal period, p. 3, Braithwaite, and Mollecke, Sandia 1978, D7

8. Can one rely on the canister as a barrier?

i. of stainless steel, not expected to survive more than a few hundred years at most, de Marsily et al, Guarantee Isolation? 1977, E5

ii. one should be very cautious in placing much reliance on such manufactured barriers as the waste container for long term containment. p. 16, IAEA SS Factors 1977, E11

iii. Panel does not consider the canister to be a significant barrier for time scales of centuries to millions of years, p. 10, EPA State of Knowledge, 1978, C7

iv. in risk assessment no credit was taken for the first barrier, the canister, in isolation in bedded salt, p. 79; there is insufficient information to predict canister longevity but enough data to indicate that this time may not be very long, Vol III, App DIV, AD Little Assessment, 1978, C3

v. present knowledge is not sufficient to exclude the possibility that failure of canister might occur earlier than that assumed by KBS, p. 12-15, Johansson and Steen, Ringhals-3, 1978, E10

vi. a number of recent reports have concluded that present understanding of the stability of the canister is not sufficient to rely on this alone as the prinicpal long term barrier to release, p. 45, NAS/NRC Implementation of Standards 1979, A3

vii. All in all, it appears possible to provide HLW canister-overpack system which can survive the potentially corrosive environments for the desired amount of time: it can protect the HLW form from aqueous leaching (assuming intruding leachant) during the period of greatest thermal output and greatest reactivity, p. 28, Braithwaite and Mollecke, Sandia 1978, D7

9. Effect of dissolved canister material:

i. may influence retention, i.e. lead would probably inhibit retention, p. IV-59, KBS Rydberg and Winchester 1978, E9

ii. optimum canister may be one that doesn't enhance attack by solution on the contents by adding corrosive materials to the solution, p. 10, EPA State of Knowledge, 1978, C7

iii. cansiter should be compatible with host rock, p. 10; once canister dissolves, the chemical characteristics of the environment depend on both the original composition and the added material from canisters and overpack, p. 23; information is needed on chemical characteristics of solid and fluid media on a large scale around the rep including the potential for large scale change resulting from canister dissolution, p. 24, NAS/NRC Implementation of Standards, 1979, A3

PART IV: OTHER CRITERIA

Part IV: No. 1

1. Monitoring/Human Supervision

1. Disposal method must be maintenance free (continued integrity must not be dependent on human action):
   - i. p. 1-3, NAS/NRC 1978, A1
   - ii. to minimize trouble and concern to future generations, p. 1-2, AECL Canada 1975, E1
   - iii. criteria must be met: method should not be dependent on political or social stability, p. 13-14, Deep Rock, Klett Sandia 1974, D8
   - iv. controls based on institutional functions should not be relied on for over 100 years to provide isolation - instead rely on as many engineered and natural barriers as are necessary, EPA Criteria for Radwastes/ Rec for Fed Guidance, Fed Reg 1978, C2
   - v. long term control should be passive, based on a system of multiple barriers, p. 16-17, NRC Branch Technical Position, 1977, C6
   - vi. for disposal concept, place no reliance on continuing services but on the properties of the waste form, container, location, p. 15, IAEA SS Factors 1977, E11
   - vii. assume constant underground surveillance and maintenance beyond operational phase is unlikely, p. 3, EPA State of Knowledge, 1978, C7
   - viii. system must not be dependent on long term stability of social and governmental institutions, p. 13, Proposed Goals for RWM, NRC 1978, C9
   - ix. assume that after closure, no further supervision or action will be necessary, p. viii, NAS/NRC Implementation of Standards, 1979, A3

2. Consequences of no perpetual care and communication of rep existence to future generations:
   - i. probability of release to land caused by human intrusion may become quite high if adequate perpetual care cannot be maintained; consequences tend to be low, p. 6-8, AD Little, Assessment 1978, C3
   - ii. if they provide a net improvement in environmental and public health protection, one should use passive methods of communicating to future people the hazards of disturbance of the rep, EPA, Criteria for RWM, Rec for Fed Guidance, Fed Reg 1978, C2
   - iii. marking or identification of rep:should land be restored to its original condition after D&D or should it be marked so that anyone today and at any time in the future would know what was buried there? To be considered. p. 20-22, NRC State Review/Analysis Nureg 0354 1978, C5
   - iv. adequate documentation of present activities and decisions shall be provided as part of the waste management system to provide future generations with a basis for action, p. 11, NRC, Proposed Goals for RWM, 1978, C9
   - v. recommendation - methods for keeping of records and their long term maintenance regarding the location and contents of the rep should be examined, p. 3, IAEA SS Factors 1977, E11

3. Rep integrity/safety should not depend on continued monitoring of rep performance:
   - i. p. 1-3, NAS/NRC 1978, A1
   - ii. p. 17, NRC, Branch Technical Position, 1977, C6
   - iii. disposal concept: place no reliance on continuing services like monitoring to assure containment, p. 15, IAEA SS Factors 1977, E11
   - iv. system not dependent on long term stability of social and governmental institutions for secure operation, p 13, NRC, Proposed Goals for RWM, 1978, C9
   - v. rep must be safe even in the absence of verification of compliance with radiation protection standards (verification of long term compliance can only be done by future generations.) Continuing monitoring and surveillance program is not an adequate long term verification procedure, p. viii, NAS/NRC Implementation of Standards 1979, A3

4. Monitoring of rep performance after closure is desirable as long as it does not compromise rep integrity:

i. for rep, choose a geologic system that can be satisfactorily sealed on closure and suitably monitored after closure to ensure satisfactory behavior of rep, p. 9-11, NAS/NRC 1978, A1

ii. It is difficult to conduct a monitoring program without compromising the confinement capability of the rep - only when such methods enhance overall protection is it prudent to use them. EPA Criteria for RW/Rec for Fed Guidance, Fed Reg 1978, C2

iii. to the extent that it can be accomplished without compromising the integrity of the site, means should be provided to permit monitoring of the state of the rep with regard to containment capabilities to the extent permitted by state of the art technology, p. 17, NRC Branch Technical Position, 1977, C6

iv. "Part of the responsible establishment of a HLW rep is the provision for a warning system in the event of loss of some of the HLW to the biosphere." 2 aspects: early warning so rep can be repaired or to confine the spread, and longer range to provide time to reduce the exposure to the contamination. But near in monitoring may provide a pathway for escape. p. 41-42, EPA State of Knowledge 1978, C7

v. prudent operating procedure: install monitoring system to observe rep behavior after D&D - indicate continuing containment capability and provide information useful in constructing other reps, p. 2-9, NRC Info Base for Rep Design, 1979, C10

vi. program includes detection and identification of evolved gases or fluids, measurements of temperature, stress, strain, fluid pressure, detection of ground uplift, p. 16, ESTP, USGS and DOE, 1979, D24

vii. to observe selected parameters, p. viii, NAS/NRC Implementation of Standards 1979, A3

5. If continued monitoring is required, waste must be placed where it will not be covered by erosion products. p. 165-168, USGS 74-158, 1974, B8

6. Monitoring of rep performance during operational phase prior to closure:

i. monitoring is judged to be generally part of early institutional controls prior to closure, EPA, Criteria for RW/Rec for Fed Guidance, Fed Reg 1978, C2

ii. to detect adverse affect on stability of medium - if tests indicate acceptable long term stability, rep can be converted to disposal status by backfilling and sealing, p. 4-71, ES of WM of LWR Cycle, NRC 1976, C8

iii. includes detection and identification of evolved gases or fluids, measurements of temperature, stress, strain, fluid pressure, detection of ground uplift, p. 16, ESTP USGS and DOE 1979, D24

iv. at WIPP to measure contributions to offsite exposure by direct radiation, airborne radioactivity, radioactivity deposited in the environment and biological media, p. 258, WIPP Conceptual Design, 1977, D12

v. part of methodology for compliance with radiation protection standards - monitoring followed by corrective action before closure, p. 9 NAS/NRC Implementation of Standards 1979, A3

7. Monitoring Techniques:

i. new procedures will need to be developed since ordinary environmental protection procedures will not be satisfactory for monitoring rep, p. IV 8-9, KBS Rydberg and Winchester 1978, E9

ii. no known monitoring instrumentation has reliability for decades, much less centuries - need to consider that leaks might occur earlier than predicted but still much beyond time when monitoring can be anticipated -

the TRU that enters biosphere undetected at such time might impose serious risks on our descendents, p. 41-42, EPA State of Knowledge 1978, C7

iii. critical technology needing development: monitoring systems. Instrument packages sealed in will have to last many years but there is no experience with such long working life requirements. Systems not directly connected with the surface by cables may be desirable, p. 2-4; design option studies to be done: needed to get information in order to be able to choose a monitoring system, p. 3-1,2, NRC Info Base for Rep Design, 1979, C10

iv. research is needed to develop acceptable monitoring procedures to detect and evaluate migrations of nuclides from or within rep. Review of Health Physics Research by NRC, 1978, E4

v. Do we adequately understand what type of monitoring system will be needed for a rep? Operational phase: models developed, assessing applicability; Post-operational phase: limited data, currently expanding data base; Can we adequately measure the proper environmental characteristics for rep monitoring? Operational phase: equipment available or techniques verified, improving sensitivity, range, and/or reliability or applying techniques; Post-operational phase: approach unknown, developing techniques, p. 43 ESTP, USGS and DOE, 1979, D24

2. Retrievability:

1. Desire for retrievability depends on the waste management concept chosen: storage - retrievability required; disposal - no intent to retrieve; provisional storage - leave retrieval option open until acceptable long term stability of the rep has been demonstrated and the rep is converted to disposal status by backfilling and sealing.
   i. p. 23.1, ERDA/BNWL Alternatives Vol 4, 1976, D17
   ii. p. 15, IAEA SS Factors 1977, E11
   iii. p. 4.71, ES of WM of LWR Cycle, NRC 1976, C8

2. For disposal concept, wastes should be retrievable until final sealing of rep and/or until satisfactory evidence of long term stability of rep is established:
   i. p. 2, Canada AECL 1976, E2
   ii. waste matrix/canister's ability to meet requiared performance criteria must be maintained during retrievable operation prior to disposal, Appendix, NRC Branch Technical Position 1977, C6
   iii. (retrievable without extreme difficulty), p. 15, IAEA SS Factors, 1977, E11
   iv. must be retrievable for this period, de Marsily et al, Guarantee Isolation? 1977, E5
   v. wastes will be retrievable with retrievability demonstrated until WIPP becomes an operational rep - i.e. until the experiments have proven that bedded salt is a satisfactory medium for disposal fo waste, p. 26, p.132, WIPP Conceptual Design 1977, D12
   vi. corrective actions like retrieval and site abandonment should be available options until closure, p. 2-3, p. 10, NAS/NRC Implementation of Standards 1979, A3
   vii. p. 4-79, ES of WM of LWR Cycle, NRC 1976, C8

3. Retrievability is desirable in general:
   i. often mentioned as a desirable feature, p. 13-14, Deep Rock, Klett, Sandia 1974, D8
   ii. procedures or techniques designed to enhance retrievability should be applied if use of these provide a net improvement in public health and environmental protection. EPA Criteria for RW/Rec for Fed Guidance Fed Reg 1978, C2
   iii. advantages of multiple locations for reps - retrievability concept can be included, p. 6, OWI/ERDA Program Plan for NWTSP, 1976, D19
   iv. retention of the retrievability option after storage has been endorsed by the American Physical Society and other scientists, Review of Health Physics Research by NRC, 1978, E4
   v. retrievability should not be precluded, p. 12; NAS says - other things being equal, those technological projects or developments should be favored that leave maximum room for maneuver in the future - the reversibility of an action should be counted a major benefit and its irreversibility a major cost. p. 15, NRC Proposed Goals for RWM, 1978, C9

4. Concerns about maintaining retrievability:
   i. if waste can be recovered intentionally, it is also susceptible to natural or accidental exposures, p. 13-14, Deep Rock, Klett, Sandia 1974, D8
   ii. it is difficult to maintain retrievability without compromising the ability to provide permanent isolation. Only when it would enhance overall protection is it prudent to maintain retrievability. EPA Criteria for RW/Rec for Fed Guidance, Fed Reg 1978, C2
   iii. retrievability should be a characteristic of a system only if there

is considerable uncertainty about its wisdom, safety or efficacy. To the extent that uncertainties are small, disposal should be permanent and irretrievable (retrievability is partly inconsistent with other goals of completeness and permanence of WM systems.) This topic needs more discussion. p. 12, NRC Proposed Goals for RWM, 1978, C9

5. If retrievability is deemed desirable, it will strongly affect site selection and rep design criteria:

i. plasticity (i.e. of salt) will limit the length of time for which wastes are retrievable and this may handicap the demonstration phase, p. 9, Canada AECL 1976, E2

ii. i.e. spent fuel in salt probably could not be recovered safely after a few decades due to creep closure (waste may be viewed as a resource - source of U - in the future and recovery attempted.) Keeping a mine open and clean requires constant maintenance and checking. Retrieval may only be feasible during operational phase. There is little experience with reopening mines or maintaining a tightly sealable open shaft and the desirability of these measures will affect the choice of rep media, p. 3; much of the uncertainty as to the basic characteristics of a rep result from policy decisions that have not been made and generally accepted, i.e. on whether retrievability should be provided for decades - this decision will affect the choice of waste form, canister, rock type and site, p. 6, EPA State of Knowledge 1978, C7

iii. mechanical stability of rep must be assured for a period significantly longer than that required for retrievability - affects site selection. p. 26, NAS/NRC Implementation of Standards 1979, A3

6. Retrieval Technology:

i. critical technology needing development: retrieval by overcoring has not yet been adequately demonstrated, p. 2-4; critical information needs to be better able to evaluate rep design: retrieval risk analysis should be done for retrieval operations to clarify the risks of planned retrieval design. Separate analyses should be done on retrieval as an emergency procedure, p. 2-5, NRC Info Base for Rep Design, 1979, C10

ii. to prepare PSAR and ER, need improved understanding of the conditions for retrievability, p. 9, ESTP, USGS and DOE 1979, D24

3. Design of Rep:

1. Design in general:

i. Design should be kept simple to reduce the number of variables so as to increase the confidence of predictions, i.e. unreprocessed spent fuel elements should not be placed in retrievable storage in a facility for permanent disposal. p. 6-9, NAS/NRC 1978, A1

ii. uncertainties are introduced into risk assessments because of the uncertainties concerning design actions needed to minimize the possibility of rep failure, p. 4-94, ES of WM of LWR Cycle, NRC 1976, C8

iii. design option studies should be done on structural design parameters like ventilation, extraction rates, thermal loading, etc (how they interact is important), p. 3-1,2, NRC Info Base for Rep Design 1979, C10

iv. events taken into account in risk assessment - technological failure due to defective design and other causes, p. 95-103, AD Little, Assessment 1978, C3

v. derived concentration limits for water (from primary limits based on dose to humans) provide a convenient design basis for radiological engineers charged with selecting the operating characteristics of a rep. Desrosiers and Njoku, Risk Limit as Standards 1978 or 9, D22

vi. safety analysis should be done - useful in identifying those rep designs that can best withstand the effects of transient geological events, i.e. choice of waste form, canister, geometrical arrangement, etc. p. 36, NAS/NRC Implementation of Standards 1979, A3

2. Mechanical Effects of Design:

a. Design should maximize stability consistent with practicable operational design:

i. optimum dimensions of rooms - maximum amount of usable space consistent with safe and trouble-free operation of mine while allowing earliest practical closure of mine and recrystallization of backfill salt (currently estimated to occur within 65 to 100 years after filling.), p. 23-25, NAS/NRC Bedded Salt 1970, A2

ii. such that maximum stresses resulting from cavities, thermal stresses and inherent state of stress in wall rock are well below the critical value for the uniaxial compressive strength of rock. Kehnemuyi, Battelle M., 1979, D23

iii. p. 57, WIPP Conceptual Design Report, Sandia 1977, D12

iv. demonstration of this stability must include consideration of the following: location and arrangement of excavation, stresses and displacements induced by excavation, location and arrangement of emplaced wastes, support design, temperature fields, thermomechanical and thermochemical stresses, effects of thermal fields on hydrology, p. 25, NAS/NRC Implementation of Standards 1979, A3

b. Design should minimize the amount and limit the rate of deformation due to subsidence and/or thermal expansion so that the integrity of the overlying strata/hydrological pattern over rep is not significantly affected:

i. so shale above salt will accomodate deformation without fracturing and aquifers easily adjust, p. 51, AEC Lyons ES 1971, D6

ii. there should also be studies on the consequences of deformation, ORNL McClain and Boch, 1974, D3

iii. subsidence should not constitute a problem, p. 28, NAS/NRC Implementation of Standards 1979, A3

3. Design components:

a. mine openings - should be placed in middle of selected zones to give uniform zones above and below rep level, p. 26, SS WIPP, Sandia 1977, D9

b. If waste is to be retrievable, use metal sleeve - same metal as canister should be used to avoid setting up an electrolytic cell that would induce rapid corrosion, p. 10-11, EPA State of Knowledge 1978, C7

c. Artificial support:

i. long term stability can be achieved by increasing support - state of the art is such that a mechanically safe cavity could ordinarily be placed in virtually any rock, p. 13-14, EPA State of Knowledge 1978, C7

ii. prudent operating procedures: stability should be enhanced by enstalling artificial support, p. 2-9, NRC Info Base for Rep Design 1979, C10

iii. demonstration of adequate stability must include consideration of support design, p. 25; but artificial support must not complicate the chemical system or at least not in unknown ways, p. 26; in situ tests needed for confirmation of adequate design: tests on mechanical and hydrological effects on rock of methods of rock reinforcement, p. 31, NAS/NRC Implementation of Standards 1979, A3

d. separate excavation from emplacement operations and have modular rep development (units constructed sequentially):

i. p. 2-6,2-7, NRC Info Base for Rep Design 1979, C10

ii. p. 94, p. 125, WIPP Conceptual Design Report 1977, D12

e. Backfill:

i. further control of nuclide mobility can be gained by addition of zeolites, clays and other ion-exchange minerals or resins to backfill, p. 11-13, NAS/NRC 1978, A1

ii. should determine sorption capacity o f surrounding rocks to allow quantification of safety analyses and to indicate whether engineered barriers (i.e. clay) would be beneficial, p. 2:19-20, GCR 1978, D10

iii. natural geochemical barrier can be reinforced by an artificial barrier set up around the wastes, de Marsily et al, Guarantee Isolation? 1977, C5

iv. serious drawback of salt - no sorption capacity. Possible way around this difficulty - wrap the wastes in materials that do have a strong tendency to fix the nuclides; research on possible materials is beginning. p. 5, USGS ES Perspectives 1978, B10

v. KBS plan: wet bentonite clay/quartz buffer, 90:10 quartz to clay ratio (for thermal conductivity, low permeability, plasticity and ion sorption capacity), p. III 23, 26,27, KBS Rydberg and Winchester 1978, E9

vi. stage of containment - possible special materials placed around waste, p. 5; no firm decisions have been made as yet on nature of packing around waste - candidates: metal sleeves (for retrievability), zeolites, clays (high ion sorption capacity), crushed host rock, cemented crushed host rock, combination, p. 5-6; the variety of packing materials is infinite but it remains to be shown that a selected material would enhance the resistance of the vessel to attack by solutions. Zeolite - ion exchange capacity may help in chemisorption of HLW but to be effective it would have to be far enough from waste to remian cool (releases water and loses sorption capacity at relatively low temperature), p. 10; another suggestion for overpack - MgO powder which on contact with water reacts to form stable magnesium hydroxide, p. 23-24, EPA State of Knowledge 1978, C7

vii. critical information needs: need information on long term behavior of backfill, i.e. will crushed salt backfill fuse as predicted? This is unproven, p. 2-6; in general it appears that backfill should have low permeability and favorable sorption capacity, p. 2-8, NRC Info Base for Rep Design, 1979, C10

viii. sensitivity analysis should be done varying sorption characteristics of backfill and overpack to identify combinations of backfill, overpack, canister and waste form that significantly affect long term release and to provide guidance for future R&D, p. 48; Do we adequately understand waste-water-backfill interactions? Limited data, currently expanding data base, p. 40; Do we adequately understand the sorption properties of backfill materials? Moderate amount of data, developing models, p. 40, ESTP USGS and DOE, 1979, D24

ix. most important areas where KBS assumptions questioned: on backfilling with clay/quartz buffer - neither small not full scale simulations were made to verify properties, p. 12-15, Johansson and Steen, Ringhals-3, 1978, E10

x. exploratory excavation to demonstrate adequacy of site - with data, updated and more confident predictions of performance can be made. If predictions indicate site will not meet standards, site should be abandoned unless changes in engineered barriers, i.e. backfill, can compensate for geological inadequacies, p. 10-11, NAS/NRC Implementation of Standards 1979, A3

4. Design Life of Rep:

i. operational life of rep - 20 to 30 years, p. 2-10, ES of WM of LWR Cycle, NRC 1976, C8

ii. WIPP - shafts, main entry system, open areas around shafts will be designed for a minimum life of 30 years; CH storage area - 15 year design life; RH storage area - to maintain at least 50% of its original height and width for 15 years, p. 72, WIPP Conceptual Design Report, 1977, D12

iii. WIPP: main haulageways, ventilation ways must be able to be used safely for 30 years without major rework; width of area for CH waste - the maximum attainable with guarantee of stability for 15 years. Chapter 5, p. 10-11, WIPP Design Criteria 1978, D11

iv. mechanical stability of rep must be assured for a period significantly longer than that required for retrievability, p. 26, NAS/NRC Implementation of Standards, 1979, A3

4. Miscellaneous Site Selection Criteria: (in no particular order)

1. Land Ownership; Existing Rights:

i. rep should be located to avoid private land,(preliminary site selection criteria, p. 1:3; rep should be located on federally controlled land to the extent possible, p. 2:20-21, GCR 1978, A1
ii. considered, p. 12-13, AECL Canada 1976, E2
iii. criteria - site should be controlled by the US government. This control should include the prohibition of all activities including mining and exploration for minerals which may interfere with the operation or adversely affect the integrity of the rep, p. 3, NRC, State Review, Nureg 0353, 1977, C4
iv. suggested modification of criteria - specify control of rep for an indefinite period by federal government, p. 30, NRC State Review/Analysis, Nureg 0354, 1978, C5
v. expanded site selection criteria - minimize state and private lands in Zones I and II, avoidance of existing potash lease rights in Zones I and II, p. 12-13, SS WIPP, Sandia 1977, D9
vi. by law rep must be on federally owned land - should consider the present value and ownership of land in site selection, p. 12, ORNL BSPP SS Factors 1973, D2
vii. use of government owned land would simplify site planning and evaluation efforts. If site is not on government land, it should be transfered to government control/ownership; existing rights - should be determined if their exercise would adversely affect rep. If there were possible interference, the availability of alternate sites would have to be balanced against buying existing rights, p. 49, IAEA SS Factors 1977, E11
viii. terrestrial disposal option is attractive since potential sites are under national jurisdiction, p. IV-8, KBS Rydberg and Winchester 1978, E9
ix. ownership of rep should be considered in site selection, p. 12-13, AECL Canada 1976, E2

2. Transportation:

i. should be capable of ready development, p. 2:20-21, GCR 1978, D10
ii. availability considered in criteria, p. 2-3, Supplemental Areas, Kn GS, 1972, B11
iii. if several suitable sites are under consideration, sites with lowest transportation risks should be given preference, subject to other relevant cost and environmental considerations. Criterion: site should be located with due consideration given to the minimization of risks associated with waste transportation, p. 6, NRC State Review, Nureg 0353, 1977, C4
iv. all aspects of waste transportation should be clarified in criteria, p. 30, NRC State Review/Analysis, Nureg 0354, 1978, C5
v. availability should be reasonable, Kehnemuyi, Battelle M, 1979, D23
vi. availability of rail lines is a cost consideration; also access to highway is desirable, p. 13, BSPP SS Factor ORNL 1973, D2
vii. system should either already exist or can be readily constructed - consideration in site selection, p. 47; site already served by existing transportation services is most desirable, p. 49, IAEA SS Factors 1977, E11
viii. availability should be considered in site selection, p. 5, Brunton and McClain, OWI/ERDA 1977, D20

3. Accessibility (see also Topography):

i. should be readily accessible for transportation and utilities, p. 2:20-21, GCR 1978, D10
ii. to be considered in making criteria, p. 12-13, AECL Canada 1976, E2
iii. information useful in site evaluation, p. 13, USGS 4339-1, 1972, B2

iv. study excluded inaccessible areas from consideration, p. 44, USGS 4339-6, 1973, B4
v. so gentle terrain is desired, p. C1, ERDA/BNWL Alternatives App C 1976, D18
vi. reasonable accessibility to powerlines, transportation desired, Kehnemuyi, Battelle M, 1979, D23
vii. accessibility for transportation, utility services - cost consideration in site selection, p. 13-14, BSPP SS Factors, ORNL 1973, D2
viii. accessibility for transportation utilities, communications should be considered in site selection, p. 49, IAEA SS Factors 1977, E11
ix. accessibility to transportation and utilities should be considered in site selection, p. 5, Brunton and McClain, OWI/ERDA 1977, D20

4. Population Density and Proximity to Population Centers:
i. considered; low density in immediate area is desirable, p. 2:20-21, GCR 1978, D10
ii. to be considered in making criteria, p. 12-13, AECL Canada 1976, E2
iii. information useful in site selection, p. 4, USGS 4339-1, 1972, B2
iv. study excluded some areas from consideration on the basis of conflict with population centers, p. 44, USGS 4339-6, 1973, B4
v. Los Medanos tract promising because there is a high degree of isolation from populated areas, p. 34-35, USGS 4339-7, 1973, B5
vi. criteria: population buffer of six miles from a town of township size, p. 2-3, Supplemental Areas, Kn GS, 1972, B11
vii. should be low, p. 2, USGS 74-158, 1974, B8
viii. problems and potential of locating rep near a population center or concentration should be considered in criteria, p. 30, NRC State Review/ Analysis, Nureg 0354, 1978, C5
ix. populated areas should be avoided; at least a five mile buffer zone should be mandatory between rep and an urban center, Kehnemuyi, Battelle M, 1979, D23
x. "...efforts should be made to minimize the population requiring evacuation in the highly unlikely event of an accident or other emergency"- so locate site in an area of low population density and as remote as practical from large population concentrations, p. 12, BSPP SS Factors, ORNL 1973, D2
xi. assume that rep site is chosen to confine wastes so population density should be of little importance. It is advantageous to have normal community activities available but large community may introduce complicating factors, p. 48-9, IAEA SS Factors 1977, E11
xii. site should be as far removed from population centers as possible, p. 4.63, HLWM Alternative, BNWL-1900, 1974, D16
xiii. waste must be isolated from present and future areas of habitation or visitation - criteria must be met, p. 13-14, Deep Rock, Klett, Sandia 1974, D8

5. Ecological Impact:
i. major impacts due to construction/operation should not occur, p. 2:20-21, GCR 1978, D10
ii. consider impact on endangered species, follow Endangered Species Act, Kehnemuyi, Battelle M, 1979, D23
iii. must be carefully investigated and evaluated, such as those connected with the spoil, p. 47, IAEA SS Factors 1977, E11
iv. consider effects on biota other than people - terrestrial and aquatic, p. 4-168, ES of WM of LWR Cycle, NRC 1976, C8

6. Archeological/Historic Features of Significance:
i. should be preserved, p. 2:20-21, GCR 1978, D10
ii. should consider Historic Preservation Act and its affect on rep siting, Kehnemuyi, Battelle M, 1979, D23

7. Demographic and Economic Effects:
   i. should not result in unacceptable sociological impacts, p. 2:20-21, GCR 1978, D10
   ii. should be considered, i.e. boom/bust economy, impact on local community (schools, hospitals, sewage systems, etc); also consider that there are no economic benefits for state in which rep is located - should economic incentives be provided for the state? p. 20-22, NRC State Review/Analysis, Nureg 0354 1978, C5
   iii. should be considered, p. 4-168, ES of WM of LWR Cycle, NRC 1976, C8
   iv. should be considered, as well as the effect on government expenditures, p. 21, NRC Goals for RWM, 1978, C9

8. Conflicts with other land use demands/ industrial activity density:
   i. to be considered in making criteria, p. 12-13, AECL Canada 1976, E2
   ii. information useful in site evaluation, i.e. for Carlsbad area, study looked at potash, oil, gas, agriculture and tourist industries, p. 11-13, USGS 4339-1, 1972, B2
   iii. study excluded some areas from consideration on the basis of conflicts with industrial development, p. 44, USGS 4339-6, 1973, B4
   iv. LPG storage, gas-oil pipelines - considered in criteria, Supplemental Areas, Kn GS 1972, B11
   v. in criteria, should consider the identification of potential restraints on adjacent land, i.e. building dams, etc. p. 30, NRC State Review/Analysis, Nureg 0354, 1978, C5
   vi. considered in criteria, Kehnemuyi, Battelle M, 1979, D23
   vii. should be considered in site selection, including potential for future development especially when large numbers of people would be attracted to the area, p. 12, BSPP SS Factors ORNL 1973, D2
   viii. possible restrictions on land use should be considered thoroughly in site selection taking into account needs for industrial, urban, agricultural or recreational activities, p. 48, IAEA SS Factors 1977, E11
   ix. anticipated conflicts involving land use will be minimized (criteria must be met), p. 6, Brunton and McClain, OWI/ERDA 1977, D20
   x. site selection - determination of suitability of broad regions in terms of utilization, p. 13, ESTP USGS and DOE 1979, D24
   xi. Winchester: one of the requirements of site suitability is availability from a human standpoint, p. IV 27-28, KBS Rydberg and Winchester 1978 and p. 170, Johansson and Steen, Ringhals-3, 1978, E10

9. Site Security:
   i. should be considered in site selection, p. 12-13, Canada AECL 1976, E2
   ii. consider requirements for site defensibility in site selection if applicable (goes for all AEC installations), Attachment: AEC App 6202, ORNL BSPP SS Factors 1973, D2

10. National Parks, Monuments, Wilderness Areas, etc.:
   i. study excluded some areas from consideration on the basis of conflict with National Parks, p. 44, USGS 4339-6, 1973, B4
   ii. exclude from consideration wilderness areas, wild and scenic rivers, National Parks and Monuments, unless an exception is made under the law for a rep, Kehnemuyi, Battelle M, 1979, D24

11. Disposal of excess rock/spoil:
   i. salt: considered in criteria, Supplemental Areas, Kn GS, 1972, B11
   ii. salt: problem should be researched, p. 9, NAS/NRC Bedded Salt 1970, A2
   iii. salt: for full scale rep, there will be 6 to 8 million tons. Can sell it or use it to backfill abandoned mines. The factors relating to the

disposal of excess salt should be considereddin site selection (cost consideration), p. 12-13, ORNL BSPP SS Factors 1977, D2
iv. considered a minor problem in site selection, p. 46-7, IAEA SS Factors 1977, E11
v. should be considered in site selection, Brunton and McClain, p. 6, OWI/ERDA 1977, D20
vi. for salt - sale, backfill abandoned mines, at sea, dissolution and injection in a low brine aquifer, p. 4-81, ES of WM of LWR Cycle, NRC 1976, C8

12. Buffer zone should be set up around the rep where subsurface activities are restricted:
i. of 1,700 ft radius, to assure thermal effects do not affect subsurface activities of other land owners and to prevent intrusions into rep by drilling, p. 3, AEC Lyons ES 1971, D6
ii. of about 1,000 to 1,500 ft radius to protect the rep from accidental drilling, p. 11, NAS/NRC Bedded Salt 1970, A2
iii. assumed, to preclude unacceptable penetrations. Width cannot be specified at this time, though probably will be on the order of 1 to 5 miles, p. 3, ORNL BSPP SS Factors 1973, D2
iv. zone big enough to guarantee the rep will not be damaged by outside activities - to protect rep from accidental breach by people, i.e. no drilling, blasting, ponding of water, etc, without thorough evaluation and authorization. Rep should be deep enough so there should not have to be restrictions on or surveillance of surface activities. p. 48, IAEA SS Factors 1977, E11

13. There are advantages in using an abandoned mine for rep:
i. reduces costs, p. 22, AEC Lyons ES 1971, D6
ii. Carlsbad study area is promising because it has mined out potash mines that may provide useful storage, p. 78, USGS 4339-1, 1972, B2
iii. advantage of salt as a host rock - there are many abandoned mines that may be suitable, p. 16, Considerations for HLWM, Gera and Jacobs, ORNL 1972, D5

14. Cost of rep:
i. must not prohibit the use of nuclear energy, p. 13-14, Deep Rock Klett, Sandia 1974, D8
ii. concern - sho is going to pay for it? both in up front costs and perpetual consts like health and safety services, monitoring, land use, p. 20-22; in criteria consideration should be given to short and long term cost of developing a rep to ensure that development costs do not dictate completion activities when it has been determined that technical confidence in the site has been compromised. Also responsibility in case of accident should be defined, i.e. the federal government should take it on, p. 46. NRC State Review/Analysis, Nureg 0354, 1978, C5

15. Off-site radiation exposures during operational phase:
i. concentrations of airborne radioactive particles from rep will be no greater than .1% of the permissible concentrations for exposure of a suitable sample of a population group, p. 18-22, NAS/NRC Bedded Salt 1970, A2
ii. will be no more than 0.1% of permissible concentrations as defined in 10CFR20, p. 4, AEC Lyons ES 1971, D6
iii. airborne concentration limits: alpha emitters - 1 pCi/cubic meter; beta and gamma emitters - 30 p. Ci / cubic meter. The

concentration limits will be redefined when sources are verified. p. 56, Conceptual Design Report 1977, D12

16. Local Sentiments/Public Opinion:

i. if technical considerations of site are adequate, then political considerations should enter site selection process, including consideration of local sentiments, p. 16; public acceptance of site should be ensured, p. 39, NRC State Review/Analysis, Nureg 0354 1978, C5

ii. in areas where groundwater is an important comodity, good aquifers near the rep site could adversely affect the availability of such rocks for rep due to public opinion.
- p. C10-12, ERDA/BNWL Alternative App C 1976, D18
- p. 41, IAEA SS Factors 1977, E11

iii. public acceptance of a rep depends on an absolute demonstration of the safety in terms understandable to members of the general public. "This may require a continuation of geologic research simultaneously over a number of potential rep sites and a willingness to reject any one of them if adverse geologic conditions are encountered during the research. Unless the inhabitants of areas where a rep may be located are confident of the thoroughness and objectivity of the research and are thus convinced of the safety of the rep, the rep design <u>cannot</u> be considered acceptable as being completely safe." p. IV32, KBS Rydberg and Winchester 1978, E9

17. Military Targets and Airports:

i. actual or potential military targets should be avoided in site selection, p. viii, NRC State Review/Analysis, Nureg 0354 1978, C5

ii. avoid areas near military or commercial airports and runways, Kehnemuyi, Battelle M, 1979, D23

iii. in site selection, consider relation to other AEC sites or defense installations and industrial complexes to avoid concentrations of important facilities in one potential target area (goes for siting of all AEC facilities, not just reps), Attachment:AEC Appendix 6202, BSPP SS Factors ORNL 1973, D2

18. Questions of Scale:

i. Is there a practical limit to the amount of nuclear waste that could safely be disposed of in Sweden? This is important in decision of whether nuclear energy is a promising long term energy alternative. Also, will risk to Sweden be greater if all European countries adopted a KBS plan? Have to keep in mind that if KBS plan is judged to be acceptably safe and practical, it may be adopted by other countries, p. IV 12-13; Soderbaum and Gillberg - safety of Swedish population is not only a function of what happens in Sweden. Should recognize a possible imitation effect of Swedish policy to expand or decrease nuclear power, Appendix p. 2; KBS Rydberg and Winchester 1978, E9

19. Really Miscellaneous Criteria:

i. consider in criteria: potentials and problems of locating rep with a reprocessing plant, p. 30; locate site away from international boundaries, p. viii; if technical considerations are adequate, then political considerations should enter into site selection process: local sentiments, zoning regulations and county and state statutes, p. 16, NRC State Review/Analysis, Nureg 0354 1978, C5

ii. reps should be provided in multiple locations in a time frame that assures nuclear power is a viable energy option, p. 6, OWI/ERDA Program Plan for NWTSP 1976, D19

iii. access to community services, i.e. housing, medical facilities, should be considered, p. 14, ORNL BSPP SS Factors 1973, D2
iv. advantageous to have access to normal community activities, p. 48-9, IAEA SS Factors 1977, E11
v. as far as practical should avoid existing easements and rights of way in site selection - i.e. power lines, railroads, highways, and especially oil, gas and petroleum products pipelines. Simply to avoid relocation costs. p. 12, BSPP SS Factors ORNL 1973, D2
vi. if rep is a demonstration facility with provision for tours, proximity to transient services becomes more important, p. 49, IAEA SS Factors 1977, E11
vii. should consider the risks of holding rep open for several decades, p. IV 31; one ecological imperative - avoidance of alternatives that have significant long run impacts upon living conditions within or outside of some specific region, p. 3 Appendix, KBS Rydberg and Winchester 1978, E9
viii. waste management system shall be within present capabilities of both technology and organizations, p. 6; also should take into account non-technological factors, i.e. affect of waste management system on civil liberties, (has not been adequately analyzed yet), psychological consequences of an accident, p. 21; non-technological elements play a key role in decision-making process to select a waste management system. Because the factual basis for decision is never complete or unequivocal, actions are often based on judgements by experts - attribution of credibility to these experts requires careful attention. p. 21, NRC Proposed Goals for RWM, 1978, C9
ix. nuclear issue should be regarded as moral rather than technological - social ethics is essential part of decision process, p. 3, Appendix Soderbaum and Gillberg, KBS Rydberg and Winchester 1978, E9
x. critical information needs: alternatives for equipment disposal should be explored, i.e. abandoning vs decontaminating, p. 2-6, NRC Info Base for Rep Design 1979, C10
xi. Lack of knowledge on which to base reliable predictions for thousands of years into future brings up the question of how the decision process should handle the uncertainties in the records. Also should consider whether methods accepted as safe will in fact be carried out. p. 74, Johansson and Steen, Ringhals-3, 1978, E10
xii. uncertainties are introduced into risk assessments because of uncertainties in projection of future societal habits and demography. p. 4-94, ES of WM of LWR Cycle, NRC 1976, C8
xiii. ownership of waste should be considered in site selection; also consider the geographical distribution of energy usage in making site selection criteria, p. 12-13, AECL Canada 1976, E2
xiv. assessment of quality and quantity of information available considered in criteria, Supplemental Areas, Kn GS 1972, B11
xv. as performance lifetime increases (i.e from 50 yr lifetime of reactor to 100,000 year of rep), the stability and character of the organizations charged with particular tasks becomes increasingly important, p. 3, NRC Proposed Goals for RWM, 1978, C9

PART V: GENERAL CONCERNS AND CONSIDERATIONS

1. On Criteria/General Objectives:

1. General Objectives:

i. it is desirable to select sites, if they are reasonably available, where the action of natural forces over time such as erosion, sedimentation, and crystallization can be projected to improve rather than reduce isolation of wastes over the time they represent a potential hazard. EPA Criteria for RW/ Rec for Fed Guidance, Fed Reg 1978, C2

ii. two objectives for radioactive waste management: (1) health and safety objective - radioactive materials should be managed so the health hazards are negligible; and (2) responsibility objective - radioactive waste should be managed so that trouble and concern to future generations will be minimized. Often there is a conflict of the two objectives, i.e. geologic disposal - no maintenance but also no absolute guarantee that none of the material will ever escape. Can only make detailed safety and probability analyses to show that even an improbable escape would not violate the safety criterion. p. 1-2, Canada AECL 1975, E1

iii. Objectives: long term isolation and efficiency of operation. p. 21, AEC Lyons ES 1971, D6

iv. Criteria on elements of the system having to do with long term effectiveness of the rep: intended to remove the burden from future generations of assuring the public health and safety from the disposal of this generation's wastes. Appendix, NRC Branch Technical Position 1977, C6

v. objectives of NWTSP: to provide disposal facilities at multiple locations in a time frame that assures nuclear power as a viable energy option. p. 6, OWI/ERDA Program Plan for NWTSP 1976, D19

vi. rep must be inaccesible and inviolable. After sealing it will be impossible to keep guard or even keep it marked for such a long time and you can't count on future generations to remember. de Marsily et al, Guarantee Isolation? 1977, E5

vii. waste management system shall be within the present capabilities of both technology and organizations, p. 6; the costs of the system should be borne by those who reap the benefits - us, p. 7; system should neither determine not contrain choices in other aspects of the energy system not be determined by them, p. 8; complete program shall be established concurrently with waste generation - the responsibility is ours and shall not be defered to future generations or unknown technologies, p. 9-10, NRC Proposed Goals of RWM, 1978, C9

viii. The recognition has been made explicit that present day society cannot commit its successors to the active management of wastes; we must take care of these wastes today with the best technology available in a way that will impose the fewest requirements for action on succeeding generations. p. D-5, ES of WM of LWR Cycle, NRC 1976, C8

2. On Criteria:

a. Their development:

i. the criteria for site confirmation (conversion to rep) will in part be developed through operation of the WIPP as a demonstration facility, p. 2:3; in most cases the nature of a factor can be indicated but not quantified a priori, p. 2:15, GCR 1978, D10

ii. will be developed through literature surveys, lab studies and field investigations, p. 12, Canada AECL 1976, E2

iii. site selection criteria - as new information and experience is gathered, some of these criteria may be relaxed and perhaps new ones added, p. 21, AEC Lyons ES 1971, D6

iv. As knowledge through experience and experiments develops, the criteria themselves become more specific. "We must look upon site selection criteria as guidelines that can grow, contract and be modified as we develop more

knowledge through research and experience." Kehnemuyi, Battelle M, 1979, D23
v. factors must be considered as tentative, subject to revision as new knowledge becomes available - these are based on current best knowledge. p. 3, BSPP SS Factors 1973 ORNL, D2
vi. criteria are qualitative and general - specifications (the numerical limits for each factor) are site specific and are usually determined as part of the site suitability investigation after selection of the study area. The specifications for the selection of a study area are determined by the evaluation of a few basic geological factors - for rapid screening of a large area. p. 1, Brunton and McClain, OWI/ERDA 1977, D20
vii. a number of policy decisions have not been made and accepted generally yet - whether waste should be reprocessed and whether retrievability should be provided for decades - these decisions will affect site selection criteria and the choice of waste form and canister. p. 6, EPA State of Knowledge 1978, C7
viii. reconcentration phenomenon - emphasizes the need to establish acceptability criteria for geologic isolation systems with great care. p. 1.8, Burkholder, Reconcentration phenomenon, BNWL 1976, D15
ix. No where in the world have siting criteria been established. But the parameters used by KBS in their safety analysis constitute an implicit set of criteria - a site is acceptable if characteristics are equal to or better than the assumed parameters (and if the model adequately represents reality and if the doses calculated with the model using actual parameters are acceptable.) p. 15-16, Johansson and Steen, Ringhals-3, 1978, E10
x. Proposed Goals: consideration shall be given explicitly to all aspects of the system including safety, environmental, organizational, institutional and implementational. For too long the focus has been solely on technological aspects but these cannot be separated from societal conditions, p. 5; values not easily quantifiable shall be actively considered - moral and ethical issues must be addressed and given whatever weight their significance demands, p. 5; the normal state of the waste management system shall be specified as precisely as possible to facilitate recognition of an undesired or unexpected event or condition. Need a clear and accepted standard of normality. Two factors that reduce the ability to specify normal state: (1) lack of knowledge of cause/effect relations that influence the system and (2) desire to retain ambiguity in order to promote the acceptance of the system. p. 11. NRC Proposed Goals for RWM, 1978, C9
xi. Panel does not make distinctions concerning the relative importance of factors and issues - the verification procedure itself should bring that out. p. 13, NAS/NRC Implementation of Standards 1979, A3

b. Their use:
i. for site selection in Los Medanos area - in most cases the nature of the factor can be indicated but not quantified a priori, since the number of acceptable combinations of factors under the multiple barrier concept is so large. p. 2:15, GCR 1978, D10
ii. need to develop rigorous ground rules for the selection of host rocks. p. 4-5, AECL Canada 1975, E1
iii. a comprehensive list of criteria will be developed and where possible quantitative values or ranges of values will be assigned to them. p. 12, AECL Canada 1976, E2
iv. Although it may be impossible to find a site where each feature of interest is at an optimum state, e.g. optimum geologic and hydrologic conditions, this may not be necessary. Instead a balance can be struck between geologic, hydrologic and engineered features of the rep system as a whole so that the entire system will ensure protection of people and the environment. p. 3, NRC State Review, Nureg 0353, 1977, C4
v. suggestion - preliminary site selection criteria should be fairly specific

and adequate and the criteria should be weighted as to importance, p. v-vi; NRC should specify mandatory factors over desirable, p. 29; in site selection criteria, need clear definition of what is meant,for example, by "multiple natural barriers", "significant radiological releases", "small fraction of MPC", " first point of reasonable accessibility", p. 29; Groups saw the failure to meet any single criteria as a reason to exclude the site from consideration - in this regard NRC should set the minimum level standards for a rep, p. 30; the groups also wanted a better definition of what was meant by "optimum site" - was it the best site, the ones that meet all the minimum criteria or what? There was a feeling that the optimum site concept would fall under site specific conditions. One group challenged the ALARA concept in relation to optimum siting approach - it would be difficult to meaningfully define ALARA, p. 39; NRC State Review/Analysis, Nureg 0354 1978, C5

vi. the specific needs for information to characterize a geologic formation and select a specific site will depend on the type of geology - criteria and procedures decribed would be used on an as-needed basis in order to minimize the time and costs required to find acceptable rep sites. p. 23.2, ERDA/BNWL Alternatives Vol 4, 1976, D17

vii. Due to the complexity of geologic systems, it is not feasible to derive strict criteria for the selection of a geologic site for a rep. Each site must be evaluated according to its own unique setting.
- p. C1, ERDA/BNWL Alternatives App C 1976, D18
- Foreword, IAEA SS Factors 1977, E11

viii. use the criteria to rule out obviously unsuitable areas. Some criteria are exclusionary (i.e. exclusion from consideration of Wilderness Areas, National Parks, though an exception might be made under the law if an otherwise suitable site were found in such areas), and others are discretionary, i.e. those that call for social evaluations. "Discretionary criteria have been well defined; the list is exhaustive..." Kehnemuyi, Battelle M, 1979, D23

ix. BSPP SS Factors - compilation of the factors which must be taken into consideration - an aid to the selection and confirmation of a site. The factors are a standard against which various individual sites can be compared and evaluated in order to identify the most suitable ones. "The discussions were intentionally formulated in completely general terms so that the considerations involved would be universally applicable to any bedded salt deposit. p. 1-2, ORNL BSPP SS Factors 1973, D2

x. IAEA report - guidance on factors that should be investigated/need to be considered to demonstrate the suitability of a site, p. 4; each site must be evaluated on its own merits - no strict criteria can be formulated for such a complex system, p. 2; requirements for a HLW rep may be more stringent than for a TRU rep (with less heat generation). Also if one finds a site with more favorable properties, may permit cheaper processing or packaging. It should be recognized that it is unlikely that any site will be found which incorporates all the advantageous factors. The acceptance or rejection of a site will inevitably involve the achievement of a balance between the advantageous and the less desirable factors. p. 16-17, IAEA SS Factors 1977, E11

xi. This document (Brunton and McClain 1977) provides a comprehensive list of geological criteria and factors that can be used to derive the specifications that will be applied to each step of a geological evaluation process, p. 1; Definitions: Criterion - a qualitative and general statement of a site requirement that must be met for disposal, applicable to any setting or region or rock unit (i.e. "expected igneous activity shall not compromise containment", p. 3) p. 7; Factors - the quantitative and qualitative items of geological or technical information that are used to determine the numerical value of each specification (i.e. under the above criterion on volcanic activity, factors to be considered are: geothermal gradient, magmatic activity, seismicity, tectonic history, volcanic activity, p. 3), p. 7; Specifications - are the quantitative (numerical) values required of a site in order for the criterion to be met - these are site specific and usually determined as part of the site suitability investigation after selection of a study area, p. 10, Brunton and McClain, OWI/ERDA 1977, D20

xii. it is necessary to consider such factors as changes in climate, in hydrology, erosion, tectonism, etc along with the short term considerations used in siting nuclear power plants: faulting, earthquakes, water motion, etc, p. 58; "Although we feel that the mechanisms discussed in this chapter are not likely to cause failure of containment for a judiciously sited waste rep, we believe that no rep can be judiciously sited unless these mechanisms have been considered in the evaluation of long term safety." p. 122, Considerations for HLWM, Gera and Jacobs, ORNL 1972, D5

xiii. "It should be recognized that these factors (of GCR) are desirable goals but in and of themselves may not be necessary to assure the safety of the rep. The consequences of real processes and postulated failure scenarios will be calculated and used in the assessment of site acceptability. The total system of multiple barriers must be considered in the evaluation of site acceptability and not simply isolated criteria." p. 2; the factors in the GCR are specific for WIPP and SENM - should not be applied to other regions or reps. p. 2; Letter from Beckner to Schueler, Dec. 1978, D13

xiv. site selection criteria and site evaluation requirements are designed to minimize the probabilities and consequences of geologic events or processes that would occur independent of the rep. p. 4-86,87, ES of WM of LWR Cycle, NRC 1976, C8

xv. "Often site selection seems to have been either geologically naive or directed politically rather than technically." p. 15, EPA State of Knowledge 1978, C7

xvi. Evaluation of potential environments - key early step is the selection of broad regions where multiple barriers appear to exist. Subsequent steps focus on successively smaller study areas to the point at which a potential rep site is identified, p. 23; site characterization - a detailed understanding of many physical aspects of site must be achieved before the site properties can be analyzed in comparison with selection criteria, p. 24; State of Knowledge: Do we adequately understand which geologic environments provide suitable combinations of natural barriers to nuclide migration? Models developed, assessing applicability. Do we adequately understand where appropriate host rocks occur in suitable environments? Moderate amount of data, developing models. Can we adequately determine when a geologic environment is <u>not</u> acceptable for further consideration as a potential rep? (1) do we adequately understand it? models developed, assessing applicability, (2) can we adequately measure/evaluate it? techniques known, developing equipment or verifying techniques; equipment available or techniques verified, improving sensitivity, range and/or reliability or applying techniques. p. 37, ESTP USGS and DOE 1979, D24

xvii. for desirable rep performance, need simultaneous optimization of several geochemical factors in delicate balance on both near field scale and longer distance scale. Winchester, Long term Geochem in Crystalline, 1978, E6

c. Which criteria or considerations are critical/most important and which are not important?

i. criteria ordered generally - public safety, engineering and geologic considerations, transportation and potential for future development, p. 87, Supplemental Areas, Kn GS 1972, B11

ii. most important general and basic considerations: hydrology, possible climatic changes, effects and rates of erosion, long term tectonic effects, seismic risk, p. 9, USGS 74-158, 1974, B8

iii. technical considerations should prevail in optimum siting of a HLW rep. If technical considerations are adequate (a site specific problem) then political considerations should enter into site selection process, like local sentiments, zoning regulations, county and state statutes. p. 15-16, NRC State Review/Analysis Nureg 0354 1978, C5

iv. It is not reasonable to expect facilities made by people to perform as primary barriers - therefore long term protection should be based primarily on other than people-made structures and systems. It is not reasonable to assume that any given barrier will continue to function over the required time - so multiple independent natural barriers should be provided. Appendix NRC Branch Technical Position 1977, C6

v. Rep should be in tectonically, hydrologically and mechanically stable geologic media. Other characteristics are selected to augment this stability. p. 23.1. Dominating factors: geologic stability, nuclide retention and potential for water intrusion, p. 23.15-17. ERDA/BNWL Alternatives Vol 4 1976, D17

vi. Physical and chemical properties are extremely important since they determine groundwater circulation, heat dissipation, radiation effects, mine and waste form stability.

- p. C6-10, ERDA/BNWL Alternatives App C 1976, D18
- p. 36, IAEA SS Factors 1977, E11

vii. Groundwater - critical element in establishing site suitability.

- p. C10-12, ERDA/BNWL Alternatives App C 1976, D18
- p. 41, IAEA SS Factors 1977, E11

viii. For host rocks with low adsorption capacity, it is imperative that the waste remain isolated from groundwater.

- p. C6-10, ERDA/BNWL Alternatives App C 1976, D18
- p. 39, IAEA SS Factors 1977, E11

ix. for salt - geometry, character, depth and stability are critical as is regional hydrology - extreme importance of keeping water away from rep. p. 4-6, OWI/DOE Salt Dep of US 1978, D21

x. occurence and control of deep boreholes is of special concern(for rep in salt), p. 10, ORNL Program Plan for BSPP , 1973, D1

xi. geologic features of site, especially those related to long term containment and operational safety, are considered to be the most important. p. 2, ORNL BSPP SS Factors 1973, D2

xii. no reliance placed on additional measures by people, p. 2; one should be very cautious in placing much reliance on manufactured barriers for long term containment, p. 16; Principal criterion - dry formation or one with little or no groundwater movement with a stable hydrological system that is projected to remain so for not less than about 100,000 years. p. 20, IAEA SS Factors 1977, E11

xiii. of the various factors, the most important is hydrological isolation to assure the waste will be safely confined within an acceptable radius of the rep - host rock should be virtually fault free and of low permeability. p. 4.4, HLWM Alternatives, BNWL-1900, 1974, D16

xiv. rep must be deep, no natural resources in the area, in geologically stable region. If the glass matrix is guaranteed indefinitely, then the choice of formation is less difficult. If the glass matrix cannot be guaranteed for millions of years, the greater the sorption capacity of the rock for the nuclides, the greater the confinement which may even be total. If there is no sorption capacity, the radioactivity will be released into the environment if water reaches the waste (no formation is entirely safe from this in the very long run). Neither the thickness of the confining layer not its low permeability are major factors in confining long lived nuclides over periods of time on the geological scale. Unless there is a total absence of hydraulic gradient during such long periods, the ion exchange capacity of the host rock vs each toxic element will be the most important factor. de Marsily et al, Guarantee Isolation? 1977, E5

xv. with predictive models, it is possible to identify the factors that will have the greatest effect on nuclide migration. p. 9-12, USGS ES Perspectives 1978 , B10

xvi. Hydrology - essential parameters are the amount of water flow and its velocity, p. III 11-13; plugging the shaft so it is as tight as original granite is essential for a successful rep, p. III 13-14; Barriers - formation, groundwater flow, canning, glass, clay buffer, retention in media - none of these are completely safe or complete failure, p. III 52; for nuclides with good retention, the lifetime of the canister and glass is unimportant. Most important parameters seem to be - water amount and velocity, rock void fraction, and the retention factors. It is important to know these parameters well. p. III 55, IV 56-57; Except for short lived nuclides - the geological medium is the only effective barrier, p. IV 31-32, KBS Rydberg and Winchester 1978, E9

xvii. site must be tectonically, hydrologically and mechanically stable and essentially free or isolated from moving groundwater - this stability is the primary element in maintaining waste isolation. p. 4-73, ES of WM of LWR Cycle, NRC 1976 , C8

xviii. containment by host rock is of paramount importance (security of people-made barriers is undemonstrated), p. 17, EPA State of Knowledge 1978, C7

xix. is site selection, minimize the potential development of aquatic pathways. p. 6-8, AD Little Assessment 1978, C3

xx. from sensitivity analysis - most important parameters are the time of canister disruption, leaching rate, groundwater transport time, retention factors, p. 149; turns out that dispersion is an important parameter, especially with short leach times - affects the concentration and length of release to recipient, p. 163, Johansson and Steen, Ringhals-3, 1978, E10

xxi. as performance lifetime increases (i.e. from 50 year life of reactor to 250,000 year life of rep) the stability and character of the organizations charged with particular tasks becomes increasingly important. p. 3, NRC Proposed Goals for RWM, 1978, C9

xxii. primary reliance on natural barriers of geosphere, p. 45-46; relative importance of factors and issues - the verification procedure of suitability of site and rep design should bring that out, p. 13; models - used for sensitivity analysis to identify factors requiring the most careful scrutiny, p. 34; possible flow of water by osmosis could be a very important consideration for a rep in bedded salt, p. 43-44, NAS/NRC Implementation of Standards, 1979, A3

2. Degree of Isolation Required/Timescale:

1. Period of Concern/Timescale for Rep:

i. while waste is still hazardous, on the order of 250,000 years, p. 2:17-18, GCR 1978, D10

ii. for RWM, need cooling and shielding (only for about 300 years) and containment for actinides for hundreds of thousands of years, p. 1, Canada AECL 1976, E2

iii. on the order of 250,000 years, USGS 4339-6, 1973, B4

iv. period of concern for rep is defined as 250,000 years, p. 5, USGS 74-194, 1974, B7

v. one million years, period set by BNWL based principally on lifetime of TRU isotopes, p. 7,8, USGS 74-158, 1974, B8

vi. required period of time(not defined); thousands of years, p. 1, AEC Lyons ES 1971, D6

vii. hazardous lifetime of waste (depends on type of waste), EPA, Criteria for RW/Rec for Fed Guidance, Fed Reg 1978, C2

viii. required life (not defined), p. 4-5, NRC State Review, Nureg 0353 1977, C4

ix. for long periods of geologic time, p. 1, OWI/DOE Salt Dep of US 1978, D21

x. up to a million years - until radioactivity decays to the same level as background, until decay renders wastes innocuous, Kehnemuyi, Battelle M, 1979, D23

xi. waste's hazardous lifetime, p. 3, BSPP SS Factors 1973 ORNL, D2

xii. as long as several hundred thousand years, Foreword; The duration of required containment of long lived wastes is an important question that must be answered to provide the time frame of reference for the assessment of any disposal option. One possible approach: time required for potential ingestion hazard of waste to approach the level of the potential ingestion hazard associated with the natural radioactive materials that had to be mined in order to produce the fuel - this a time period on the order of several thousand years. Problems with this approach: (1) the concentrated form of radwaste and (2) uncertainties about the environmental behavior of many nuclides. So it is prudent to design for containment for a significantly longer time. Another approach: observation of the variation with time of the potential hazard shows that up to about 100,000 years, a significant reduction in potential hazard takes place. After 100,000 years, the reduction becomes very slow and little additional change takes place over the following few million years. Therefore disposal can be appropriately designed on the basis of a containment time of the order of a 100,000 years or so. p. 10, IAEA SS Factors 1977, E11

xiii. until decay has reduced the waste to non-hazardous levels, p. 4.1; periods up to about one million years, p. 4.61, HLWM Alternatives, BNWL-1900, 1974, D16

xiv. on the order of several 100,000 years, p. 1, p. 58, Considerations for HLWM, Gera and Jacobs, ORNL 1972, D5

xv. 600 years for Sr 90 and Cs 137; I 129 poses a hazard for at least its half life of 16 million years; radium and selected actinides remain toxic for as long as 10 million years. "The variation in potential hazard from 100,000 to 10 million years is so limited and slow that is is virtually impossible to make a rational case for any specific length of required containment falling within that time interval. Either containment failure can be considered acceptable after a period on the order of 100,000 years or containment must be assured for periods of time exceeding at least five million years." (quoted in text from Gera, "Geochemical Behavior of Long-lived Radioactive Wastes", ORNL-TM-4481, 1975). But assuring containment for more than 5 million years in impracticable - reliable geologic predictions for that length of time are beyond present capability. p. 9-12, USGS ES Perspectives 1978, B10

xvi. about ten million years, when hazard of all the radioactive products formed in the reactor would be less than the hazard of the radioactive products destroyed in the reactor. Another time limit that has been suggested for Sweden: 10,000 years, since at that ime there may be a new ice age which would strongly change conditions for life in Scandanavia. p. II 9-10; several million years, p. IV 3-32, KBS Rydberg and Winchester 1978, E9

xvii. 250,000 years, p. 2-11, ES of WM of LWR Cycle, NRC 1976, C8

xviii. time during which waste is hazardous - maximum time scale: hundreds of thousands to millions of years. Special attention is given to the first thousand years when the levels of radioactivity are the highest, p. 1; predictions must be made over long periods: 250,000 years, p. 29, a million years, p. 36-40, EPA State of Knowledge 1978, C7

xix. estimates of the required duration of isolation range from a minimum of 1,000 years to over a million years, p. 7; the stable products of decay of some radwaste species are also toxic and thus represent a permanent hazard if present in sufficient concentrations, p. 7, ESTP USGS and DOE 1979, D24

xx. isolation - most fission products on a thousand year time scale, of some TRU elements on a million year time scale, Winchester, Long term geochem in crystalline, 1978, E6

xxi. for 20 to 30 half lives so many TRU require isolation for hundreds of thousands of years, p. 46; as long as required for decay to harmless levels, p. 67; time horizon - hundreds of thousands to million years is new for the societal decision-making process, p. 73, Johansson and Steen, Ringhals-3, 1978, E10

xxii. 100,000 years performance lifetime for rep, p. 3, NRC Proposed Goals for RWM 1978, C9

xxiii. for short lived nuclides, until decay to harmless levels, p. 17; (for longer lived - assume they escape), NAS/NRC Implementation of Standards 1979, A3

2. Degree of Isolation Required:

a. just isolation from biosphere, degree not specified:

i. p. 1, Canada AECL 1976, E2
ii. p. 1, AEC Lyons ES 1971, D6
iii. Foreword, p. 17, IAEA SS Factors 1977, E11
iv. p. 4.1, 4.61, HLWM Alternatives, BNWL-1900, 1974, D16
v. p. 1, Considerations for HLWM , Gera and Jacobs, ORNL 1972, D5
vi. p. 9-12, USGS ES Perspectives 1978, B10
vii. p. 2-11, ES of WM of LWR Cycle, NRC 1976, C8
viii. p. 46, Johansson and Steen, Ringhals-3, 1978, E10

b. total containment within rep or within an acceptable radius of the rep (no waste released to biosphere):

i. the suitability of the host rock is to be based mainly on its ability to effectively contain the wastes - to limit their movement to an acceptable radius from the site that precludes contamination of the environment for one million years, p. 8, USGS 74-158, 1974, B8

ii. Criteria must be met: waste cannot be allowed to enter the food chain, water supply or air supply, p. 13-14, Deep Rock, Klett, Sandia 1974, D8

iii. Goal of control of any type of hazardous waste is its complete isolation over its hazardous lifetime - use as many engineered and natural barriers as are necessary to achieve this. Locations should be chosen whenever practicable, if they are reasonably available, to enhance isolation over time - where the action of natural forces over time such as erosion, sedimentation and crystallization can be projected to improve rather than reduce isolation of the wastes over the time they represent a potential hazard if they were to enter the biosphere. EPA Criteria for RW/Rec for Fed Guidance, Fed Reg 1978, C2

iv. site is selected to assure there will be no radiation exposure to the general public, either through direct contact or by indirect means involving other portions of people's ecosystem. This fundamental requisite could be met in different ways in different geologic environments. p. C1, ERDA/BNWL Alternative, App C 1976, D18

v. In broad sense, there is one criterion: characteristics of site must be such that thorough and rigorous analyses and evaluations confirm that the waste will remain totally isolated throughout their hazardous lifetime. p. 3, BSPP SS Factors, ORNL 1973, D2

vi. of various factors, the most important is hydrologic isolation to assure that the waste will be safely confined within an acceptable radius of the emplacement zone. p. 4.4, HLWM Alternatives, BNWL-1900, 1974, D16

vii. required time of containment - several hundred thousand years. "The only realistic solution to such a problem is the utilization of a relatively deep geological formation which by its nature is capable of permanently preventing waste from entering the biosphere." p. 58, Considerations for HLWM, Gera and Jacobs, ORNL 1972, D5

viii. Demands made on barriers: one of levels of containment that could be chosen - absolute physical confinement with no leaks at all. This is not realistic considering the geologic history of the earth. Therefore one should not base a radiologic safety study of the rep on this concept. de Marsily et al, Guarantee Isolation? 1977, E5

ix. with the expansion of effort and viewpoints in the field of WM came the realization that total containment in the immediate waste rep probably cannot be guaranteed and the recognition that a series of independent barriers could offer the redundancy needed to compensate for the uncertainties in predicting long term isolation, p. 8, ESTP USGS and DOE, 1979, D24

c. Rep should remain essentially intact, not be breached, during hazardous lifetime of wastes:

i. dissolution must not breach rep while waste is still hazardous, p. 2:17-18, GCR 1978, D10

ii. p. 37, USGS 4339-6, 1973, B4

iii. probability of escape of nuclides to surface during hazardous lifetime should be negligible, Kehnemuyi, Battelle M, 1979, D23

iv. so consider the probability of breaches, i.e. by magma incursion or faulting over a million years, p. 36-40, EPA State of Knowledge 1978, C7

d. Nuclides should not enter the biosphere in amounts or at rates above certain limits:

i. hydrological analysis of the site must determine that fluid transport will not move hazardous material to the biosphere in amounts and rates above prescribed safe limits (not defined here).

- p. 9-11, NAS/NRC 1978, A1
- Kehnemuyi, Battelle M, 1979, D23

ii. Proposed criteria: no reasonably foreseeable events should result in significant releases of radioactivity to the environment at any time over the rep lifetime; radionuclide concentrations in any pathway to people, at the first point of reasonable accessibility should be ALARA and in any case not exceed a small fraction of the limits specified in 10CFR20, Appendix B, considering any credible failure or combination of failures in the system. p. 4-5, NRC State Review, Nureg 0353 1977, C4

iii. suggested modification - include chemical as well as radiological dangers in prescribed limits; set air and water standards for release from rep consistent with EPA regulations, NRC State Review/Analysis Nureg 0354 1978, C5

iv. multiple natural barriers should be capable of reducing the concentrations of radionuclides at the first point of reasonable accessibility in any pathway to people to ALARA levels, which, in any case, based on the failure of any single barrier in the system, shall not exceed a small fraction of the limits specified in 10CFR20, Appendix B, p. 17, NRC Branch Technical Position 1977, C6

v. if one chooses a host rock containing some water, it must be demonstrated that mobilized radionuclides would move at such a slow rate that significant quantities would never reach the biosphere, being confined to some acceptable zone in the subsurface.

- p. C10-12, ERDA/BNWL Alternatives App C 1976, D18
- p. 42, IAEA SS Factors, 1977, E11

vi. proper HLWM requires that the radionuclides will not appear in the biosphere in amounts that would constitute a biological hazard. p. 1, OWI/DOE Salt Dep of US 1978, D21

vii. site must be evaluated to ascertain that "radionuclides will not appear in biosphere in amounts that would constitute a biological hazard." Isolation means that disposal must not result in radiation exposure to the public, either from direct contact or via critical pathways in the ecosystem, exceeding applicable dose limits.

- Foreword, IAEA SS Factors 1977, E11
- p. 1, Brunton and McClain, OWI/ERDA 1977, D20

viii. Demands made on barriers: confinement but at what level? (1) total - unrealistic; (2) relative confinement such that rock allows some migration but introduces such a delay that no significant amount of radioactivity will reach the human environment (it will have disappeared by decay during migration); and (3) relative confinement conforming to the recommended standards of radiological protection - it is accepted that important quantities of radioactive elements will return to the human environment but the concentration in any medium that will reach people, at any moment, must be less than what the radiological protection standards allow. Here the rock formation ensures a delayed dilution of the radioactivity of wastes. de Marsily et al, Guarantee Isolation? 1977, E5

ix. Disposal in a "completely safe" way*: assurance in KBS report that rep shall never leak out radioactive material which would deliver doses to the population exceeding accepted levels at any time without limit, p. II 9-10; "Completely safe" was interpreted by KBS to mean that neither extreme happenings nor slow releases from rep shall lead to radiation doses which now or in the future exceed the dose limits currently recommended by ICRP - ICRP #26 concludes that a lifetime dose of 1mSv/year and person (100 mrem/year and person) would provide a sufficient degree of safety to the individual (taking into account risk of cancer and of genetic effects). For comparison (no standards have been set yet for rep) Swedish Radiation Protection authorities require that nuclear power plants be designed so that releases give rise to doses of less than 10 mrem/year for people living close to the plant and in any case not to exceed 50 mrem/year under special conditions. p II 22-23, KBS Rydberg and Winchester 1978, E9

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* The Swedish Stipulation Act passed in 1977 required the energy industry to show that radioactive wastes can be disposed of in an "absolutely safe" way before another nuclear reactor could get an operating license. The KBS report is meant to fulfill this requirement.

x. trend in radiation protection since World War II has been the lowering of limits - assume the trend will continue in centuries to come, p. viii; wastes must be stored in such a manner that leakage from rep will be inconsequential to public health over the times during which the wastes are hazardous, p. 1, EPA State of Knowledge 1978, C7

xi. also should consider that the stable products of decay of some radwaste species are also toxic and thus represent a permanent hazard if present in sufficient concentrations, p. 7, ESTP, USGS and DOE, 1979, D24

xii. research is needed on the development of criteria to determine acceptable levels of migration of radionuclides from and within disposal site. ACRS recommends that NRC be more active in conducting research on the development of ALARA criteria for the control of environmental releases and associated population exposures from disposal sites. Review of Health Physics Research by NRC, 1978, E4

xiii. suggestion of background level or below as possible limit for releases from rep, Incentive for Partitioning, Burkholder 1976, D14

xiv. ICRP#26 - recommends an upper limit of 10^{-5} to 10^{-6} health effects per person-year at risk for non-occupational doses. Risk limit applies to sum of risks from annual external exposures and 50 year internal dose commitments. Risk assessments will be systematically incorporated into standards and criteria for waste disposal if the primary standards are given in units of effective whole body dose equivalent; i.e. ICRP's recommendation is equivalent to an effective whole body dose of 7 to 70 mrem. This primary standard can be used to derive an operating limit: a maximum permissible concentration of various radionuclides in water, which can be used by radiological engineers in their design of rep. Desrosiers and Njoku, Risk Limit as Standard, 1978 or 9, D22

xv. The waste management system shall be capable of meeting all relevant radiation protection standards and criteria for both normal and accidental situations throughout its operation - for all the time during which there will be concern about radioactivity, p. 14, NRC Proposed Goals for RWM, 1978, C9

xvi. no current technology can be expected to be absolutely effective in the isolation of wastes. So decisions on waste management must assure that it doesn't pose an unreasonable risk to human health and the environment. EPA Criteria for RW/Rec for Fed Guidance, Fed Reg 1978, C2

xvii. ensure the concentration of radioactive substances which may reach the biosphere will be harmless (what is harmless is determined in radiation protection standards, p. 2) p. 5; no standards yet for rep but for power plants in Sweden, design for expected additional dose of less than 10 mrem/year for critical group; measures must be taken if dose exceeds 50 mrem/year, p. 6 Appendix, Introduction to KBS Report, Johansson and Steen, Ringhals-3 1978, E10

xviii. What is "absolutely safe"*? The usual practice is to define safe in nuclear activities by reference to the appropriate radiation standards, p. 7-8; no standards are yet set for rep, but for nuclear power plants exposure to critical group must not exceed 50 mrem/year and should rather not exceed 10 mrem/year p. 8; ICRP recommends an upper limit for additional doses to individuals of 100 mrem/year, p. 32-33; there is a wide range of

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*The Swedish Stipulation Act passed in 1977 requires that the energy industry show that radioactive wastes can be disposed of in an "absolutely safe" way before another nuclear reactor could get an operating license. The KBS Report is meant to fulfill this requirement.

opinion on the interpretation of "absolutely safe" - is it sufficient to show that the waste management methods will, with reasonable assurance, comply with the applicable standards and guidelines regulating exposures to radiation? p. 50; Swedish National Institute of Radiation Protection has adopted a general guideling of a maximum cumulative dose commitment of 1.0 person-rem/MW-year for the entire fuel cycle. Half of that - .5 person-rem/MW year - has been allocated to the reactor itself, the remaining portion to all the other steps in the cycle. Only a minor portion of that can be alloted to final disposition of wastes (exposures from reprocessing will be relatively large.) p. 69; Trends towards lower permissible levels could well continue, p. 69; also in regulations will probably be the concept of ALARA, taking into account the economic and social consequences of every measure for the limitation of releases, p. 70; USNRC recommends a value of $1,000 as justifiable expense to reduce the dose commitment by one person-rem p. 70; also should take into account the increasing amount of knowledge on uptake of nuclides - new data suggests that uptake of Pu, Np and Am at low concentrations from food may be several hundred times larger than previously thought - this could lead to a change in the MPC's in water and affects risk estimates by a similar factor, p. 72; also consider that different organisms in ecosystems are affected differently by radionuclides. Considering the uncertainties of this kind and the limited amount of information available on many important factors affecting routes of TRU elements in nature, perhaps a large gap should be left between the "worst cases" based on present knowledge and doses which might be acceptable. Size of gap would be related to the degree of uncertainty, the judgement to be done in the political process, p. 72-73; as yet no standards exist for waste management. In the standards for power plants it is not necessary to address the effects that occur far into the future. The collective dose commitment calculated by KBS is significantly larger than those potulated for reactors, even if the dose to an individual or a generation might be small, p. 77; SSI uses the concept of limited dose commitment over 500 years - below 1 person-rem/MW year for entire cycle to give less than 10 mrem/year average dose commitment to world population. Then can calculate the average world population dose for reps all of KBS and KBS variant type (or other type) for the 500 year nuclear age. (one way of looking at dose delivered.) p. 158; the standards of 1 person rem/MW year was developed considering short lived radionuclides from power plants. But calculated cases exceed this by a lot when doses are summed over tens of thousands of years or more. Also whether this standard should be applied to long lived radionuclides must now be discussed. p. 161, Johansson and Steen, Ringhals-3, 1978, E10

xix. fluid transport of short lived radionuclides must result in long enough transit time so radioactivity decays to harmless levels before reaching biosphere; decay of long lived nuclides may be insignificant over these time periods so the rate at which nuclides are carried to the biosphere must be low enough to be harmless, p. 17; Objective of properly designed and sited rep - to delay the release and transport of nuclides to the biosphere to essentially negligible or acceptably low rates and quantities, p. 6; Problem of how to verify that long term future performance of rep will continue to satisfy the standards - not by monitoring present emissions, but by ascertaining that rep is properly designed and located in appropriately selected formations, p. 1-2; For verification, at each step in the siting, design, construction and operation process, use the models developed and the data collected to predict the rates of release of nuclides to the atmosphere and aquifers ordinarily accessible to significant numbers of people. If the predicted value of release rates and concentrations, taking into account its uncertainty (which should be less with each step - increasing amount of data), is sufficiently below the prescribed standard, the process can go on to next step, until the rep is closed and sealed. p. 10. NAS/NRC Implementation of Standards, 1979, A3

3. Information and Understanding Needed/Predictions

1. Information needed and predictions to be made:

a. Data needed in general:

i. need more than educated judgements on suitability of site - there must be firm evidence of the astuteness of such judgements, as derived from a defensible data base. Kehnemuyi, Battelle M, 1979, D23

ii. for rep, all reasonable release mechanisms should be analyzed and their probabilities and consequences assessed - need a lot of data to do this, p. 122, Considerations for HLWM, Gera and Jacobs, ORNL 1972, D5

iii. It is desirable to conduct a thorough review of the scope and magnitude of data input used by KBS and the limitations this may bring to the quantitative reliability of the predictions. p. IV-17, KBS Rydberg and Winchester, 1978, E9

iv. need a lot of data and extrapolation on past experience with the probability of several phenomena in order to identify the events that could lead to rep failure, estimate their probabilities and calculated their consequences, p. 4-86, ES of WM of LWR Cycle, NRC 1976, C8

v. attempts to model the behavior of a geologic system must rely not simply on the best available data but on sufficiently good data that are truly pertinent and on consideration of all of the important factors that may affect the outcome, p. viii, EPA State of Knowledge 1978, C7

vi. what demands will be placed on the quality of technical and scientific evidence is a central question which must be settled by the responsible authorities and political officials, p. 5; reliability of models depends among other things on the quality of the input data, p. 12; In the review of the KBS plan and supporting documents, it was to be determined whether the data presented are relevant, whether all the relevant facts are known and understood, and whether all significant aspects of the problem were considered, p. 59-60, Johansson and Steen, Ringhals-3, 1978, E10

vii. Normal state of the waste management system shall be specified as precisely as possible to facilitate the recognition of an undesirable or unexpected event or condition. Need a clear and accepted standard of normality so need knowledge of the cause/effect relations that influence system operation, p. 11, NRC Proposed Goals for RWM, 1978, C9

viii. need special lab and field studies to evaluate the pristine characteristics of site, and large scale in situ tests on effects of rep on site, p.2; to ascertain whether rep will provide adequate isolation, need a data aquisition program and models based on thorough understanding of the phenomena involved, p. 2-3; critical to have knowledge of processes occuring among waste, canister, engineered barriers and geologic media - these factors must all be investigated and their contribution to waste isolation assessed with appropriate thoroughness, p. 7; the level of assurance depends on the adequacy of the scientific understanding of the phenomena involved, and the quality and extendibility of the data from which predictions are made, p. 8, p. 34; consideration in selection of site and waste form - confident understanding of past behavior, p. 9; at each step of rep development, (site selection, investigation, exploration, excavation, tests during excavation, tests during emplacement) data is acquired and used to predict releases - at each step the predictions are more confident and are used to decide whether to continue with development or to abandon the site as inadequate. Objective of lab and field experiments - to provide the scientific understanding of processes enabling the development of models that can predict with adequate confidence. Objective of large scale in situ experiments - provide supporting data and experimental confirmation of earlier expectations and predictions. p. 10-12; In order for prediction to provide adequate assurance of future compliance with standards, the evaluation of every conceivable circumstance that may adversely affect the rep's performance would be required, p. 13, NAS/NRC Implementation of Standards, 1979, A3

ix. especially important in predicting unlikely events is an accurate understanding of the interaction between the wastes and its surroundings, p. IV 8-9, KBS Rydberg and Winchester 1978, E9

b. on geology of site in general:

i. based on geologic history, general location and maximum effects of future geologic events can be predicted, i.e. faulting, volcanic and seismic activity, glaciation, etc., p. C12-13, ERDA/BNWL Alternatives App C 1976, D18

ii. by study of geologic history, structure, and general geologic framework of the site (must be known) it is possible to interpret the geologic processes that affect the region and to forecast the future impact of such processes on rep for long periods of geologic time, p. 3-4, OWI/DOE Salt Dep of US 1978, D21

iii. need to define the present geological characteristics of the formation and, based on past development, estimate future conditions, ORNL, McClain and Boch, 1974, D3

iv. Judgements need to be derived from a defensible data base. Need to know with precision the extent and nature of the prospective host rock and the nature of the surrounding rocks - core drillings are necessary. Kehnemuyi, Battelle M, 1979, D23

v. the demonstration of safety of rep in a salt dome requires very extensive geologic investigations.

- Gera, ORNL, Salt Tectonics, GSA 1972, D4
- p. 115-116, Gera and Jacobs, Considerations for HLWM, ORNL 1972, D5

vi. is is possible to investigate a formation, and by extrapolation of past events and other studies, to forecast the general characteristics and ranges of possible future changes in relevant geological, climatic and other factors, p. 16, IAEA SS Factors 1977, E11

vii. for site characterization and risk assessment, need detailed definition of geologic systems of site and vicinity and the properties of the host rock and confining media (thermal, mechanical, mineralogic and geochemical), p. 14-15; for risk analysis, need to predict disruptive events like faulting, volcanism, erosion, that might breach the rep, p. 16-17, ESTP USGS and DOE 1979, D24

viii. data most important for modeling - on structure and properties of rep geology - this information is site specific though there are representative generic data available. There are ongoing programs to extend the data base. p. 4-94, ES of WM of LWR Cycle, NRC 1976, C8

ix. information required to assure long term compliance with standards - for confirmation of site suitability need measurement of geologic conditions. p. 13, NAS/NRC Implementation of Standards, 1979, A3

C. on hydrology of site and surrounding region:

i. has to be enough information available on hydrologic history of the site region so that predictions can be made as to the long term hydrological isolation of the rep. p. 9-11, NAS/NRC 1978, A1

ii. need accurate knowledge of parameters of aquifers over- and under-lying site, p. 2:17-18, GCR 1978, D10

iii. thorough knowledge of hydraulic conditions in any basin considered for rep is absolutely essential, p. 145, USGS 74-158, 1974, B8

iv. need bigger and more complex studies to determine the acceptability of hydrologic structure around salt domes or anticlines (as compared to information needed on bedded salt sites.)

-. p. 23 AEC Lyons, ES 1971, D6
- p. 115-116, Considerations for HLWM, Gera and Jacobs, ORNL 1972, D5

v. need to carefully examine groundwater flow and retention potential for each site; Need to determine volume, direction and velocity of groundwater flow, and the porosity, hydraulic conductivity and hydraulic gradients of the host and other rocks along flow path. Data representative in 3 dimensions should be sought.

-. p. C10-12, ERDA/BNWL Alternatives App C 1976, D18

- p. 39, 42-43, IAEA SS Factors 1977, E11

vi. by study of hydrology of region, it is possible to interpret the processes that affected the region in the past and at present and also to forecast in general the future impact of such processes on rep for periods of geologic time, p. 3; need comprehensive geohydrological study of the entire region to establish the relationships, interconnections and fluid characteristics of all aquifers above and below salt, to identify recharge and discharge points, determine if there is or has been dissolutioning and the potential for future dissolutioning. Need to determine the direction, velocity and volume of flow. p. 5-6, OWI/DOE Salt Dep of US 1978, D21

vii. essential to determine the hydrological characteristics of the rocks that lie in close proximity to the salt. p. 5, ORNL Program Plan for BSPP, 1973, D1

viii. need to have in situ measurements of sorption (applicability of those done in lab is questionable), p. 23.17-22, ERDA/BNWL Alternatives Vol 4 1976, D17

ix. items that must be considered in evaluation of fluid-bearing rocks: effective porosity, total porosity, storage coefficient, water transport, water levels, recharge and discharge points, fluid density and temperature, dispersivity, p. 8 Brunton and McClain, OWI/ERDA 1977, D20

x. the possibility of groundwater reaching the waste and transporting it must be evaluated with maximum care. For rep in salt need even more special care since salt is soluble. p. 80-81, Considerations for HLWM, Gera and Jacobs, ORNL 1972, D5

xi. in order to be able to predict contaminant movement, the physical and chemical properties of the media that control transport must be known for a length of flow path sufficient to describe movement for the required containment time, i.e. need to know permeability, effective porosity, sorption capacity, hydraulic gradient and flow path, p. 8, USGS, ES Perspectives, 1978, B10

xii. the demonstration of safe isolation for a rep is a complex geochemical problem, p. III-15; important to know data on groundwater chemistry (including organic constituents) and the physicochemical nature of fracture surfaces and their coatings, p. III-16; data base must be sufficiently detailed to determine radionuclide migration by both diffusion and flow transport mechanisms, p. III-18; it is an extremely complicated task to evaluate the different geochemical processes which, however, is fundamental for predicting radionuclide migration; it is important to know well the most important parameters: water transport velocity, rock void fraction and the K_d values, p. III-55; the long term stability and predictability of water flow must be demonstrated, p. IV 8-9, KBS Rydberg and Winchester 1978, E9

xiii. need information to determine the suitability of broad regions in terms of suitable regional hydrology, p. 13; for site characterization, need detailed definition of the distribution of hydrological properties of rock masses at site including: water content, permeability, total and effective porosities, hydraulic dispersivity, 3 dimensional distribution of head, groundwater flux, velocities and directions, chemical characteristics of water including changes as it moves through various media and isotopic content, flux across land surface and unsaturated zones, and the relationship between surface and groundwaters. p. 14; need knowledge of the ability of system to contain, retard movement and disperse species present in water in order to predict nuclide concentrations in system as functions of time and space - for long term risk assessment, p. 17; need knowledge of the natural features and processes of region the influence radionuclide migration including chemical characteristics of water and rocks of region, especially as they relate to sorption, p. 16-17, ESTP USGS and DOE 1979, D24

xiv. need knowledge of permeability of host rock, p. 13; delay in transport of radionuclides by groundwater can be predicted from data on three key factors - actual rock permeability (primary and secondary), flow rate and sorption. The experiments to determine sorption have to be done under the same conditions as expected in rep (high temperature and pressure, strong solutions), p. 25-26, EPA State of Knowledge 1978, C7

xv. reconcentration phenomenon emphasizes the need to measure sorption equilibrium constants, Burkholder, Reconcentration Phenomenon, BNWL 1976, D15

xvi. need 3 dimensional data on fractures and flow pattern - this data is site specific. USGS - information needed as a minimum: permeability and porosity of media, hydraulic head gradients in 3 dimensions, sorptive characteristics along all flow paths, p. 113-114; GS of Canada - need integrated broad overview of fractures and fracture characteristics as they relate to permeability to determine the suitabilty of the site, p. 168; need thorough examination and testing of excavation itself (i.e. for major fractures that may dominate water regime), p. 172, Johansson and Steen, Ringhals-3, 1978, E10

xvii. evaluation of adequacy of site will require careful measurement of the following factors: directions, quantities and velocities of regional groundwater flow, hydraulic gradients and velocity in rock joints, shears and faults, fracture permeability and porosity, rock matrix permeability and porosity, total water content of rock mass, p. 17; careful investigation of hydraulic properties of any fracture system is a pre-requisite for predicting rep performance, p. 18; information on water content, hydrous phases and chemical properties of water will be important for calculating the potential for leaching of canister and waste and the degree to which subsequent chemical reactions may occur, p. 19; need to evaluate transient geologic conditions for causing changes in hydrologic regime: climatic change, tectonism, erosion, stream capture, glaciation, osmotic potential, p. 20; evaluation of geochemical processes is essential - need sufficient information to predict transport within and beyond rep to points of human access. Need to carefully evaluate: (1) hydrological characteristics that may regulate chemical transport; (2) chemical characteristics of fluid medium around waste including the concentrations of dissolved organic and inorganic substances, oxidation/reduction and acidity properties and the potential for forming chemical complexes; (3) the chemical characteristics of solid surfaces near and on large scale around rep including retention capacity, p. 21-24; for confirmation of adequate engineering design, need a comprehensive set of large scale hydrological tests of existing conditions. The importance of these data in verifying in situ conditions and reducing uncertainties in predictions based on modeling cannot be overstated. Also needed are tests on the hydrological effects on rock of excavation and rock reinforcement methods, p. 31; It is essential to have large scale field testing of chemical transport model(which is based on lab data), p. 32; need in situ measurements of porosity and permeability with realistic temperature and pressure conditions, p. 40-42; also need to obtain data on the dilation and contraction of fractures in response to changes in fluid pressure and temperature, p. 43; also need to measure osmotic potentials in the field - possible flow by osmosis could be important if rep is in salt, p. 43-44, NAS/NRC Implementation of Standards 1979, A3

d. on natural resources of the area:

i. no area should be considered if there is not enough information on it to provide a basis for reasonable analysis of its resource potential (this does not mean a full scale resource evaluation has to be done), p. 13-15, NAS/NRC 1978, A1

ii. information is needed on potash reserves and oil and gas potential in region, p. 4, ORNL Program Plan for BSPP, 1973, D1

iii. need information to determine the potential for denial of natural resources - part of determination of suitability of broad regions, p. 13; need to identify mineral resources that might serve to cause people to penetrate rep in the future, p. 16-17, ESTP USGS and DOE 1979, D24

e. regional stability:

i. need bigger and more complex studies on tectonic stability for site in salt domes and anticlines (as compared to site in bedded salt.) p. 23, AEC Lyons ES 1971, D6

ii. need to evaluate the structural stability of a formation for long periods into the future, p. 32, OWI/ERDA Program Plan for NWTSP 1976, D19

iii. to be done - microearthquake studies to determine the mode of occurence of recent earthquakes and to determine the Design Basis Earthquake for the facility, p. 3, ORNL Program Plan for BSPP 1973, D1

iv. must investigate tectonism, especially faulting, diapirism and microseismicity (can indicate deeply buried faults); also need to study the consequences of deformation, ORNL McClain and Boch 1974, D3

v. should be abel to predict future vertical displacement of a region - get indications from present movements, gravity anomalies, thickness of crust, p. 93-94, Considerations for HLWM Gera and Jacobs, ORNL 1972, D5

vi. need information on this to determine suitability of broad region, p. 13, ESTP, USGS and DOE, 1979, D24

vii. need to predict future stability - future seismicity is predicted on the basis of present day instrumental records, p. 121, Johansson and Steen, Ringhals-3, 1978, E10

viii. information needed for confirmation of site suitability - on seismic and tectonic activity. Document historical record of earthquakes in large surrounding region and look at the geologic record; in situ determinations of stress are also useful (historical record is short), p. 14; need to evaluate future tectonism for effect on hydrologic regime, p. 20; It must be demonstrated quantitatively that the proposed location of the rep is tectonically very stable. p. 26, NAS/NRC Implementation of Standards 1979, A3

f. Salt dissolutioning:

i. avoid areas of pronounced uplift/subsidence since it makes predictions of future dissolutioning uncertain, p. 2:18-19, GCR 1978, D10

ii. for rep in salt, careful studies must be made on present dissolutioning and future rates considering climatic changes, p. 26-27, USGS 74-158 1974, B8

iii. long term R&D needed to estimate future rates of subsurface leaching, p. 14-15, NAS/NRC Bedded Salt 1970, A2

iv. when groundwater is in contact with the top of salt beds - rep must be deep enough so projected rates of dissolution (taking into account climatic changes) will not uncover wastes while they are still hazardous.

- p. C10-12, ERDA/BNWL Alternatives App C 1976, D18
- p. 4-5, OWI/DOE Salt Dep of US 1978, D21

v. need to establish the nature and rates of dissolutioning within the study area, p. 6-7, ORNL Program Plan for BSPP 1973, D1

vi. need to establish the nature and rates of dissolutioning and how they would be affected by climatic or hydrological change, p. 4.63, HLWM Alternatives, BNWL-1900, 1974, D16

g. erosion and denudation:

i. areas of pronounced uplift/subsidence should be avoided since it makes preditions of future erosion uncertain, p. 2:18-19, GCR 1978, D10

ii. careful studies must be made in order to accurately predict the future denudation and erosion rates over the lifetime of the rep, p. 26-27, USGS 74-158, 1974, B8

iii. long term R&D needed to estimate the future rates of erosion, p. 14-15, NAS/NRC Bedded Salt 1970, A2

iv. need information to determine and define the rates and characteristics of past and present erosion, in order to establish the probable nature and extent of erosion during the next few 100,000 years, p. 3, Program Plan for BSPP, ORNL 1973, D1

v. must be investigated, ORNL McClain and Boch, 1974, D3

vi. all available information must indicate that no significant increase in the rate of erosion is likely in the future, p. 93, Considerations for HLWM, Gera and Jacobs ORNL 1972, D5

vii. need to evaluate future erosion for causing changes in hydrologic regime, p. 20, NAS/NRC Implementation of Standards 1979, A3

h. Salt Diapirism:

i. should avoid areas of pronounced uplift/subsidence since it makes predictions of future salt flow uncertain, p. 2:18-19, GCR 1978, D10

ii. if there is extreme surface relief, examinations must ascertain that diapirism is not incipient and geologic processes during the next few hundred thousand years will not create conditions conducive to such movements.

- p. C4-5, ERDA/BNWL Alternatives App C 1976, D18
- p. 35-36, IAEA SS Factors 1977, E11

iii. domes may be especially suitable if it is determined that they are now stable and flowage will not be renewed during wastes' hazardous lifetime, p. 4-5, OWI/DOE Salt Dep of US 1978, D21

iv. must demonstrate that formation has never experienced even the first stages of diapirism, ORNL McClain and Boch, 1974, D3

v. in order to evaluate the possibility of diapiritic processes affecting the long term stability of the rep, a thorough understanding of all aspects of salt diapirism is needed, Gera, ORNL, Salt Tectonics, GSA 1972, D4

vi. possibility must be investigated and the possible extent of deformation for several hundred thousand years must be evaluated, p. 101, Considerations for HLWM, Gera and Jacobs, ORNL 1972, D5

i. waste-rock interactions:

i. pure and homogenous beds are desired so as to lessen the uncertainties in predictions of thermally driven geochemical interactions, p. 2:19-20, GCR 1978, D10

ii. drill core should be analyzed physically and chemically to predict the nature of rock-waste interactions, p. 3, USGS 74-158, 1974, B8

iii. it is important to foresee <u>all</u> potentially important waste-rock interactions now before the waste is emplaced. Need a systematic procedure for identifying these interactions, not only intuition. p. IV 19-20, KBS Rydberg and Winchester 1978, E9

iv. waste-rock interactions must be understood and characterized before operational safety can be evaluated, p. 4-76, ES of WM of LWR Cycle, NRC 1976, C8

v. need knowledge of waste-media interactions including: mineralogical phase changes, crystal deformation, fluid release and migration, mineral solution, radiolysis, changes in water chemistry, release of gases, etc, p. 15, ESTP USGS and DOE 1979, D24

vi. waste-media interaction studies are designed to furnish data for the understanding and minimization of the probabilities and consequences of geologic processes that result from the presence of the rep, p. 4-86; data of most importance for modeling - nuclide interactions with geosphere pathways, (including sorption) - data is site specific though there is some representative generic information available. There are ongoing programs to extend the data base and evaluate the possibilities that interaction phenomena change with time as a result of the physical and chemical properties of pathway materials and radioactive nuclides, p. 4-94, ES of WM of LWR Cycle, NRC 1976, C8

vii. need information on the possibility of formation of volatile chemical compounds from a combination of fission products and brine, p. 2-5, NRC Info Base for Rep Design, 1979, C10

viii. information required to assure long term compliance - for confirmation of engineering design need information on waste-rock interactions, p. 13 ; also on the susceptibility of solid surfaces near the waste to physical and chemical alteration caused by the waste and on large scale change resulting from canister dissolution, p. 23-24, NAS/NRC Implementation of Standards 1979, A3

j. Homogeneity/impurities:

i. when hydrated minerals occur near the disposal zone, need to evaluate the rate of dewatering, the mechanisms and pathways by which freed water might escape or be recombined.
- p. C6-10, ERDA/BNWL Alternatives App C 1976, D18
- p. 39-40, IAEA SS Factors 1977, E11

ii. need to determine the quantities, distributions and dewatering characteristics of the hydrated minerals at the disposal level of study area, p. 11, ORNL Program Plan for BSPP 1973, D1

iii. need careful mineralogical analysis for hydrated minerals, ORNL, McClain and Boch 1974, D3

iv. site selection and evaluation will be based on the understanding of the effects of the following inhomogeneities on long term containment: interbeds, hydrated minerals, p. 4-75, ES of WM of LWR Cycle, NRC 1976, C8

v. for salt bed rep, for site testing need a drilling program with provision for continuous coring to detect all lithological breaks and with detailed (microscopic) study of core samples to determine their brine and solid inclusion content. Realistic estimates of water and brine content is critical to proper estimation of the fate of the canister and rate of creep, p. 18, EPA State of Knowledge, 1978, C7

vi. need information on the physical chemistry of dense brines that will be in contact with the canisters/waste, p. 2-5, NRC Info Base for Rep Design 1979, C10

vii. USGS - confidence in site comes from knowledge of lithological features on scales of a few meters to tens of kilometers, p. 170-171, Johansson and Steen, Ringhals-3, 1978, E10

k. Radiation/thermal properties and effects:

i. essential to establish the identity and magnitude of radiation effects on the host rock, p. C6-10, ERDA/BNWL Alternatives App C 1976, D18

ii. need information on radiation effects in salt, p. 15; need thermal analysis of transiant thermal conditions in and around the rep, p. 16, ORNL Program Plan for BSPP, 1973, D1

iii. recommendations for Lyons: need to study the possibility of metamict effect in salt, p. 10, NAS/NRC Bedded Salt 1970, A2

iv. for site characterization, need detatiled definition of geochemical properties of host rock and confining media and the effects of heat and radiation on those properties, p.15, ESTP, USGS and DOE 1979, D24

v. need firm information on the identities and amounts of radiolytic and thermal reaction products around waste canister from in situ experiments to help establish suitable burial and operating procedures, p. 4-76, ES of WM of LWR Cycle, NRC 1976 , C8

vi. need knowledge of mechanical integrity of host rock despite high temperature, p. 13, EPA State of Knowledge 1978 , C7

vii. most data needed for predicting temperature distribution and gamma radiation intensity are site specific and it should be possible to measure most of the parameters during the early stages of rep development, p. 2-2; need information on the explosive potential of unstable species formed by radiolysis, release of stored energy when salt is below annealing temperature, p. 2-5, NRC Info Base for Rep Design 1979 , C10

viii. in situ tests are needed on hydrogen generation by radiolysis, brine migration due to thermal gradient and to confirm the accuracy of thermal calculations, p. 17, ORNL Program Plan for BSPP 1973 , D1

ix. fracture forecast should include temperature effects, p. 124, Johansson and Steen, Ringhals-3, 1978, E10

x. for confirmation of site suitability, need information : (1) to determine if thermal stress is at an acceptable level and (2) detailed data on thermal conductivity, heat capacity, p. 16-17; for evaluation of adequacy of rep, need information on changes induced by rep - i.e. thermal effects creating a convective cell or fractures, p. 19-20; need information on the susceptibility of solid surfaces near waste to radiolysis and on the potential for solid and fluid media change on a large scale around rep under the imposed thermal gradients, p. 23-24; demonstration of rep stability must include consideration of thermomechanical and thermochemical stresses and the effects of thermal field on hydrology, p. 25; the variation of stability of rep must be shown to be acceptable under the most adverse thermal conditions generated, p. 28; need in situ tests to gather data on effects of radioactive and thermal loading, p. 31, NAS/NRC Implementation of Standards 1979 , A3

l. Surface water:

i. future behavior of streams/rivers must be predicted, p. C10-12, ERDA/BNWL Alternatives App C 1976, D18

ii. must be ascertained that surface water will not interfere with operation or jeopardize integrity of rep

- p. C10-12, ERDA/BNWL Alternatives App C 1976, D18
- p. 41, IAEA SS Factors 1977 , E11

m. boreholes:

i. need to identify all in area, p. 6, OWI/DOE Salt Dep of US 1978, D21

ii. need to identify all in area, and to evaluate materials and techniques for plugging, p. 10 ORNL Program Plan for BSPP 1973, D1

iii. need to identify all excavations in the area, p. 46, IAEA SS Factors 1977 , E11

iv. when picking site, premium placed on those where precise location of all abandoned drillholes and mines are known, p. 18-19, EPA State of Knowledge, 1978, C7

n. Mechanical properties and effects:

i. need to predict deformations that are likely to occur and evaluate the consequences. Need to measure physical properties of host rock - i.e. thermal properties, deformational properties, rock mechanical analysis. p. 11-13, ORNL Program Plan for BSPP 1973, D1

ii. need knowledge of the state of natural stress and bulk and mechanical properties, effects of stresses caused by thermal loading, and the mechanical effects of backfilling and subsidence, p. 15, ESTP USGS and DOE 1979 , D24

iii. need site specific analyses of the effect of slow subsidence on the integrity of overlying rock - for site selection, p. 4-82; facility stability studies are designed to furnish data for the understanding and minimization of the probabilities and consequences of geologic processes that result from the resence of the rep, p. 4-93, ES of WM of LWR Cycle, NRC 1976, C8

iv. need knowledge of the strength of the host rock and its mechanical integrity despite high temperature, p. 13, EPA State of Knowledge 1978, C7

v. need in situ information on structural behavior of salt under stress, p. 2-5,6, NRC Info Base for Rep Design 1979, C10

vi. fracture forecast should include mining effects, p.124, Johansson and Steen, Ringhals-3, 1978, E10

vii. information required to assure long term compliance with standards - for confirmation of engineering design, need information on the effects of excavation, p. 13; for confirmation of site suitability need information on ambient stress conditions, rock mass stability. Experimental determination of state of stress at site is of primary importance to assure the ability of the formation to remain stable under rep induced thermal and mechanical stresses, p. 15-16; demonstration of stability must include consideration of the following - stresses and displacements induced by excavation, p. 25; must demonstrate that mechanical stability is assured for a period significantly longer than that required for retrievability, p. 26; the variation of stability throughout rep lifetime must be calculated and shown to be acceptable under the most adverse thermal conditions generated, p. 28 ;tests needed on mechanical effects on rock of excavation methods and methods of rock reinforcement, p. 31, NAS/NRC Implementation of Standards, 1979, A3

o. Ecological effects:

i. need information on ecosystem processes and related radionuclide behavior - needed for risk assessment, p. 16, ORNL Program Plan for BSPP, 1973, D1

p. Criticality:

i. need careful quantitative analysis of the possibility for the formation of a critical mass in rep, p. III 45, KBS Rydberg and Winchester 1978, E9

q. Gas transport:

i. need in situ data on bulk bedded salt permeability to gases - crushed salt before reconsolidation will not significantly retard gas migration, p. 4-82, ES of WM of LWR Cycle, NRC 1976, C8

ii. need in situ tests on salt permeability to radionuclides, p. 17, ORNL Program Plan for BSPP 1973, D1

r. Structure (see also Hydrology and Homogeneity sections of this chapter)

i. confidence in site comes from knowledge of structural features on scales of a few meters to tens of kilometers. Many critical features are subtle, like small faults and fracture systems, p. 170-171, Johansson and Steen, Ringhals-3, 1978, E10

ii. for confirmation of site suitability, need information on faults and other geologic structures: detailed high quality maps, 3 dimensional data, p. 15; need careful measurement of fracture size and spacing for evaluation of adequacy of rep (affects hydrology), p. 17, NAS/NRC Implementation of Standards 1979, A3

s. Volcanic activity:

i. for confirmation of site suitability, need information on volcanic activity - geologic record of history and frequency over surrounding region to determine the probability of future activity, p. 14; need detailed data on geothermal gradient, p. 16-17, NAS/NRC Implementation of Standards 1979, A3

2. Can predictions be made? Inadequacies in data and understanding:

i. it is the view of many geologists that disposal in suitable geologic formations represents the most predictable long term containment of radwastes, p. 4; can reasonably project the continued integrity of some formations for at least 100,000 years. p. 16, IAEA SS Factors, 1977, E11

ii. the selection of a suitable formation for a rep will require the capability of making some kind of geologic predictions for the time period covering the next million years. But geology up to the present time has been a science with limited predictive capability. So far no consistent comprehensive theory capable of explaining the major geologic features of the earth has been available. Recently - new theory of plate tectonics has been developed. If this theory survives the test of reinterpretation of detailed knowledge of continental geology in agreement with moving plates, then "geologic predictions should become feasible." At present we can evaluate the upper limits for order of magnitude of geologic changes expected in the next few 100,000 years (based on the present rate of geologic processes and the magnitude of changes that have occured in the recent geologic past, though there is much disagreement in the literature even about the best known of all geologic periods - the Quaternary.) p. 58-59; Conclusion: the evaluation of a formation for long term stability can be improved by better understanding of the mechanisms responsible for large scale motions of the earth. If the hoped-for development of recent discoveries furnishes a successful explanation of world tectonics, it is reasonable to expect that understanding of local phenomena will follow. The same considerations apply to the problem of future climate - no serious predictions are possilbe until we have actual knowledge of the causes of change. p. 81, Considerations for HLWM, Gera and Jacobs ORNL 1972, D5

iii. the predictive aspect of geology, a new scientific discipline, may have to be developed as the international community gets involved in waste management. p. 15, AECL Canada 1975, E1

iv. An approach to assessing containment capability of a formation: quantify the probability of occurence of disruptive events and their consequences. This approach does not seem realistic to the authors since no geologist can seriously give reasonable figures for these probabilities. For example, our knowledge of the mechanisms of faulting does not suffice to provide an answer on the probability of faulting in a certain area and the past stability of an area is not sufficient to assess the probability coefficient for the future stability of the same area. It also must be noted that sorption phenomena are not well understood. de Marsily et al, Guarantee Isolation? 1977, E5

v. conservative limits may need to be set initially on thermal loading of rep until problems are resolved on the effects of thermal output on whole systems. The uncertainties associated with hot wastes that interact chemically and mechanically with rock and fluid system appear very high. p. 6; Assuming containment for five million years is impracticable - reliable geologic prediction for that length of time is beyond present capability. Predicting future rates of geologic processes on those of the past has a high degree of uncertainty. Also long term prediction in the biological and earth sciences is unreliable and impossible to perform with high confidence limits because of the great complexity of possible interactions among processes, both identified and unidentified. The track records of prediction of geologic response to people's disturbances over 100 years is not particularly good (i.e. responses to construction of tunnels, etc.) So predictive models are invaluable tools for the analysis of the problem and for identifying factors that are likely to have the greatest effect on nuclide migration. However models have unpredictable components. p. 9-12; Conclusion: construction of a rep and emplacement of waste will initiate complex processes that cannot at present time be predicted with certainty.

The inability to predict can be offset by use of the multiple barrier approach. p. 13, USGS ES Perspectives 1978, B10

vi. A perspective on the current level of geologic knowledge is helpful in trying to reach a judgement concerning the feasibility of geologic disposal. Modern geologic development - only since the 1950's and has been rather low on the priority scale at that. So the level of certainty in geology is much less than it is for, say, physics. Now geology is in a period of rapid development - our beliefs in the mechanisms should be tempered with the realization that new evidence may arise in the near future showing them to be false. As of 1978, there is only poor scientific understanding of many earth phenomena, i.e. weather, etc. In evaluating nuclear power impacts on the earth, it is useful to deep such questions on the level of uncertainty in knowledge in mind to maintain perspective in judgement. p. IV 9-11; We would like to make a judgement on whether some of the geologic basis for the KBS design might be subject to change in the near future as the field of earth sciences advances - in part a question of methods and procedures of geoscience as well as a question of fact as understood at present. Winchester recommends that an independent judgement be obtained on this subject. p. IV 18-19; Winchester: "As an earth scientist,I feel strongly that we have much less than a desirable amount of information about earth properties in order to be confident of success in an undertaking such as the disposal of HLW in crystalline rock." p. IV 43; Rydberg: Can the KBS plan be carried out so radiation doses to people in the future do not exceed the levels we accept today? "Since this cannot be answered with absolute certainty until the scheme has been tested in practice, one has to rely on present scientific knowledge, in the belief that the laws of nature will be the same in the future as they have been during the past billion years, plus some imagination with regard to unlikely events." Because the level of knowledge in some areas is unsatisfactory, like geochemistry, provide multiple barriers. p. IV 59-60; Soderbaum and Gillberg: the uncertainties with regard to future radiation standards are just part of the total spectrum of uncertainties related to nuclear energy systems - in geologic knowledge, metallurgy, effects of the existence of waste on social systems, etc. p. 2-3, Appendix. KBS Rydberg and Winchester 1978, E9

vii. knowledge of the future is imperfect, but studies indicate that no failure in containment will result in disaster to life on earth or even to people, p. 2-11, ES of WM of LWR Cycle, NRC 1976, C8

viii. With the expansion of effort and view points in the field of waste management came the realization that total containment in the immediate rep probably cannot be guaranteed - series of independent barriers could offer the redundancy needed to compensate for the uncertainties in predicting long term isolation. p.8; the responses of most media to thermal, chemical and radiation stresses are insufficiently known. The development of a rep requires an improvement in the state of the art in most areas of earth sciences, p. 8; During the process of acquiring enough information to move forward, some issues may be totally resolved; however many others will not be completely resolved and for them enough information must be gained to confidently assess the implication of these knowledge gaps and to place bounds on each of the earth science variables. p. 19; "Our ability to predict natural events and processes over the lifetime of the rep is subject to considerable uncertainty." p. 22; ESTP USGS and DOE 1979, D24

ix. EPA recognizes that there may be significant uncertainties and controversy regarding geologic knowledge, especially as relates to the ability to provide long term containment for radwastes, p. v-vii; there is no experience or empirical data base for long term sealed underground storage of such materials, p. 1; One must consider a variety of geochemical reactions with host rocks over a 100 to a million years - but there is little knowledge on how nuclides react with real rocks at the temperature and pressure expected, p. 2; The reliability of predictions falls off dramatically with time: beyond a few hundred years, estimates are rather uncertain, beyond 10,000 years they are marginally reliable, and beyond a million years they are so poor they are little better than guesses, p. 2; Major discrepancies are possible between the available data and those needed to bear directly on what the models are trying to determine - need to take this into account, p. 8; There is not enough information to be able to predict the continued integrity of people-made barriers of waste form, canister and overpack - so the Panel assumes that near-in stages of containment cannot be relied upon to effects any significant retardation of the release of HLW for times longer than a decade. p. 10-11; We are far from the capability to predict with accuracy the behavior of rocks other than salt in response to elevated temperature, p. 13-14; for risk analysis, there is the necessity to forecast over long periods (250,000 years) with uncertain information, especially about hydrological characteristics of the site. The decision-maker must be made cognizant of the degree of uncertainty inherent in forecasts, p. 29; risks of disruptive events may have to be quantified in order to make decisions but extreme numerical uncertainties are attached to most, p. 35; There is great uncertainty on the long term effectiveness of shaft seals and another risk for which no trustworthy probability estimates can be applied is the intrusion at some future date by people in search of minerals - the unpredictability of people far outstrips that of most imagined geologic hazards. p. 35-36; The probability of magmatic intrusion or of the occurence of earthquakes and faults may be astronomically low in some regions but numerically uncertain in any case. About all we can confidently say is that the risk is much less in some regions and we can estimate the relative order of danger. For earthquakes there is a lack of systematic data so there is little reason for confidence in forward predictions covering a million years, p. 36-40; it is unpredictable where uplift will occur and how one can make an orders of magnitude conjecture concerning the probability of the rep being uplifted and uncovered by erosion is beyond the Panel's ability to resolve, p. 36-40; Conclusion: it seems clear that the uncertainties in forecasting the behaviors of conceptual reps are due principally to inadequate knowledge of the relevant mechanical, radiochemical and hydrological properties of the candidate rock types - most of these can be measured by well established methods, p. 43-45, EPA State of Knowledge 1978, C7

x. There is insufficient historical data on seal performance to allow predictions of long term behavior, p. 2-3; analytical techniques for predicting fractures and effective premeabilities is a critical technology needing development, p. 2-3,4; NRC Info Base for Rep Design 1979, C10

xi. there is insufficient information to predict the longevity of cansiters, but enough data to indicate that this time may not be very long, Volume III, Appendix D IV, AD Little Assessment 1978, C3

xii. there is insufficient data to predict the continuing integrity of the glass or of the canister, p. 12-15; also retention has only been measured in the lab and it is uncertain how well data represent actual conditions, p. 12-15; Can reliable predictions be made for thousands of years ahead on how different technical designs will behave? Lack of knowledge brings up the question of how the decision process should handle the uncertainties in the records, p. 74; Glass leach rates can be considered very tentative - there is little basic science data available to predict the long term leaching of waste forms or to estimate the occurence of cracking, p. 100-102; Also the experiments done on glass have been limited in time - all extrapolations of glass behavior over thousands of years are done from these limited data, p. 104; American Physical Society - knowledge is inadequate to place reliance on glass as a principal barrier, p. 104; Cansiter - new types of corrosion do occur and it is hard to predict corrosion in a new environment, p. 105-6; There are many uncertainties concerning the lifetime of the canister, p. 109; Need for data on hydrological characteristics of site severely taxes the data base and the technology for generating it. Most available data have such large error limits that their usefulness in predictive models is limited, p. 114; Hard to predict dilution, p. 125-6; Retention is a complex phenomena and current data is a good start but not adequate for conditions to be encountered in rep. Because of the uncertainties, inclusion of retardation terms in models cannot be expected to lead to very useful results. There is no reliable basis for making even very general estimates for K_a values for fracture systems in granite. Uncertainty about retention values are large, p. 130-3; Uncertainty and lack of knowledge concerning nuclide pathways in the biosphere - we do not know all the pathways and the pathways can change, i.e. people can change their eating habits. p. 135-8, Johansson and Steen Ringhals-3 1978, E10

xiii. Proposed Goals for RWM: the existence of scientific, technological and organizational uncertainties in any waste management system shall be made explicit - the system will be implemented in the face of admitted uncertainties. These will be resolved through some procedure like expert opinion, limited testing, which gives confidence despite the uncertainty. p. 6; Because the factual basis for decisions is never complete or unequivocal, actions are often based on judgements by experts - attribution of credibility to these experts requires careful attention, p. 21; Because inherent uncertainties permeate almost all subject matters on which the regulation of radwastes is based, NRC should treat its regs as working hypotheses to be verified with practice and testing, p. 22, NRC Proposed Goals for RWM, 1978, C9

xiv. considerations in the selection of sites and waste forms: uncertainties and additional variables introduced into predictions by the disturbance of the inherent integrity of the formation caused by the presence of the rep - must be taken into account, p. 9; The relevant geochemical properties and substances present that should be investigated will differ among media and are not well understood at present, p. 23; The properties of subsurface media and their response to excavation and other perturbations are understood poorly by most engineering standards but minimum performance of rep must be predictable with a high degree of confidence for time periods of unprecedented duration in terms of normal engineering experience - so exceptionally cautious approach should be used. p. 29-30; Much is known but certain important questions must be answered before the adequate performance of a rep can be assured, p. 37; i.e. a number of recent reports have concluded that present understanding of the stability of canister and waste form is not sufficient to rely on these alone as the principal long term barriers to release, p. 45; Among the most important limitations in our knowledge: geochemical uncertainties. Geochemical requirements are stringent but much less is known about these processes than about the relevant geophysical processes. p. 48-9, NAS/NRC Implementation of Standards, 1979, A3

3. Suggestions on Research that is needed:

i. on thermal stress, backfilling and sealing techniques, waste handling techniques, p. 4, Canada AECL 1976, E2

ii. research is needed to develop new techniques for borehole plugging, p. 10, ORNL Program Plan for BSPP 1973, D1

iii. studies are needed on the long term behavior of waste and the possibility of people penetrating rep in the future, ORNL McClain and Boch 1974, D3

iv. Research needs: (1) on behavior of rock salt, centering on its high solubility. The question of whether the workings of a mine in salt can be predicted to stay dry will have to be faced; (2) on media other than salt; (3) to develop more tools to evaluate potential reps; (4) on effects of rep and waste on environment around rep; (5) on the uncertainties involved in geologic predictions over long time spans, p. 12-13, USGS ES Perspectives 1978, (B10)

v. Research is needed on groundwater chemistry and physicochemical nature of fracture surfaces and their coatings at depth, p. III 16; on alterations of mineral precipitates or coatings on fracture surfaces with elevated temperature as well as the resulting changes in permeability and retardation capability, p. III 16; on retardation of actinides and on the possibility of complexation reducing retardation, p.III 18; on sorption in fractured rock and with saline groundwater, p. III 19; on the possible hydrogen embrittlement of Ti and on the dissolution of glass - a field where much research ought to be done, p. III 30; retention - because of its importance it is necessary to study the field more carefully and extensively than has been done. Measurements should be made for site rock types and under appropriate groundwater and other geochemical conditions, p. III 41, KBS Rydberg and Winchester 1978, E9

vi. need improved understanding of mine stability, waste-rock interactions, waste leaching by groundwater, p. 9; ESTP USGS and DOE 1979, D24

vii. studies are needed on ceramics and glasses under expected conditions of temperature and pressure and high ionic strength solutions, p. 6-7; research needed on the behavior of rocks other than salt under elevated temperature conditions - lack of knowledge can only be alleviated with much more work (need to develop lab procedures, testing machines, etc) p. 13-14; Much more must be known about thermoelastic expansion, thermal conductivity, permeability, especially as they are affected by thermal cracking, p. 13-14; some impermeable, chemically inert cement to grout and plug boreholes must be developed, p. 18-19; need data on sorption obtained under the same conditions as are expected (high temperature and pressure, strong solutions), p. 25-26; research is needed to determine the extent to which a rep is an open system, i.e. access to fluids via cracks, p. 43-45; several questions like the determination of real permeabilities in rocks at site or nature of long term monitoring system - answers must await the invention of a new technology, p. 43-45, EPA State of Knowledge 1978, C7

viii. critical technology needing further development: shaft and borehole sealing materials and techniques, safe methods of waste emplacement and retrieval, drilling techniques that minimize disturbance to rocks, monitoring systems, p. 2-3,4; critical information needs: on long term behavior of crushed salt backfill (will it fuse?), p. 2-6; design option studies are needed for information to be able to choose a monitoring system, waste/container properties, backfill and sealing technology and structural design parameters, p. 3-1,2, NRC Info Base for Rep Design, 1979, C10

ix. research is needed on development of criteria to determine acceptable levels of nuclide migration from and within rep, on development of monitoring procedures to detect and evaluate migrations, and on the development of regulatory procedures to correct any problems. Research is underway on methods of coping with major accidental releases of radioactive materials. Review of Health Physics Research by NRC, 1978, E4

x. reconcentration phenomenon emphasizes that research is needed on sorption equilibrium constants and on actinide migration phenomena, as well as on the leaching behavior of waste. Burkholder, Reconcentration Phenomenon, BNWL 1976, D15

xi. research is needed on leaching of waste glass considering all parameters (glass composition, groundwater composition and flow, time, radiation, temperature and pressure), p. 12-15, p. 100-101; need complete investigation of canister corrosion based on groundwater flow and composition data, p. 105-6; Johansson and Steen, Ringhals-3, 1978, E10

xii. research is needed - testing of borehole seals in situ, p. 30; R&D is needed to allow reliable determination of state of stress and rock strength in situ (much uncertainty in current methods), p. 37-8; substantial amounts of additional research on in situ salt dissolution must precede emplacement of wastes in a salt rep, p. 44; In view of the multiplicity of geochemical effects that must be considered and the limited time and effort which can be expended on them, new research approaches will be needed for predicting the behavior of complex geochemical systems, p. 46; Areas that need more attention: interaction with organic matter or micro-organisms, precipitation of new solid surfaces, natural chemistry of groundwater, p. 46; urgent need for better geochemical knowledge concerning transport, p. 47, NAS/NRC Implementation of Standards 1979, A3

4. Information Gathering (see also Information Needed):

1. Information gathering techniques used should be nondestructive to the extent possible and host rock integrity should not be compromised by them:

i. use of non-penetrative techniques for information gathering is advised where possible and all information boreholes would require extraordinary care in sealing and plugging. Preference should be given to the site on which you can gather the most information with the least disruption of the integrity of the site. p. 4-5, NAS/NRC 1978, A1

ii. Proposed criteria: geologic medium should be such that use of state-of-the-art techniques for site exploration will not compromise site effectiveness, p. 4-5; testing and exploration techniques used in the selection and/or development of the site should be such that their potential effects on the long term integrity of the site will be insignificant, p. 6; for site evaluation, need to consider the results of geological investigations to a radius of 200 miles and should consider the potential effects and implications of such investigations on the integrity of the barriers, p. 5-6, NRC State Review, Nureg 0353, 1977, C4

iii. site area evaluation techniques - one or several exploratory boreholes in areas slightly distant from chosen site will have to be drilled - as their location is known it/they can be carefully plugged afterwards, p. 23.14, ERDA/BNWL Alternatives Vol 4 1976, D17

iv. research is needed on minimizing uncertainty through field observations, in situ measurements of hydrological and geological parameters (without jeopardizing site integrity), p. 29-34, EPA State of Knowledge 1978, C7

v. R&D will provide new capabilities in geophysics, geochemistry and computer modeling which will aid in site selection and evaluation with a minimum of test drilling, p. 9; site evaluation - investigative techniques are generally those that can be performed without disturbing the potential site, p. 13, ESTP USGS and DOE 1979, D24

vi. The necessary structural integrity and lithologic homogeneity cannot be assumed simply through detailed surface mapping and coring (especially if the number of boreholes is limited to preserve integrity)p. 170-1; remote exploratory techniques are being developed and should be applied as soon as practical - i.e. high resolution seismic and acoustic techniques (to detect fine scale structural and lithologic variations), electric and electromagnetic methods (sensitive to the distribution of water), short pulse radar and continuous wave interferometry (use limited to high resistivity rocks like salt), borehole to borehole electrical techniques. These techniques are non-destructive and the critical need to map the original subsurface structure, lithology and groundwater regime warrants the aggressive utilization of such techniques where appropriate. p. 171, Johansson and Steen, Ringhals-3, 1978, E10

vii. thorough scientific and engineering investigation of site should be made "employing techniques that do not significantly impair the site." p. 10; It is especially important that the integrity of the site not be jeopardized by exploration - asset to use non-destructive measurement techniques, p. 15; there is a definite need to develop new field techniques for measuring permeability, ideally without impairing the integrity of the site, p. 40-42, NAS/NRC Implementation of Standards, 1979, A3

2. When information should be gathered/for what purpose:

i. information on the geometry and the physical, chemical and mineralogical properties of the prospective site must be gathered before development of the site. p. 4-5, NAS/NRC 1978, A1

ii. various stages of information gathering: (1) regional evaluation,

(2) local evaluation (for more detailed basin-wide information so one or more small local areas can be chosen), (3) site area evaluation - if all site area data continues to mesh favorably, characterization process may have focused on a potential rep site. In the absence of any major discrepancy between newly aquired data and those projected for site, next step can be taken - install shaft and begin excavation of pilot plant. However data acquired within disposal zone itself may ultimately indicate against final approval of site. Therefore the site characterization process should continue and overlap with implementation. p. 23.10-23.14, ERDA/BNWL Alternatives Vol 4, 1976, D17

iii. many of the data needed for models are site specifica and it should be possible to measure most of the parameters during the exploration and the early stages. p. 2-2, NRC Info Base for Rep Design 1979, C10

iv. information needed for confirmation of site suitability and adequate rep design - special lab and field studies, and in situ tests to study the effects of rep on site done through the operational period, p. 2; analyses and field studies - objective is to provide scientific understanding of processes so that models can be developed that can predict with adequate confidence; large scale in situ tests - objective to provide supporting data and experimental confirmation of earlier expectations and prediction. p. 11-12, NAS/NRC Implementation of Standards, 1979, A3

v. Sowards group suggested that the authorization to proceed with development of a rep should be given if there is substantial evidence that the site is a good and suitable one - the evidence must not be arbitrary or capricious. p. 16, NRC State Review/Analysis Nureg 0354 1978, C5

3. Quantity and Quality of Information Gathered:

i. preference should be given to the site on which you can gather the most information with the least disruption of the integrity of the site.p. 4-5, NAS/NRC 1978, A1

ii. need geological information for determining of site suitability of an area extending to a 200 mile radius from the site (such is required in siting of reactors), p. 5-6, NRC State Review, Nureg 0353, 1977,C4;state representatives suggested that this radius is too large, p. 47, NRC State Review/Analysis, Nureg 0354, 1978, C5

iii. Quality Assurance Program (QAP) - activities which provide input to design of safety related aspects of structures, systems and components should be included in QAP, i.e. the collection and evaluation of information on geology, hydrology, seismology and meteorology of the area (needed for design and risk assessment), Appendix, NRC Branch Technical Position 1977, C6

iv. criteria considered the quality and quantity of data available on the areas, p. 2-3, Supplemental Areas, Kn GS 1972, B11

4. State of the Art Technology in Information Gathering and its Limitations:

i. conventional methods of investigation to determine hydraulic properties may be ineffective, especially when rocks have very low conductivities.
  - C10-12, ERDA/BNWL Alternatives, App C 1976, D18
  - p. 42-43, IAEA SS Factors 1977, E11

ii. research is needed on minimizing uncertainty through field observations, in situ measurements of hydrological and geological parameters, p. 29-34; it seems clear that the uncertainties of forecasting rep behavior are due principally to inadequate knowledge of the relevant mechanical, radiochemical, and hydrological properties of candidate host rock types - most of these can be gathered by well established techniques. p. 43-45, EPA State of Knowledge 1978, C7

iii. the state of ES technology for site selection and evaluation is well advanced. R&D will provide additional knowledge and new capabilities in geophysics, geochemistry and computer modeling that will aid in site selection and evaluation (multiple barriers counterbalances the remaining uncertainties in predictions) p. 9; Do we adequately understand the effects of scale among lab, bench scale and in situ measurement? moderate amount of data, developing models, p. 43; Do we adequately understand how to determine the value of data from natural reactors for verifying models of radionuclide transport? limited data, currently expanding data base, p. 45, ESTP USGS and DOE 1979, D24

iv. need for hydrological data severely taxes the available data base and the technology for generating it. Most of the available data, i.e. on sorption, have such large error limits that their usefulness in predictive models is limited, p. 114; Royal Technical Institute, Stockholm - with present techniques it is not possible to determine completely safely in detail the crack system of an area or to predict new cracks and crack systems that may be created over the long term, p. 172; Wynne-Edwards - theoretical studies based on rock properties (detected from corings) are likely to be less reliable than a thorough examination and testing of the excavation itself, p. 172, Johansson and Steen, Ringhals-3, 1978, E10

v. special lab and field studies are needed to evaluate the pristine characteristics of the site, p. 2; determination of velocities and quantities of flow becomes progressively more difficult with decreasing permeability, p. 18; extraordinary consideration for radioactive waste management - extent and duration of measurement - for information on subsurface conditions, most must be made over periods of years or decades to be considered reliable, p. 33-34; additional R&D is needed to allow reliable determination of state of stress and strength of rock mass for any site, (there is much uncertainty in current methods), p. 37-38; there is a definite need to develop new field techniques for measuring the permeability of low permeability rocks, p. 40-42; need accurate measurement of hydraulic head but must be done over a very long time since test borehole can drastically distort the head, p. 43, NAS/NRC Implementation of Standards 1979, A3

5. Host Rock / Mining Method Considered:

1. Host Rock Considered:
   - i. bedded salt, GCR 1978, D10
   - ii. plutonic crystalline rock, bedded salt and serpentinite, with emphasis on plutonic rock of the Canadian Shield (where most of the nuclear energy consumption is), Canada AECL 1976, E2
   - iii. bedded salt, USGS 4339-1, 1972, B2
   - iv. bedded salt favored, Pierce and Rich, USGS Bulletin 1148, 1962, B1
   - v. shale, mudstone and claystone, (as part of series done for Advanced Research Project Agency for disposal of noxious chemical wastes and for AEC for disposal of radioactive wastes), USGS 4339-5, 1973, B3
   - vi. crystalling rock (especially for deep drilled holes, matrix and exploded cavity methods because of strength and low permeability) ; rock salt in beds or stable domes, tuff , some metamorphic and igneous rocks and carefully chosen shales (for mined chamber method), USGS 74-158, 1974, B8
   - vii. salt, AEC Lyons ES 1971, D6
   - viii. formations being investigated in US as potential rep sites: bedded salt (including Permian Basin), domed salt, carbonate sites, metamorphic rocks, flood basalt, shales, talc/serpentine deposits, p. Ci4, ERDA/BNWL Alternatives App C 1976, D18
   - ix. focus on salt for first pilot plant since most is known about it, p. 8; at present time twelve specific geologic formations have been identified as offering potential for rep and are under investigation: Salina Salt of NE, interior Gulf Coast salt domes, midcontinent shales, midcontinent limestone, Permian Basin Salt (with separate program examining the Delaware Basin portion), shales on East Coast, volcanic rocks especially flood basalts, igneous crystalline rocks, Paradox Salt, Pierre Shale, clay along Gulf Coast, Eleana formation at Nevada Test Site - to a certain extent the list reflects current degree of interest. The fifth ranked Permian Basin is included at a high priority primarily as a contingency for the two top ranked salt formations, p. 32,36,37, OWI/ERDA Program Plan for NWTSP 1976, D19
   - x. primary focus in US is on salt, p. 1, OWI/DOE Salt Dep of US 1978, D21
   - xi. various types show promise, p. 2 IAEA SS Factors 1977, E11
   - xii. hard brittle rocks are unsuitable for disposal since their fractures don't heal, p. 92; very little work has been done on formations other than salt, p. 99, Considerations for HLWM, Gera and Jacobs , ORNL 1972, D5
   - xiii. salt, shale, limestone, granite, basalt, clay - each has advantages and disadvantages, p. 3-4; evaluations of media other than salt should continue, p. 12-13, USGS ES Perspectives 1978, B10
   - xiv. bedded salt - choice favored by many today and has the greates amount of substantive information on it. p. 2-9, ES of WM of LWR Cycle, NRC 1976, C8
   - xv. rocks that now seem suitable - bedded and domed salt, shale, basalt, and certain of the granitic clan, perhaps anhydrite and impermeable tuff, p. 1; of all the geologic media suggested, dry domes of the Gulf Coast seem mechanically the best for disposal, p. 19-20; it is the Panel's opinion, and apparently that of several foreign countries, that a sizable body of granite underlying a hydrologic basin of appropriate dimensions may prove in the long run to be an excellent choice for rep (need research.)"...particularly because there may be either sociopolitical or geologic reasons why burial in salt may be ruled out." p. 22, EPA State of Knowledge 1978, C7
   - xvi. bedded salt is the leading candidate, p. 63, AD Little, Assessment 1978, C3
   - xvii. salt - considered in W. Germany to be one of the most promising, safest and best established methods, Krause and Randl, W. Germany 1972, E7
   - xviii. Do we adequately understand potential candidate host rock characteristics? Salt - models developed, assessing applicability; Anhydrite, tuff - limited

data, currently expanding data base; granite, shale, basalt - moderate amount of data, developing models, p. 37-38, ESTP USGS and DOE 1979 , D24

2. Mining methods considered: most reports assumed that the method used would be a mined chamber using conventional mining techniques. Others:

i. very deep drill holes (30,000 to 50,000 ft), a matrix of drill holes (1,000 to 20,000 ft), mined chamber, mined chamber with separate people-made structures, exploded cavity, p. 1; Advantages of mined chamber method: principally the ability ot provide safe emplacement in highly suitable rocks that are too thin for drilled hole emplacement to be practicable (which methods is generally prefered since it has greater potential to place the wastes farther from people.) Disadvantages of mined chamber method: possible short flow path, danger of exhumation by erosion, of flooding including by rising sea level and from unpredictable changes in groundwater regime, p. 28, USGS 74-158, 1974 , B8

ii. use an abandoned/nonproducing salt or potash mine:
- p. 22, AEC Lyons ES 1971, D6
- USGS 4339-1, 1972, p. 78, B2
- Krause and Randl, W. Germany, 1972 , E7
- p. 16, Considerations for HLWM , Gera and Jacobs, ORNL 1972, D5

iii.drilling, mined (mechanical and solution), exploded cavity, hydraulic fracturing considered, HLWM Alternatives, BNWL-1900, 1974 , D16

6. Programs and Procedures:

1. Programs and procedures suggested for siting and developing a rep:

i. Canadian development program for hard rock (basically the same procedure for salt and serpentinite, the other host rock types considered):
(1) from available data, aerial photos - 20 to 30 sites will be chosen and ranked according to available factors.
(2) about six of the most promising sites will be chosen for field reconnaisance.
(3) the three most promising sites will be chosen for further investigation - detailed field mapping, diamond drilling, studies of seismicity, geophysics and hydrology of the area.
(4) Decision point: is hard rock the most suitable media? No - study other media; Yes - go to 5.
(5) most promising site will be chosen and studied extensively.
(6) Decision point: is the site suitable? No - choose another site for study; Yes - go to 7.
(7) shaft sinking commences.
p. 14-15, Canada AECL 1976, E2

ii. Sowards group: suggested that authorization to proceed with the development of a rep should be given if there is substantial evidence that the site is a good and suitable one - the evidence would have to be <u>not arbitrary and capricious</u>, p. 16; Main concerns of groups as to procedures: (1) development of procedures for optimum siting; (2) factors should be weighted with health and safety being the most important, (3) make DOE examine all optimum sites; (4) make DOE present alternative sites; (5) insure public acceptance of any site; (6) gain state approval of a proposed site before development activities begin; (groups also wanted a better definition of what was meant by "optimum site" - was it the best site, the ones that meet all the minimum criteria or what?) p. 39, NRC State Review/Analysis, Nureg 0354 1978, C5

iii. Three step selection, design and qualification procedure: (1) identify sites with appropriate environmental and geologic characteristics; (2) design and size site specific system so that facilities, structures and methods of emplacement satisfy design, performance and licensing requirements; (3) perform design evaluations and conduct experiments to confirm system performance, p. 23.1; For site selection there are various levels of evaluation: (1)regional evaluation for the elimination of totally non-prospective regions, and the selection of one or several more promising regions for further investigation; (2) local evaluation for more detailed basin-wide information so one or more small local areas can be chosen. At this stage, selection of one or more potential site areas is within the program's capabilities. If such a decision is made, three or four additional steps should be taken. (3) site area evaluation: if all site area data have continued to mesh favorably, characterization process may have focused on a potential rep site. In the absence of any major discrepancy between newly acquired data and those projected for site, the next step is to install the shaft and begin excavation of a pilot plant rep. However data acquired within the disposal zone itself may ultimately indicate against final approval of the site. Site characterization process should continue and overlap with implementation. p. 23.10-14, ERDA/BNWL Alternatives, Vol 4, 1976, D17

iv. steps in site selection: (1) technical evaluation of rock types to determine their suitability for waste disposal - done on a regional basis; (2) detailed study of promising areas; (3) "vault" tests to simulate on a reduced scale aspects of an actual facility (like Project Salt Vault in Lyons, Kansas); (4) narrow studies to specific locations to confirm favorable characteristics; (5) pilot plant constructed - limited amount of waste, readily retrievable; (6) expanded pilot plant to evaluate full scale handling and storage operations, readily retrievable; (7) convert facility to rep with license from NRC, p. 8-9; In geologic investigations and qualification experiments, it is recognized that there is a greater probability that a particular site will be found to be unsuitable than suitable and consequently rejected - so examine a multiplicity of rock types in a number of regions. Twelve generic formations/regions having potential have been identified and others will be added to the list as the program progresses. Within each formation, the geological investigations are structured to identify at least six areas qualifying for detailed examination in the expectation that no more than two will be qualified as prospective sites. Steps in geologic studies: preliminary regional evaluations to special investigations at study areas to detailed confirmation and qualification of sites. p. 31-32. OWI/ERDA Program Plan for NWTSP 1976, D19

v. Sweden - Stipulation Act - first national government to take the step of legislation which would restrict nuclear power development unless practical and safe waste disposal program was developed. Burden is on the proposers of the technology to develop the waste disposal program. p. IV-6; Public acceptance of rep depends on an absolute demonstration of the safety in terms understandable by members of the general public. "This may require a continuation of geologic research simultaneously over a number of potential rep sites and a willingness to reject any one of them if adverse geologic conditions are encountered during the research. Unless the inhabitants of areas where a rep may be located are confident of the thoroughness and objectivity of the research and are thus convinced of the safety of the rep, the rep design cannot be considered acceptable as being completely safe." p. IV 32, KBS Rydberg and Winchester 1978, E9

vi. Periods of development of rep in salt: (1) site selection and evaluation, (2) prepare PSAR and ER, (3) prepare FSAR, (4) construction, (5) performance assessment, p. 9-17, ESTP USGS and DOE 1979, D24

vii. storage configuration for WIPP for RH TRU waste: (1) WIPP storage which assures retrievability but is not cost effective if retrieval is not required. So this configuration will be limited to quantities to be stored before the successful completion of pilot plant program and subsequent deletion of retrieval requirements. (2) Post WIPP configuration - not used until retrievability is no longer a requirement. WIPP Conceptual Design Report 1977, D12

viii. West German program - first experimental storage of HLW - during a period of several years the consequences of this operation can be observed and compared with the results of the calculations and experiments, leading to the definition of optimum conditions for safe storage. p. 10, Krause and Randl, WM in W. Germany, 1972, E7

ix. Steps in program: (1) site selection; (2) investigation of site - with model and data acquired, predict the rates of release of nuclides - if the predicted value of these release rates and concentrations, taking into account its uncertainty, is sufficiently below the prescribed standard, exploratory excavations may begin, (3) exploratory excavation to demonstrate adequacy - with new data, updated and more confident predictions can be made. If still meets standards, excavation may continue; if not, site should be abandoned unless changes in waste form or engineered barriers can compensate for geological inadequacies. (4) testing during excavation - provides updated and more confident predictions - if still meets standards, clearance may be given to emplace wastes while preserving retrieval and abandonment option. (5) testing during emplacement - provides updated and more confident predictions of rep performance - if still meets standards, rep may be sealed. p. 10-11, NAS/NRC Implementation of Standards 1979, A3 x.

D. Evaluation Procedure

Criteria can be used formally for a geological investigation leading to selection and confirmation of a rep site. Steps (especially manner in which criteria and specifications affect procedure): p. 11

1. Geological formation of interest is identified; programmatic decision made to investigate the possibilities. p. 11

2. Set of screening specifications is derived for the criteria based on first principles and on readily available information. p. 11

3. Reconnaissance surveys performed regional in scope. Available information is compiled, new data developed as necessary. p . 11

4. Screening specifications applied to results of surveys to identify one or more study areas for more detailed investigation. p 11

5. Set of evaluation specifications is derived from criteria based on information obtained in surveys - these are merely refined and more elaborate versions of screening specs. p. 11

6. Detailed study programs are carried out at study areas: field mapping, geophysical surveys, etc. Number of areas and level of effort is controlled by programmatic considerations and technical requirements. p. 11

7. One or more study locations identified by application of evaluation specs - sufficiently promising for confirmation studies. p. 11

8. Set of location evaluation specs is derived from criteria based on additional information obtained from the detailed studies and applicable rep preconceptual designs. p. 11

9. Location evaluation studies performed at one or more locations (depending on program and budget.) p. 12

10. Location evaluation specs applied to results of studies. If location meets specs, it is considered to be acceptable on the basis of geological and hydrological criteria. p. 12

11. Proposed site is reviewed on the basis of other criteria like socioeconomic. p. 12

12. Detailed site specific design developed for rep at proposed site.

13. Thorough and detailed analysis is made of specific rep design at site. Analysis: operation master plan, all expected impacts, long term risk analysis. Results - basis for supporting documentation for funding request, i.e. DEIS, PSAR, conceptual design report. p. 12

14. Formal <u>external</u> review of facility begins: NRC, EPA, Congress, etc p. 12

Brunton and McClain, OWI/ERDA, 1977, D20 xi.

Licensing Procedures for Geologic Repositories of HLW
Federal Register, Vo. 43, No. 223, Nov. 17, 1978

Proposed general statement of policy regarding the establishment of procedures for licensing.

It is not clear whether the NRC would have licensing authority over WIPP - if so, these procedures will apply. WIPP might not be licensable if it is primarily for defense TRU wastes or if it is regarded as a R & D facility.

In fashioning the procedures, several unique features of geologic HLW repositories were carefully considered:

a. the suitability of the site becomes crucial, for the integrity of the site is essential to ensure containment - sound policy suggests that NRC be afforded the opportunity to participate in DOE's site selection process, though only in an informal advisory capacity.

b. construction of the repository shaft will constitute the first major penetration - if it is improperly constructed or sealed, it could impair containment over long periods of time. But the shaft would also give lots of data necessary for the design of the repository - need to take into account in the safety review prior to the sinking of the shaft that only limited data may be available.

c. there should be a formal safety review of main repository design features before substantial committments are made and alterations become impractical.

d. NRC should examine the methods of contruction and any new informatior developed during construction before formally authorizing the receipt and storage of radioactive materials.

e. if the repository is subject to NRC licensing, the entire repository is subjected to review since loss of integrity of any part of the repository could imperil the integrity of the entire repository.

f. EIS should be prepared prior to authorizing construction of the main shaft. This EIS could be updated prior to receipt and storage of radwaste should new information so warrant.

Proposed Policy:

1. Early notification to states and other interested parties, in order to provide opportunity for early input; NRC on receipt of DOE license application or request for informal early site review would:

a. publish a notice in the Federal Register

b. make a copy of the application or request available

c. transmit copies of the request to the governor of the state and to the chief executive of the municipality in which the repository is tentatively planned and the governors of contiguous states. Staff would offer to meet with them.

2. Licensing procedures, 4 parts:

a. Review of DOE site selection, informal NRC staff consultation to DOE on site suitability matters after DOE's site selection - to point out those aspects of a location which in its judgement might require special attention or present special problems and would help define kinds of information that might be needed for licensing decisions. NRC may provide advice but not make formal findings or take formal action. DOE remains free to bring in any license application it believes conforms and NRC remains free to approve or disapprove it.

b. Review of repository development: formal licensing review process would begin with filing application for a license by DOE prior to commencement of construction of the shaft. Application would be docketed for review, notice published in Federal Register offering interested parties to intervene and request a hearing. Application will include information on site suitability, on repository design features important to safety. Also to be submitted - environmental report by DOE addressing matters set forth in section 102(2)(C) of NEPA. It is probable that some of the information necessary to make a definitive finding on safety will not then be available. Nevertheless NRC could authorize construction upon completion of review of all NEPA, safety and common defense and security issues and upon finding:

1. after considering reasonable alternatives, benefits exceed costs under NEPA

2. there is reasonable assurance that the types and amounts of waste decribed in the application can be stored in repository without unreasonable risk to health and safety of the public or being inimical to the common defense and security.

If there is not enough information prior to shaft sinking, safety review could be conducted in two phases:

1. Construction of the shaft would commence if : after considering alternatives, benefits exceed costs under NEPA, and assurance that the site is suitable without unreasonable risk and plans for construction of the main shaft and related structures can be implemented in a manner compatible with the use of the site for a repository. Full findings would have to be made before construction of the surface and underground structures. Safety issues that could not be resolved based on available information might be defered until the repository operating license review provided that: there is an adequate program to resolve the issues, and there is a reasonable assurance that the issues can be resolved in a favorable manner at a later date.

The applicant would report to NRC during construction on any site characterization data obtained that is not within the predicted limits on which design was based. Also required to report deficiencies in design and construction that would have significant adverse effect on the repository at any future time.

c. Repository licensing: Prior to receipt of any radioactive material at repository, DOE will need to file updated license application. License authorizing actual receipt would be issued after NRC conducts a final review of health and safety and defense in light of:

a. any additional geologic, etc, data obtained during construction

b. conformance of construction to design

c. results of research program carried out to resolve questions identified during prior reviews

d. plans for startup and routine operation

e. plans for identifying and responding to any unanticipated releases of radioactive materials

Issuance of a license requires a definitive finding under the Atomic Energy Act that receipt, etc, will not constitute unreasonable risk to health and safety of public and defense. If there is new information available that would materially alter NEPA cost/benefit balance, the earlier EIS will be updated. A hearing may be requested.

If special restrictions are imposed in the license, (i.e retrievability, or limits on amount or types of waste) ammendment will be required before committing waste to irretrievable disposal or receipt of additional waste. Required review procedures would be similar.

DOE is required to conduct and monitor operations, keep records, submit to routine and special reports. All operations are subject to appropriate continuing NRC inspection activities.

d. Review of repository closure: After it is filled but before closing the shafts and D&D of surface facilities, NRC approval is required of the licensee's proposed program for compliance with regulatio on sealing of repository, D&D of surface, storage of permanent records, long-term monitoring. Following the comletion of review, a change in the license status may be warranted.

Licensing Procedures, NRC, Fed Reg 1978, C1

2. Specific Program Issues in Miscellaneous Order:

i.

One or 2 national vs many regional repositories: p. 23-24
- regional rep. would minimize the risks of transportation
- national rep is preferable from a population exposure standpoint
- one or 2 national would be cheaper
- a few national sites seem to be preferred ; at least two should be developed at the same time in case one is not suitable after all.

NRC State Review/Analysis, Nureg 0354, 1978, C5

ii.

Advantages of multiple locations: p. 6
1. feasibility of a timely operation of a facility is improved because of the parallel approach.
2. retrievability concept can be included
3. make it possible for more than one site to serve the country as a terminal facility
4. reduced transportation costs

OWI/ERDA Program Plan for NWTSP 1976, D19

iii.

Elements of overall Waste Management Strategy that can have a profound effect/influence in rep design include: p. 4-1
a. requirement to leave open the option of retrieving waste for subsequent reprocessing.
b. desire to locate rep to minimize distance the waste must be transported.
c. decision to maximize (or minimize) duration of storage prior to ultimate emplacement.
d. philosophy that dictates maximum (or minimum) emphasis be placed on waste form and container as means of preventing release of radionuclides.

Question for all of the above options: which option has the minimum of risks and costs considering the whole waste management system.

NRC Info Base for Rep Design 1979,
C10

iv.

Schemes for policy makers to obtain scientific advice on controversial highly technical situations (i,e. recombinant DNA technologies, nuclear power):

1. Science Court
2. Scientific Mediation

Neither has been actually tried. Government group chose to get not a direct critique of the KBS but a review in such a way as to make relevant facts and arguments of both sides (pro and anti nuclear power) generally accessible and intelligible and to introduce into the public arena the basic concepts necessary for meaningful debate on the issue. Job is to provide information and understanding to encourage public participation in technological decisions which may have substantial social consequences.

Instead of scientific mediation, decided to hire two scientists - on skeptical (Winchester) and one with confidence in technology (Rydberg) to write a joint report, answering the following questions:

1. What relevant facts can be considered established?

2. What is believed in areas of uncertainty? Who believes what and on what grounds?

3. What technical and/or nontechnical information, if any, appears indispensable before any decision should be made on the matter? What information would be highly desirable and also obtainable in the reasonably near future? If the co-authors disagree, how does each justify his opinion?

4. Do any methodological defects and/or misleading statements appear in the KBS report, and how important are they in the perspective of the whole issue? (Co-authors must agree or explain disagreements.)

5. What weight should be given by the non-expert reader to each of the problems dealt with? i.e. if a weakness in KBS is pointed out, how should the reader decide whether this is crucial or a peripheral point? How can he/she evaluate the relative importance of dangers or uncertainties?

6. What other dimensions of the issues not discussed in KBS are crucial to the decision the government must make?

Rydberg and Winchester also used a "reference group " of experts in fields related to the issue for consultation and for feedback on their report.

KBS Rydberg and Winchester, 1978
E9

v.

Program will also be carried out on the utilization of solidified HLW as a radiation source in inactive sewage treatment (i.e. for sterilization purposes) or for a partial decomposition of biologically non-degradable organic compounds. Separation of Cl from polychlorinated phenols has been found to be the preferred reaction which takes place when waste waters from biocide industries are irradiated at dose rate of about 2 MCi (that needed to sterilize about 24,000 m^2 of sewage/day). "Should future results in this field continue to be promising and irradiation be to perform at reasonable cost, the problems connected with appropriate heat dissipation during ultimate storage of solidified HLW would be greatly reduced." p. 21

Krause and Randl, WM in West Germany 1972, E7 vi.

Verification that long term future performance will continue to satisfy the standards cannot be established by monitoring present emmissions. Panel concluded that a satisfactory level of confidence/degree of assurance of the probability that a rep's long term performance will comply with such standards can be achieved. (that the rep will provide adequate isolation and containment.) p. 1-2

Assurance procedure includes: confirmation of site suitability, confirmation of adequacy of rep's engineering design. The nature of subsurface media requires special lab. and field studies to evaluate pristine characteristics of site, and that the effects of rep on site be studied by large scale in situ tests. One of tools of assurance procedure: predictive modeling. p. 2

Recommendations: p. 2-3

a. adopt procedure to ascertain whether rep will provide adequate isolation: data acquisition program (experimentation in lab and field; exploration; in situ testing) and appropriate models based on a thorough understanding of the phenomena involved - basis for quantitative prediction of releases.

b. procedure continuing from site selection through final assessment before wastes are committed to disposal. Corrective actions like retrieval and site abandonment should be available options until closure.

Extraordinary considerations for rep, aspects needing careful attention:

a quality of data and uncertainties associated with them.: Opportunity for gaining experience and for replication is limited for rep - site should be used for experimentation . One approach : have an independent group do investigations based on longer and broader range scientific objectives while another group does the design and construction of rep. p. 33

NAS/NRC Implementation of Standards 1979, A3 vii.

Proposed Goals for Radioactive Waste Management
by a group of consultants organized by Sandia, prepared for NRC, May 1978
Consultants: W.P. Bishop, D.H. Frazier, NRC
I.R. Hoos, U. of Calif, Berkeley
PE MacGrath, Sandia
DS Metlay, Indiana Univ
WC Stoneman, Quarry Hill, Inc
RA Watson, Washington Univ.

As performance lifetime increases (ie. from 50 year lifetime of reactor to 100,000 year of rep), the stability and character of the organizations charged with particular tasks becomes increasingly important. p. 3

Three time frames of interest:
1. period of active use of nuclear power
2. period during which society takes an active role in managing wastes, even if action is only surveillance
3. period , due to social discontinuity or lack of concern, when society ceases active management of wastes. During this period the system must continue to operate as designed.

Also time frames tend to group goals by topic:
1. decision making process
2. stress on implementation
3. radiologic hazard

All goals must be anticipated in the design and early implementation of the WM (Waste Management) system. p. 3

I. Goals for Period of Active Use of Nuclear Power

A. Decision making process

1. decisions and actions shall be based on assessments of all impacts on both present and future human environments p.5

2. consideration shall be given explicitly to all aspects of the system including safety, environmental, organizational, institutional, and implementational. For too long the focus has been solely on technological aspects, but these cannot be separated from societal conditions. p.5

3. Values not easily quantifiable shall be actively considered in the decision-making process. Quantifiable - cancer deaths, pollution, land commitment for example. But moral and ethical issues can no longer be waved aside; must be addressed and given whatever weight their significance demands. p. 5

4. The existence of scientific, technological and organizational uncertainties in any WM system shall be made explicit, along with the logic and procedures used to address them. System will be implemented in the face of admitted uncertainties - these will be resolved through some procedure like expert opinion, limited testing, which gives confidence despite the uncertainty. p. 6

5. The system for managing existing and future wastes shall be within present capabilities of both technology and organizations. (Though the system for future wastes can be changed.) p.6

6. There shall be broadly based involvement of interested groups, citizens and jurisdictions in decision and planning processes. p. 6

7.State, local and regional jurisdictions shall be involved in the decision process from the inception of ideas to implementation of the system. p. 6

8. The decision making process shall involve the public at large, including interested groups and individuals. Part of this is also to make available to the public all the information on which decisions are based. Public participation legitimizes the final decision. p. 7

9. To the extent possible, all costs of a WM system shall be identified and financial resources assured. Costs should be borne by those who reap the benefits - by this generation. p. 7

B.Organizational Considerations

1. Organization involved shall have the flexibility to accomodate present and future requirements - changes in knowledge and in perceptions will alter what is required or is considered optimum at any given time. p. 7

2. The organizational infrastructure shall be capable of responding successfully to either gradual or abrupt changes in the rate and scale of activities. p. 7

3. WM system shall be designed so that
 a. its operation is independent of the existence of the commercial power system
 b. that other fuel cycle operations do not restrict the flexibility of the system
 c. the system does not limit future choices in the fuel cycle.

There several policy decisions pending, i.e. whether to recycle plutonium, use of breeder, etc. System should neither determine nor constrain choices or be limited by them. p. 8

4. Organizational and institutional components of the system shall be designed to ensure detection and rectification of errors. p. 8

5. Organizations implementing system shall assure competence of operating personnel, (not true in past.) p. 8

6. Intermediate operations (i.e. collection, transportation, etc.) shall be performed so as to provide reasonable assurance of protecting the public health and safety. p. 8

7. Radioactivity in effluents to environment shall be minimized. p.9

8. System before disposal shall be designed to minimize the probability of radionuclide release, i.e. due to untoward events. p. 9

9. Procedures shall be established to deal effectively with unintended incidents leading to radioactive release. p. 9

10. The time from generation of wastes to time of ultimate disposition shall be minimized. p. 9

C. Technological Considerations

1. Complete program for managing wastes shall be established concurrently with waste generation. Responsibility for WM program is ours and shall not be defered to future generations or unknown technologies. p. 9-10

2. The need to manage radwastes already in existence shall not dictate the nature of solutions for waste yet to be generated. Present wastes - given a particular chemical form and past management of these wastes, a solution which falls short of meeting other goals proposed here may be necessary. It is important that acceptance of a system for immediate disposition of existing wastes not be permitted to dictate acceptance of less-than-adequate management system for future wastes. p. 10

Time Frame II - Period of Active Implementation of WM System

D. Procedural Considerations

1. Budgetary considerations shall not be the sole or even dominant constraint with regard to selection, implementation or continued operation of WM system; should have the systems set up and money allocated to them in advance. p. 10

E. Organizational/Institutional Considerations

1. Organizational systems shall be such as to insure the detection and rectification of errors. For example, for detecting - redundancy, overlapping jurisdiction, frequent checks, etc; for rectification - prior allocation of funds like a trust fund. Many measures obviously sacrifice efficiency for the sake of reliability. p. 10-11

2. Normal state of the WM system shall be specified as precisely as possible to facilitate recognition of an undesired or unexpected event or condition. Need clear and accepted standard of normality - Two factors that reduce ability to specify normal state:

a. lack of knowledge of cause/effect relations that influence system operation - gain the knowledge.

b. desire to retain some ambiguity in order to promote acceptance of the system - but ambiguity compromises ability to detect errors and so should be avoided. p. 11

3. Adequate documentation of present activities and decisions shall be provided as part of WM system to provide future generations with a basis for action. p. 11

4. Organizational elements of WM system shall not be self-perpetuati[ng] nor shall they permit WM activities to become ends in themselves, independent of needs of society. Should protect against runaway organizations (eg "priesthoods") and be cognizant that large technologies can develop into societal forces in their own right, independent of the needs of the larger society. p. 11

5. Organizational elements of WM system shall not be affected by or require changes in the political system. p. 11

6. The national WM system shall take account of and include international considerations to the extent possible - active role in developing internationally acceptable WM solutions and systems (if it leaks, could be of global concern.) p. 12

F. Technological Considerations

1. Intermediate handling and storage of radwastes shall be performed in a manner that does not prevent further actions leading to their ultimate disposal - i.e. interim steps should not become final solutions, leaving management half done. p. 12

2. If wastes are disposed of on earth, their retrievability, assuming a technology as advanced as at present, should not be precluded. Retrievability should be a characteristic of a system only if there is considerable uncertainty about its wisdom, safety and efficacy. To the extent that uncertainties are small, disposal should be permanent and irretrievable (retrievability is partly inconsistent with other goals of completeness and permanence of WM systems.) This goal needs more discussion - doubts about it. p. 12

Time Frame III

G. Technological and Social Considerations

1. Waste disposal facilities shall be sited and operated to avoid as much as possible the foreclosure of future options. People will seek anything of value and are now one of the major driving forces for geological change (erosion, solid movement and water movement for example) - to the extent predictable, we should design and locate facilities so as to avoid motivation for penetrating disposal volume. p. 13

2. Waste management system shall not require long term stability of social and governmental institutions for its secure and continued operation. p. 13

3. The WM system shall be capable of meeting all relevant radiation protection standards and criteria for both normal and accidental situations throughout its operation. Key goal - for all the time during which there will be concern about radioactivity, the WM system should operate in compliance with relevant standards. p. 14

NAS says - other things being equal, those technological projects or developments should be favored that leave maximum room for maneuver in the future. The reversibility of an action should be counted a major benefit; its irreversibility a major cost. p. 15

When setting up the organizations to oversee treatment, transport and disposal of radwastes, have to take into account:

1. That it must be able to continue to perform its operations as it loses its initial sense of excitement and becomes routinized. p. 20

2. that a bureaucracy often reacts, when threatened, to protect its central resource, its constituency or the role for which it is responsible - tend to lose sight of original large purposes. p. 21

Some nontechnological factors which should be taken into account:

1. affect of WM system on civil liberties, has not been analyzed exhaustively p. 21

2. also the psychological consequences of an accident p. 21

3. effect on the economy, distribution of population, on govt. expenditures p. 21

Nontechnological elements play a key role in decision making process to select WM system. Because the factual basis for decisions is never complete or unequivocal, actions are often based on judgements by experts - attribution of credibility to these experts requires careful attention. p. 21

These goals incorporate some that are already implicit or explicit in current programs or in existing legal framework. p. 21

NRC regulations - because inherent uncertainties permeate almost all subject matters on which the regulation of radwastes are based, NRC ought to treat its regs as working hypotheses to be verified by experimental and empirical means. So methods for testing regulations validity must be simultaneously established with the regs. Criteria must be established in advance for judging when a reg-hypothesis has been disconfirmed. NRC must be willing to revise regs and a mechanism for this should continue to be available. NRC should have a program or organizational component which is responsible for validating regs, developing new hypotheses and transforming both into new regs as needed. p.22

NRC-Proposed Goals for RWM, 1978, C9

7. Risk Analysis/Assessment:

1. Risk analysis/assessment must be done for rep site through the use of analytical models:

i. Radiation protection requirements for radwastes should be based primarily on assessment of risk to individuals and populations; such assessments should be based on predetermined models. EPA Criteria for RW/ Rec for Fed Guidance, Fed Reg 1978, C2

ii. to demonstrate the effectiveness of the barriers is adequate to reduce the releases to very low levels, assuming any credible failure, p. 4, NRC State Review, Nureg 0353, 1977, C4

iii. to determine the level of risk, p. 47, NRC State Review/Analysis, Nureg 0354 1978, C5

iv. to be able to reduce both the potential for and the effects of releases to the environment to ALARA level, p. 16-17, NRC Branch Technical Position 1977, C6

v. to show that even an improbable escape would have negligible health hazards - since you can't give an absolute guarantee that none of the wastes will ever escape.

- p. 1-2, AECL Canada 1975, E1
- p. 2-11, ES of WM of LWR Cycle, NRC 1976, C8

vi. and appropriate remedial measures developed as necessary, p. 15, ORNL Program Plan for BSPP 1973, D1

vii. a complete model of contaminant flow by groundwater transport must be constructed before final selection if the site. p. 7, USGS ES Perspectives 1978, B10

viii. required for PSAR, licensing, p. 9, ESTP USGS and DOE 1979, D24

2. Different Risk Timescales:

i. (1) near term (during operation of rep) and (2) long term (after emplacement). For the long term, focal point is the potential for and consequences of nuclide release after human control ceases. p. 23.15-17, ERDA/BNWL Alternatives Vol 4 1976, D17

ii. (1) immediate - during operational period, (2) decades - failure of scheme during temporary storage before conversion to permanent disposal, (3) centuries - due to unexpected system failure during fission product lifetime, risk principally due to Sr 90 and Cs 137, (4) millenia for long lived nuclides, p. IV 2-3; decrease in risk is most rapid in the first thousand years due to the decay of Sr 90 and Cs 137 - so consider two risk periods - high risk during the first thousand years and after that low risk, p. IV 51-52, KBS Rydberg and Winchester 1978, E9

iii. for likelihood of different failures: (1) inadequacies in design, site selection and construction - in first hundred years these dominate the probabilities of release, (2) inadvertent human intrusion - negligible for first hundred years, indeterminable after that, (3) hydrological changes - 10,000 to 100,000 years after sealing, (4) naturally induced failures caused by, for example, meteorites, etc - on order of a million years. p. 6-8, AD Little, Assessment 1978, C3

iv. (1) first several centuries when fission products constitute most of the radioactivity in the wastes, (2) longer term which may extend to a million years or more when some actinide elements, their decay products and some fission products are present in significant amounts. TRU may present the most difficult disposal problem. p. 45-46, NAS/NRC Implementation of Standards 1979, A3

3. What must be examined in the models:

i. at least the following: amount and concentration of radwaste in rep and its physical, chemical and radiological properties; projected effectiveness of alternative methods of control; potential adverse health effects on individuals and populations for a reasonable range of future population sizes and distributions, and uses of land, air, water and mineral resources for 1,000 years or any shorter period of hazard persistence; estimates of environmental effects or of health effects using generalized parameters/assumptions for as long as wastes pose a hazard, when such estimates could influence the choice of control option; probabilities of release due to failures of natural or engineered barriers, loss of institutional controls or intrusions; uncertainties in risk assessments and models used for determining them. EPA Criteria for RW/Rec for Fed Guidance, Fed Reg 1978, C2

ii. geologic media selected, definition of site specific system; assessment involves assumption concerning the time and mode of escape, data on nuclide movements in geologic media and estimates of effects of radioactivity that enters the biosphere, p. 23.15-17; for catastrophic events - emphasis is on the type and the probabilities of the intiating event; for degradation processes that are assumed to occur, the emphasis is on rates and characteristics of release and migration, p. 23.17-22, ERDA/BNWL Alternatives Vol 4, 1976, D17

iii. convective transport by flow, dispersive and diffusive transport, chemical interactions with rocks along flow path, rates at which wastes come into solution, p. 7, USGS ES Perspectives 1978, B10

iv. knowledge of natural features and processes of region that affect long term containment capability of host medium or that influence nuclide migration, i.e. regional distribution of rock types and structural features as they affect groundwater flow, prediction of disruptive events, chemical characteristics of water and rocks of region and waste/rock interactions, regional hydrology, predictions of nuclide concentration in system as function of time and space. p. 16-17, ESTP USGS and DOE 1979, D24

4. Results of some general risk analyses:

i. even if rep fails despite meeting criteria, global risk for people would be effectively limited because: the movement of Pu and Am through sorptive media is a slow process, most likely mode of intake is ingestion whose hazard index is much lower than for inhalation, and to date no significant reconcentration phenomena are known, i.e. in food chain. p. 131, Considerations for HLWM, Gera and Jacobs, ORNL 1972, D5

ii. long term impacts will be nonexistent if the rep performs as expected, p. 2-10; the studies that have been done indicate that the consequences of all but the most improbable events will be small - the risks inherent in the long term for geologic disposal will therefore also be small, p. 2-11; knowledge of the future is imperfect but studies indicate that no failure in containment will result in disaster to life on earth or even to people, p. 2-11; we expect that probable releases after D&D will be negligible per reference reactor year, p. 2-12, ES of WM of LWR Cycle, NRC 1976, C8

iii. trends in risks for HLW rep: despite careful selection and evaluation of site to minimize the potential development of aquatic pathways, cumulative probability indicates that these pathways are likely to occur eventually, but the consequences of release tend to be low; probability of release by catastrophic events is very low but the consequences are apt to be very high; probability of release by human intrusion may become quite high if adequate perpetual care cannot be maintained and the consequences tend to be low; chances are that over the long life of the rep, at least one event will occur - the series of independent barriers tend to require the occurence of more than one event thus reducing overall risks. p. 6-8, AD Little, Assessment 1978, C3

5. State-of-the-art in risk assessment and its problems/limitations:

i. one approach - quantify the probability of disruptive events and their nuisance value to people (consequences). Then by adding up the results, one tries to assess the safety coefficient of the rep. This approach does not seem realistic to the authors - no geologist can seriously give reasonable figures for these probabilities. For example, you can estimate the probability of faulting in a tectonically active area since you can get a lot of data on it, but since the probability would be high you wouldn't want to put a rep there. In a stable area, no such data is available and our knowledge of the mechanisms does not suffice to calculate this probability or to assess the probability for future stability of the area from past stability. Also the problem of what happens to the nuclides once they reach the surface is very complex - can evaporate (I and Pu), enter the food chain, be diluted in surface water used by us or by sea water and enter the aquatic food chain. There are reconcentration mechanisms that generate abnormal concentrations. The number of hypotheses and parameters necessary to quantify these mechanisms are much too complex for study on a general basis - must have site specific study of what happens once the nuclides reach the surface. de Marsily et al, Guarantee Isolation? 1977, E5

ii. uncertainties introduced into transport model-making: presence of fractures, boreholes, difficulty in measuring the permeability and hydraulic head in low permeable strata. p. 8, USGS ES Perspectives 1978, B10

iii. risk assessment is a new field of science, p. III 45; "A great deal of ingenuity has gone into refining methods of extrapolation: improving the underlying data base, clarifying the meaning of probability, developing more precise and powerful mathematical methods, creating tree-like logical sequences of events and consequences, modeling systems, quantifying subjective estimates and stretching the imagination by scenarios. All such methods are hampered by common and sometimes subtle distortions of assumptions and method and by the limits of human cognitive processes." (from R.W. Kates, in Ambio 6, 1977), p. III 46; KBS - four models - source, for release and transport of nuclides to the surface (GETOUT model), for uptake by humans (BIOPATH model) and for calculation of dose and consequent risk. Of the four models, those for source and dose are fairly unambiguous. Model for radionuclide transport in groundwater is much more uncertain. Radionuclide movement at the surface is fairly well known. p. III46-47; Problem with GETOUT model - lack of data base, p. III 49; in some cases direct experimental data were lacking and judgements about the relative importance of some of the processes for which we lack data were made. This causes uncertainties in the results of the model over and above the explicit incertainty in the data. p. IV17; It is useful to conduct sensitivity analysis to determine the sensitivity of the calculation to uncertainties in the parameters,and to calculate the most probable dose - not just the worst case that appears to provide an upper limit on dose to humans, p. IV 14-15; other models have been refined by comparing predictions with measurements and then by successive approximations improving the model and the overall reliability of predictions (i.e. in weather forecasting models.) For rep radionuclide transport model, verification procedure may not be direct but some kind is necessary to judge the reliability of the predictions. p. IV 15-16, KBS Rydberg and Winchester 1978, E9

iv. two approaches to risk assessment: (1) radiotoxic hazard indices (how much air or water is needed to dilute the radioactive material to MPC); (2) modeling of transport through the geosphere and biosphere, ingestion and dose to people calculated, p. 2-11, 4-93; uncertainties introduced into the assessment: effect of waste on rep stability, probability and consequences of human intrusion, validity of data used, design and regulatory actions needed to minimize the possibility of rep failure, projection of future societal habits and demography, relative importance of various potential intiating events, p. 4-94; Methodology - events that could produce or lead to rep failure can be identified, probabilities of the events estimated and the consequences calculated. The degree of confidence in the results depends on the availability and applicability of the data and the validity of the extrapolations, p. 4-86; modeling studies take into account the dynamics of rep failure and thereby overcome the limitations associated with the Radiotoxic Hazard Index concept. p. 4-93, ES of WM of LWR Cycle, NRC 1976, C8

v. EPA recognizes that there may be significant uncertainties and controversy regarding geologic knowledge, especially as relates to the ability to provide long term containment of radwastes, p. v-vii; attempts to model the behavior of geologic systems must rely not simply on the best available data but on sufficiently good data that are truly pertinent and on consideration of all of the important factors that may affect the outcome. Must know the reliability of any estimates before they can be used as a basis for practical decisions, p. viii; models based on available data must not lose sight of the major discrepancies possible between available data and those needed - for example it is known that (1) rates measured in dry systems are orders of magnitude lower than those in wet systems, (2) leaching rates measured with pure water or dilute solutions are often far slower than those in concentrated solutions, (3) complexing of ions may permit considerably higher concentrations of the cation in solution, p. 8; there is the necessity to forecast over long time periods with uncertain information. There are uncertainties in hydrological characteristics of site, the mathematical representation of transport, and the solution of resulting equations for realistic physical conditions. Need to make the decision maker cognizant of the degree of uncertainty inherent in the forecasts, p. 29; there are two operational models currently and it is important to consider the possibility of quantifying the uncertainty in the models so decision-makers are aware of the degree of uncertainty - i.e. use sensitivity analysis, etc. In using available analyses for establishing standards, EPA should consider: (1) the existing simulations are limited to a small number of hypothetical problems associated with selected waste disposal scenarios, (2) problems are indicative rather than representative of a real case, (3) the relationship between the parameters and processes of the model and real life is very uncertain, (4) credibility of the model would be enhanced by satisfactory simulation of transport at the Nevada Test Site, (5) current models do not incorporate uncertainties into the forecast, (6) scenarios are largely arbitrary and may or may not correspond to the real thing, (7) adequacy of the forecasts depends on the sensitivity of the decision making process to the state-of-the-art of transport modeling. Research is needed on quantifying and incorporating uncertainty into the forecasts and on minimizing uncertainties (better data), p. 29-34, EPA State of Knowledge 1978, C7

vi. two steps in risk assessment: (1) estimation of quantity of radioactivity to which humans might be exposed, (2) estimation of the quantitative relationship between radiation exposure and observed human damage - there are large uncertainties in estimates of damage, p. 71; K_a values in the literature are not representative of those under rep conditions - their inclusion in models cannot be expected to lead to very useful results, p. 130; Model of transport of nuclides once they reach the surface - very complex problem. We do not know all the pathways and also pathways may change, i.e. people can change their eating habits from meat to algae, p. 135-138, Johansson and Steen, Ringhals-3, 1978, E10

vii. calculations of dose based on the description of biosphere and geosphere pathways - considerable experience in this field - critical pathways can be identified and calculations fo dose can be made with confidence in particular impact studies, p. 7; accuracy of the models depends on the scientific validity of the models and the quality of the data used in them, p. 32; Four aspects of the process require extraordinary attention (since with rep there is little data, has longer required time of function, the consequences of failure may be perceived to be greater, and the accuracy and certainty of knowledge about subsurface phenomena are far less than in most other fields of scientific and technological enterprise): (1) quality of data and its uncertainties, p. 33; (2) the extent and duration of measurement, i.e. for measurement of subsurface conditions most must be made over periods of years or decades to be considered reliable, p. 33-34; (3) credible modeling - validity and accuracy of the model depends on the extent to which is reproduces the chemical and physical processes involved. A premium must be placed on obtaining an adequate understanding of the processes and phenomena through field and lab studies. In interpreting the results of the model, careful attention should be paid to the adequacy of the model itself and of the data used, and to the uncertainty in the final results (the confidence level in the predictions.) Ideally it is desirable to test the model against reality, i.e. model transport at Oklo, Nevada Test Site, ore deposits, p. 34-35; (4) risk assessment and safety analyses taking into account events that are expected and also unexpected disturbances, p. 36, NAS/NRC Implementation of Standards, 1979, A3

8. Risk Acceptability (see also Degree of Isolation Required for assumed acceptable levels of risk):

1. Who determines what level of risk is acceptable?
   i. Each federal agency that is involved in establishing policy for radwaste disposal will be responsible for estimating the consequences of likely radiation exposure circumstances and for determining whether they are acceptable based on an examination of their consistency with other established social values that have evolved for comparable circumstances. EPA Criteria for RW/ Reċ for Fed Guidance, Fed Reg 1978, C2
   ii. state groups raised the question of who would make the assessment of what is an acceptable risk. Davis and Lavine groups - this responsibility should be shared by NRC and the states. p. 19, NRC State Review/Analysis, Nureg 0354 1978, C5
   iii. determination of acceptable levels of risk is a political matter, Desrosiers and Njoku, Risk Limit as Standard, 1978 or 9, D22
   iv. determination of whether the level of risk is acceptable - a value judgement to be handled through the political process using the best available information, p. 21; This has to be recognized as an ethical and political question which should be handled explicitly by the political process and not implicitly by scientists, p. 74, Johansson and Steen, Ringhals-3, 1978, E10

2. Methods of determining what is an acceptable risk:
   i. use of the ALARA concept suggested by NRC - needs to be discussed more fully and better defined, p. 18, NRC State Review/Analysis, Nureg 0354 1978, C5
   ii. judgement of risk acceptability must be based on cost/benefit analysis, p. III-51, KBS Rydberg and Winchester 1978, E9
   iii. it is a subjective judgement, p. 4-94, ES of WM of LWR Cycle, NRC 1976, C8
   iv. there are four methods of determining the acceptability of risks: (1) risk aversion which involves the maximum reduction of risk possible with little or no comparison with other risks or with benefits; (2) risk balancing - assumes that some level of risk above zero is acceptable and defines the level through comparison with appropriate reference cases, such as similar technologies, natural background levels, or risks previously determined to be acceptable; (3) cost effectiveness - seeks to maximize the reduction of risk for each dollar expenditure for safety, i.e. acceptable risk may be set by breaks in the slope of risk reduction efficiency; (4) cost/benefit balancing - acceptable risk is defined by balancing the benefits of an activity against the level of risk it presents and the risk tolerated, therefore, increases proportionately with the magnitude of the benefits involved, p. 35; Tool in determination of risk acceptability - diagraming full scope of hazard evolution - in cases where the "downstream" stages (i.e. events and consequences) are poorly understood, prudent hazard management recognizes the ineffectiveness of downstream blocks and concentrates on upstream options such as choice of technology and modification of human wants, p. 18, Handling Hazards, Kasperson et al, 1978, E8
   v. assessment of society's perceptions of benefits and risks of radiation exposures, Desrosiers and Njoku, Risk Limit as Standards 1978 or 9, D22
   vi. Cochran -there are serious deficiencies in other methods of judging the acceptability of risk from rep: (1) risks should be small compared to background - comparison of a cost with an unrelated cost; (2) risk should be small compared to other risks of the fuel cycle - but benefits are the same for all components. p. 79, Johansson and Steen, Ringhals-3, 1978, E10

3. What should be considered in determination of risk acceptability:
   i. <u>not</u> the quality or quantity of radwastes which may be produced in the future - this should not be permitted to influence the decisions on what level of risk associated with such radwastes is acceptable. Curtailment of

production of certain types of radioactive wastes could be determined to be an appropriate waste management control concept in certain circumstances. EPA Criteria for RW/ Rec for Fed Guidance, Fed Reg 1978, C2

ii. variation in potential hazard of wastes from 100,000 to 10 million years after emplacement is very limited and slow - so it is virtually impossible to make a rational case for any specific length of required containment falling within that time interval. Either containment failure is considered acceptable after a period on the order of 100,000 years or containment must be assured for over five million years. From Gera, "Geochemical Behavior of Long-lived Radioactive Wastes", ORNL-TM-4481, 1975, quoted in USGS ES Perspectives 1978, B10

iii. need to take into account the question of scale - i.e. will risk to Sweden be greater if all European countries adopted a KBS plan and if so is the adequacy of the KBS design therefore perceived as less; p. IV 12-13, Appendix Soderbaum and Gillberg p. 2; Also consider the likelihood that future radiation standards will be more stringent than those currently used, either because of a reassessment of the biological effects of radiation or because of the fraction of total future environmental or human body burden which would be assigned to our waste disposal releases. We should recognize that future generations may revise standards and this revision may change the criteria for acceptability of the rep design. Need a thorough review of this subject. p. IV 20-21, Appendix Soderbaum and Gillberg p. 2; What dose is considered safe depends on whether you consider the dose to the individual over a year or over a lifetime, or the dose to a population, over an average lifetime or over a prolonged period until the waste decays - a complete discussion of this is needed for a decision on what is absolutely safe dose level, p. IV 41, KBS Rydberg and Winchester 1978, E9

iv. consider that the trend in radiation protection since World War II has been the lowering of limits and should assume that the trend will continue in the centuries to come, p. viii, EPA State of Knowledge 1979, C7

v. take into account that the future generations get most of the risks while we get all of the benefits, and the risks cannot be clearly defined and estimated, p. 78; "The discussion of acceptable future radiation exposure from the final storage of radwastes has just started." p. 160, Johansson and Steen, Ringhals-3, 1978, E10

4. What level of risk is acceptable/unacceptable?

i. any risks due to radwaste disposal should be deemed unacceptable unless it has been justified that the further reduction in risk that could be achieved by more complete isolation is impractical on the basis of technical and social considerations (ALARA concept); in addition risks should be considered unacceptable if: (1) the risk to a future generation is greater than that acceptable to the current generation; (2) probable events could result in adverse consequences greater than those of a comparable nature generally accepted by society; (3) the probabilities of highly adverse consequences are more than a small fraction of the probabilities of high consequence events associated with productive technologies which are accepted by society (i.e. events likely to occur are acceptable only if adverse consequences are low and of a common type; events with high adverse consequence potential must be virtually certain not to occur.) EPA Criteria for RW/ Rec for Fed Guidance, Fed Reg 1978, C2

ii. it seems unfair to now prepare for delivering higher doses to future people than we today find acceptable for our general public, which is less than for critical groups. The authors suggest that the dose delivered to any future person, wherever he/she may live, shall not exceed 10mrem/year from the whole nuclear fuel cycle and that the contribution from the waste rep be kept considerably below this value, p. II 23, KBS Rydberg and Winchester 1978, E9

iii. Cochran - the cumulative risk to all future generations from radwaste should be less than, or (considering the uncertainties in the calculations) comparable to the cumulative risk to all future generations from the original uranium resources from which the radwastes were derived, assuming these uranium resources were unmined - this criterion was implicitly suggested by KBS, p. 78, Johansson and Steen, Ringhals-3 1978, E10

Abbreviations used in the report

BSPP - bedded salt pilot plant

D&D - decontamination and decommissioning

EPA - Environmental Protection Agency

HLW - high level waste

MPC - maximum permissible concentrations

NRC - Nuclear Regulatory Commission (not to be confused with NAS/NRC - National Academy of Sciences/National Research Council)

NWTSP -National Waste Terminal Storage Program

R&D - Research and Development

Rep - repository

RW - radioactive waste

Radwaste - radioactive waste

RWM - radioactive waste management

SS - site selection

TRU - trans-uranic as in trans-uranic waste

WIPP - Waste Isolation Pilot Plant

U.S. - United States (of America)

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