Geological Criteria for Repositories for High-Level Radioactive Wastes (1978)

Pages
27

Size
6 x 9

ISBN
030933540X

Panel on Geological Site Criteria; Committee on Radioactive Waste Management; Commission on Natural Resources; National Research Council

Geological Criteria for Repositories for High-Level Radioactive Wastes

Panel on Geological Site Criteria
COMMITTEE ON RADIOACTIVE WASTE MANAGEMENT

Commission on Natural Resources
National Research Council

NATIONAL ACADEMY OF SCIENCES
Washington, D.C. 3 August 1978

NOTICE: The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the Councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the Committee responsible for the report were chosen for their special competences and with regard for appropriate balance.

This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

This study was supported by the U.S. Nuclear Regulatory Commission under Contract No. NRC-02-77-162.

Available from
Committee on Radioactive Waste Management
National Academy of Sciences
2101 Constitution Avenue, N.W.
Washington, D.C. 20418

Printed in the United States of America

COMMITTEE ON RADIOACTIVE WASTE MANAGEMENT

EARNEST F. GLOYNA, University of Texas at Austin, Chairman
MICHAEL S. BARAM, Bracken, Selig & Baram (Boston)
STANLEY N. DAVIS, University of Arizona
E. LINN DRAPER, University of Texas at Austin
PATRICIA W. DURBIN, Lawrence Berkeley Laboratory, University of California, Berkeley
JOHN T. EDSALL, Harvard University
MERRIL EISENBUD, N.Y.U. Medical Center
JAMES A. FAY, Massachusetts Institute of Technology
JOHN C. FRYE, Geological Society of America (Boulder, Colorado)
HAROLD L. JAMES, Port Townsend, Washington
ROGER E. KASPERSON, Clark University
KONRAD B. KRAUSKOPF, Stanford University
TODD R. LAPORTE, University of California, Berkeley
JOSEPH LUNDHOLM, JR., National Aeronautics and Space Administration
COLIN A. MAWSON, St. Andrews, New Brunswick, Canada
FRANK L. PARKER, Vanderbilt University
THOMAS H. PIGFORD, University of California, Berkeley
RUSTUM ROY, Pennsylvania State University
EDWARD WENK, JR., University of Washington

Staff:

WINFRED E. BERG, Special Projects Officer
JOHN H. POMEROY, Technical Secretary
JOHN T. HOLLOWAY, Staff Officer
RICHARD I. MILSTEIN, Staff Officer

PANEL ON GEOLOGICAL SITE CRITERIA

JOHN C. FRYE, Geological Society of America (Boulder, Colorado) *Chairman*
WILLIAM R. MUEHLBERGER, University of Texas at Austin, *Vice Chairman*
GEORGE A. COWAN, Los Alamos Scientific Laboratory
HAROLD L. JAMES, Port Townsend, Washington
FRANK L. PARKER, Vanderbilt University
IRWIN REMSON, Stanford University
LAURENCE L. SLOSS, Northwestern University
CHARLES E. WEAVER, Georgia Institute of Technology

Staff:

JOHN H. POMEROY, Staff Officer and Technical Editor

CONTENTS

1. INTRODUCTION

An acceptable repository for high-level radioactive wastes would be a facility that is located, designed, constructed, operated, and tested in such a way that society would be reasonably assured that the potentially hazardous radionuclides sealed in the repository will not enter the biosphere in harmful amounts or levels. This study considers the use of a carefully engineered structure located deep underground in a suitable geological environment. The character and configuration of the local rocks, their structural and tectonic stability, their geochemical properties, the character of contained fluids and their movement, including an evaluation of the deliberate or inadvertent effects due to construction on each of these properties, and anticipated or possible disturbances above or below the repository, are all items of concern.

This study was intended to develop criteria for evaluating the suitability of geological environments for the storage or disposal of high-level radioactive wastes. General criteria were developed; these are presented and discussed in this brief report. A detailed analysis of the interrelationships of these criteria with each other needs to be made when they are applied to specific rock types.

These criteria are not of equal importance, nor are they to be construed as specifications for the construction of a geological repository; rather they are intended as a basis for the determination of the suitability of the repository site. The Panel did not review the following topics, because they were not within the scope of this study: transportation of wastes to the site; institutional or organizational constraints; and other possible methods of disposal such as transmutation and placement into outer space or beneath the ocean floor.

2. STUDY ASSUMPTIONS

The basic assumptions used by the Panel in this study are as follows:

a. The use of a deep repository in a suitable geological environment is the most feasible way at present to attempt the isolation of radioactive wastes from the biosphere for several hundred years in the case of beta- and gamma-emitters, and a few hundred thousand years for the alpha-emitters.

b. The criteria developed in this report are addressed only to the question of terminal disposal of wastes in a repository, not to their temporary storage.

c. Acceptability of a repository will be based on the predicted size of the radioactive releases as a function of time, both as a predictable result of normal events or as a result of unusual events, considered together with their probability and associated errors.

d. The radioactive wastes to be placed into a deep geologic repository will be in a chemically stable, low-leach, solid form, with properties selected to restrict the mobility of the hazardous nuclides, and will not include unmodified spent-fuel elements in a retrievable mode.

e. Based on a careful analysis of the past history of each geological system and others like it, and with some dependence on time symmetry, the future behavior of many geological systems can be predicted for a period adequate for a waste repository system.

f. Based on accepted principles of chemistry, physics, and geochemistry, it is possible to predict an upper limit to the rate of transport of radionuclides in a system of specifically defined geological and hydrogeological variables, thereby providing the bounds of the geologic barrier in a waste isolation system.

g. Movement by ground water is the most probable method by which radioactive wastes might escape from a geological repository.

h. A properly designed repository in a suitable site has hydrological properties that can be predicted with reasonable assurance for about 1,000 years. This is about 30 half-lives of the critical beta, gamma-emitters, strontium-90 and cesium-137.

i. It is possible to identify and select a specific geochemical environment, which includes the surrounding rock, in which the principal long-lived alpha-emitters (i.e., thorium and the transuranic radionuclides neptunium, plutonium, americium, and curium), when placed in a properly designed system, will be essentially immobile for about 100,000 years. After this time, radium-226 would be the isotope of concern.

j. Present considerations suggest that the volume of a single repository will probably be in the range of 3,000 to 3 million cubic meters (100,000 to 100 million cubic feet).

k. The integrity of a repository site will not depend upon continued human supervision or action.

3. GEOLOGICAL CRITERIA

It is generally understood that when high-level radioactive wastes are placed in a deep geological repository, the geological, hydrological, and geochemical environments of the repository are among the principal barriers to the migration of hazardous radionuclides to the biosphere. This section of the report reviews the various factors that should be carefully considered in the evaluation and choice of such a total environment.

3.1 Geometrical and Dimensional Criteria

This section of the report is concerned with the physical location of the waste repository with respect to the surface of the ground or to the boundaries of the rock body containing the repository.

3.1.1 The repository should be at a depth sufficient to separate the repository from any surficial process or event that might cause a breach of the repository.

Most surface and near-surface forces or phenomena, such as weathering and wind scour, are confined to relatively shallow depths. The scour of advancing continental ice, however, may extend in some places to depths in excess of 300 meters, and long continued stream erosion, active over some tens of millions of years, may cut to great depths, as in the Grand Canyon. The geologic locale and the depth of the repository chosen should be such as to eliminate the possibility of even such extreme conditions of scour or erosion. The effects of a major meteorite impact or the largest man-made explosions at the surface would penetrate to a depth no greater than 100 meters, although fractures may extend beyond this depth. Therefore, if burial were deeper than a few hundred meters, protection against the latter two events would be adequate.

3.1.2 The size and shape of the specific body of rock in which a repository is to be constructed should be adequate to allow room for both the repository and also a sufficiently large buffer zone around the repository.

Shapes of prospective host bodies of rock fall into two major classes: (1) tabular or stratiform, and (2) equi-dimensional to irregular. Stratiform bodies include sedimentary rocks, volcanic flows, and igneous sills commonly occurring as horizontal or gently inclined successions. Such bodies tend to be markedly anisotropic or non-uniform in many significant properties. Hydrological transmissivity of water flow, for example, may be significantly greater parallel to stratification than across it; therefore, the areal extent of undisturbed strata of repositories in tabular bodies would commonly require special consideration of tabular or discoid shapes. Equidimensional and irregular bodies may include a variety of igneous intrusions plus plugs, domes, or diapirs of gypsum, anhydrite, mud, or salt. Such bodies are commonly relatively isotropic with respect to transmissivity and other pertinent properties and would require appropriate shapes of buffer zones and barrier envelopes.

3.1.3 Information on the geometry and physical, chemical, and mineralogical properties of the prospective host rock body and the associated rocks is essential in advance of development of the site.

It is implicit in this criterion that samples of rocks be recovered by core-drilling for laboratory analysis. Further, such boreholes would be utilized for in-hole geophysical logging and, perhaps, for stress measurements and tests of other characteristics. However, each borehole presents a danger of subsequent leakage of fluids and of weakening the mechanical integrity of the host body and surrounding rocks, especially as the rock is heated. Therefore, all boreholes not subsequently used as pilot holes for shafts, etc., would require extraordinary care in sealing and plugging.

The number of exploratory and test boreholes can be minimized by the use of available non-penetrative geophysical techniques to acquire information of the geometry, character, and fluid content of prospective rock bodies. Additional non-penetrative techniques, such as those using multi-channel seismic reflection, are currently in the experimental stage and show much promise; their continued development should be encouraged.

In selecting a repository site, preference should be given to a site that can be mapped with the greatest level of confidence without disrupting the future integrity of the site, and that can be expected to present the fewest surprises.

3.2 Long-Term Stability Criteria

Because the radioactive wastes must be controlled over a long period of time, the repository should be chosen and designed to provide long-term isolation. This section summarizes the criteria required for such stability.

3.2.1 The repository should lie within a structurally stable geological block and not near a tectonic boundary.

Regional changes in the position of a structural block will not necessarily affect the stability of a repository. However, the boundaries of a block are where stress concentrations could occur that might open fractures that would change the conditions in that marginal zone. Rates of geological movement are small; differential rates between blocks may range from essentially zero (fractions of a millimeter per year in the interior plains region) to a few centimeters per year (e.g., along the San Andreas Fault).

Diapirism is the upward intrusion of a material that is plastic under pressure, such as rock salt or clay. The rate of diapirism at a site, which can be influenced by the mechanical, thermal, and chemical stresses in the rock resulting from the construction and operation of a waste repository, must be low enough so that, during the required period of isolation, the waste will not reach a location where the containment might be breached by either fracture, flow, or solution. The required period of isolation extends through the period during which the radioactive waste presents an unacceptable hazard to the biosphere.

3.2.2 Faults along which rupture could occur must be avoided.

Faults that are seismically active or for which there is geomorphologic evidence of slip during the last million years of the Quaternary Period can be expected to move again--and possibly within the lifetime of the repository. The movement along the faults may unpredictably change the estimated values of the parameters of containment; therefore, a repository should not be placed in such a location. Seismic shaking is not a significant problem in the design of underground workings, and surface facilities can also be designed to be earthquake resistant. Meteorite impact and large-scale, man-made explosions could destroy surface installations. The probability of a large natural or man-made explosion producing a cavity more than 100 meters deep is vanishingly small, although fracture propagation may penetrate to greater depths.

3.2.3 Areas with abnormally high geothermal gradients or with evidence of relatively recent volcanic activity are possible candidates for future volcanic events and should be avoided.

Igneous activity is not a random process but is concentrated along active tectonic boundaries or above so-called geological "hot spots." An area that has experienced volcanic activity in the Quaternary Period is likely to have further activity in the future. Generally, the total geologic environment must be considered in evaluating these manifestations.

3.2.4 The mechanical and geophysical properties and the state of stress in the repository host rock should be such as to ensure the stability of the repository during its operation.

The facility must remain open at the operating temperature without failure or collapse during the period of active operation. The design of excavated vaults and the spacing of passageways should be such that the maximum stresses resulting from the cavities, thermal stress, and inherent state of stress in the wall rocks should be well below the critical value of the uniaxial compressive strength of the rock.

3.2.5 Backfilling and sealing of each segment of the mine cavity should be accomplished as soon as the waste is in place and the final checking and proving of that part of the facility has been completed.

Backfilling and sealing of the cavities would inhibit ultimate roof collapse and prevent subsidence fractures from propagating from the repository vaults and tunnels through the host rock and possibly breaching the containment of the repository.

3.2.6 To keep the design and operation of a repository simple, and to reduce the number of variables in the total system, unchopped and unreprocessed fuel elements should not be placed in retrievable storage in a geological repository designed for the permanent disposal of radioactive wastes.

It is important to keep the total design, construction, and operation of the repository and its associated facilities as simple and well-understood as possible. Reducing the number of variables in the total system helps to increase the confidence of predictions on the long-term effectiveness of the repository.

Introduction of unchopped and unreprocessed spent fuel elements for retrievable storage into a repository used for the permanent disposal of radioactive wastes creates complications that could be avoided. These could include the potential problems of leakage of volatile radionuclides, increased geochemical interactions with the host rock, and the contradictory design and operational requirements for both permanent disposal and temporary storage of wastes. The potential rates of escape of radionuclides to the biosphere would be significantly higher than the rates characteristic of wastes that had been chemically processed for optimum stability.

While the Panel was primarily concerned with the criteria needed to determine the suitability of sites for geological storage or disposal of high-level wastes, it was also concerned with the effects of this dual objective on such factors as the size and design of entry and exit shafts, vault ceiling heights, geochemical options, and the indefinite maintenance of a repository environment suitable for safe retrieval operations.

3.3 Hydrological Criteria

Because movement by water is the most probable means by which radionuclides might escape to the biosphere, the hydrological factors of the waste repository are among the most critical in choosing a site.

3.3.1 Hydrologic analysis of the perturbed geologic system involving a repository must determine that fluid transport will not move hazardous material to the biosphere in amounts and rates above prescribed limits.

The hydrologic performance of a geological material or structure depends upon the hydrogeologic system of which it is a component. Therefore, a hydrologic analysis must take account of the hydrologic and geochemical properties of the total geologic system, including its perturbation by the construction and presence of the repository, the specific geologic materials, the transported radionuclides, the transporting fluids, and the chemical and physical properties of the sources of radionuclides in the repository. The specific hydrological parameters are the dispersivity and the ground water flow rates, which are largely determined by factors such as porosity, permeability, fractures, and hydraulic heads and gradients in the geological environment.

3.3.2 Because the vertical shafts of an underground repository may be the most probable route for the hydrological transport of radionuclides to the active biosphere, a geological system should be selected that can be satisfactorily plugged and sealed when the repository is closed, and suitably monitored to ensure that the behavior of the overall hydrogeological system will continue to function satisfactorily after closure.

The sequence of overlying rock units, the host rock, and the plugs and seals of the shafts are among the most critical of the barriers inhibiting the migration of the radionuclides to the biosphere. The plugs and seals should be credibly expected to stay secure against leakage without maintenance or repair for a long time relative to the half-lives of the waste radionuclides.

3.3.3 The geological record of previous hydrological conditions, or the paleohydrogeological record, should be such that predictions can be made that are favorable for long-term hydrological isolation of the repository site in a perturbed geologic environment.

Many areas that are deserts today were lake beds a few thousand of years ago, and may be lake beds again in the not-too-remote future, geologically speaking.

Long-range climatic predictions are uncertain, especially in view of the increasing significance of human activity (cf. increased production of carbon dioxide, destruction of tropical forests, diversion of rivers, and pollution of water and air). Probable future hydrological conditions must be carefully considered in evaluating the geological suitability of a repository site.

3.4 Geochemical Criteria

It is important to consider the geochemical factors in a perturbed environment when a waste repository site is selected and a repository is constructed, because the geochemical properties and reactions of the radionuclides determine their mobility between the initial site and the biosphere.

3.4.1 Radioactive heat and radiation should not reach levels high enough to produce physical and chemical reactions in the repository rock that would compromise the geological containment.

To ensure that thermally induced geophysical processes remain within predictable limits, an upper operating temperature should be prescribed for every combination of repository rock type and waste form and composition for the operating life of the repository. Over a period of hundreds of years, the radioactive heat will accelerate diagenetic reactions that will affect rock properties such as porosity, pore water volume, transmissivity, exchange capacity, ion retardation, rock volume and thermal diffusivity, including, in the case of salt, the migration of fluid inclusions toward heat sources. While the chemical and physical effects of radiation will be minor, radiation-induced distortion of the crystal lattices of minerals will generally increase their solubility and decrease their thermal stability.

3.4.2 The interaction of water, repository rock, and the waste material should be controlled in such a way as to minimize the rate of dissolution of the waste form.

The choice of the form of the waste, its container, the properties of the specific host rock, the composition of the available water, the ambient temperature and pressure, the nature of any intentionally added materials, and the equilibrium constants of the possible chemical reactions define a complex interacting chemical system that determines the rate at which dissolved species become available for hydrological transport. This subject, including the appropriate values of the partitioning coefficient between crystals and fluids, is beyond the scope of this study and needs to be considered in a more comprehensive and systematic way than has been the case to date.

3.4.3 Water in the repository, if present, should not react chemically or physically with the repository rock to increase its permeability, which would compromise geological containment.

Interaction of water with the repository rock, especially as the temperature rises, could alter containment of the radionuclides by affecting the frequency and size of fractures, solution cavities, pore space, and channels within the rock. The extent of such interactions would be affected by the mineralogy of the host rock, the amount and composition of the water and the nature of its transport within the rock, the initial size and spatial distribution of pores within the rock, and thermal effects.

3.4.4 The properties of the geochemical system of the radionuclides, the repository rock, and its associated water should be such as to restrict or prevent the mobility of the radionuclides and to delay or prevent their migration to the active biosphere.

The chemistry of the hydrological transport processes of most of the reactor waste products is likely to be quite complex. Sorption of dissolved ions by the minerals of the rock can be a significant factor in reducing the mobility of radionuclides. The rate and fraction of each product carried to the biosphere will thus be critically affected by the immediate geochemical-mineralogical environment. This environment can be further managed by the addition of appropriate materials such as zeolites, clays, or other ion-exchange minerals or resins. On the basis of presently available data, it is evident that the retention of the long-lived alpha-emitters of neptunium, plutonium, americium, and curium can be sufficiently high in certain geochemical-mineralogical environments to strengthen assurance of long-term containment. Laboratory and in situ experiments in this area should provide quantitative answers on nuclide migration and would suggest improved procedures for waste management.

4. GEO-ECONOMIC CRITERIA

This section of the report is concerned with the effect of exploration for mineral resources on the physical integrity of the geological environment of the repository site.

4.1 No area with a present or past record of resource extraction, other than for bulk materials won by surface quarrying, should be considered as a geological site for radioactive wastes.

This restriction rests on one or more of three possible considerations:

a. present or predictable future importance as a potential source of needed raw materials;

b. disturbance of the natural hydrologic regime in consequence of present or past underground development and exploration, such as tunneling, hydraulic fracturing, etc., resulting in greater uncertainty as to the paths and volumes of fluid flow; and

c. potential attractiveness to future developers and explorers for natural resources who may be drawn to the area by evidence of past activities of resource extraction.

The construction and operation of a repository for radioactive wastes should not create a potential future source for valuable materials; therefore, unreprocessed spent fuel elements should not be placed in a non-retrievable repository for radioactive wastes. (Criterion 3.2.6 also precludes their retrievable storage in a repository.) If spent fuel elements were disposed of in a non-retrievable repository in this way, it would localize fissionable material that would be potentially highly valuable to future mankind, and therefore make the repository highly attractive to future explorers for natural resources whose searches for fissionable uranium and plutonium could violate the security of the repository. Although the generation of heat by radioactive wastes may be considered a potential resource, it is not considered of sufficient value to attract future explorers for natural resources.

4.2 No area should be considered as a potential site for a repository unless sufficient geological information is at hand to provide a basis for a resonable analysis of resource potential.

Analysis of resource potential does not mean a full resource evaluation, since in general this could not be done without many closely spaced drill holes, which in themselves could compromise or eliminate the site for consideration as a repository. It does, however, mean a dependable appraisal of the kinds of resources that may be present (including those of low-grade or unorthodox character), their general configuration and probable distribution, and their potential for either present or predictable future economic exploitation.

4.3 No area adjacent to an actual or potential major dam site should be considered as a potential site for a repository.

The flooding of a large area behind a dam will profoundly modify the hydrologic system. It may take many decades for the area to come into equilibrium with the perturbing force. Further, the added water load on the reservoir floor and the introduction of fluid to greater depths may induce unpredictable seismic disturbances. Several earthquakes in the past have been attributed to this effect.

APPENDIX

A BIBLIOGRAPHY OF PUBLISHED REPORTS FROM THE COMMITTEE ON RADIOACTIVE WASTE MANAGEMENT (CRWM) COMMISSION ON NATURAL RESOURCES NATIONAL ACADEMY OF SCIENCES/NATIONAL RESEARCH COUNCIL

September, 1978

(For availability, see Note 3)

1. Radioactive Wastes at the Hanford Reservation: A Technical Review
   Report of the NRC Panel on Hanford Wastes, March 1978. Available as ISBN 0-309-02745-3; xvi + 269 pp., paperbound, $8.50 (See Note 1)
2. The Shallow Land Burial of Low-Level Radioactively Contaminated Solid Waste
   Report of the NRC Panel on Land Burial, December 1976. Available as ISBN 0-309-02535-4; xvii + 150 pp., paperbound, $7.00 (See Note 1)
3. Interim Storage of Solidified High-Level Radioactive Wastes
   Committee on Radioactive Waste Management, Panel on Engineered Storage, National Research Council, Washington, D.C. 1975. Available from Printing and Publishing Office, National Academy of Sciences, as ISBN 0-309-02400-5; viii + 82 pp., Paperbound, $8.50 (See Note 1)
4. An Evaluation of the Concept of Storing Radioactive Wastes in Bedrock below the Savannah River Plant Site
   Committee on Radioactive Waste Management, Panel on Bedrock Disposal, National Academy of Sciences, Washington, D.C. 1972. Available from Printing and Publishing Office, National Academy of Sciences, as ISBN 0-209-02035-2; viii + 88 pp., paperbound, $3.50. Microfiche available from NTIS - PB212962 (See Notes 1 and 2)

5. Disposal of Solid Radioactive Waste in Bedded Salt Deposits
Committee on Radioactive Waste Management, Panel on Disposal in Salt Mines, November 1970. 28 pp., Published by U.S. Government Printing Office, Washington, D.C.; Available from NTIS - PB 265197; papercopy $4.00; microfiche $3.00 (See Note 2)

6. Report to the Division of Reactor Development and Technology, United States Atomic Energy Commission
NAS/NRC Committee on Geologic Aspects of Radioactive Waste Disposal, May 1966, National Research Council, 100 pp. Available from NTIS - PB 265196; papercopy $5.00; microfiche $3.00 (See Note 2)

7. The Disposal of Radioactive Waste on Land
Report of the NRC Committee on Waste Disposal of the Division of Earth Sciences, National Academy of Sciences/National Research Council, Washington, D.C., September 1957. Publication 519. 144 pp. Available from NTIS - PB 130035/AS; papercopy $6.00; microfiche $3.00 (See Note 2)

STUDIES IN PROGRESS:

8. The Solidification of High Level Radioactive Wastes
Sponsoring Agency: Nuclear Regulatory Commission
Estimated Publication Date: October 1978

9. Implementation of Long-Term Radioactive Radiation Standards: The Issue of Verification
Sponsoring Agency: Environmental Protection Agency
Estimated Publication Date: November 1978

10. Radioactive Waste at the Savannah River Plant: A Technical Review
Sponsoring Agency: U.S. Department of Energy
Estimated Publication Date: September 1979

Note 1: Printing and Publishing Office, National Academy of Sciences, 2101 Constitution Avenue, N.W., Washington, D.C. 20418 (orders for reports must be prepaid)

Note 2: NTIS is the National Technical Information Service, operated by the U.S. Department of Commerce, 5285 Port Royal Road, Springfield, Virginia 22161

Note 3: Copies of completed reports in this list are on file at the Library of the National Academy of Sciences. They may be obtained upon request through inter-library loan. If necessary, photocopies of out-of-print reports can be made by the NAS Library, but will be charged for at the current service rate. The Library is located at 2101 Constitution Avenue, N.W., Washington, D.C. 20418.