Heat, High Water, and Rock Instability at Hanford

A Preliminary Assessment of the Suitability of the Hanford, Washington Site for a High-Level Nuclear Waste Repository

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WITH A SUPPLEMENT BY DONALD E. WHITE, PH.D.

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PREFACE

Many citizens and local and state governments have become increasingly concerned that the disposal of high-level radioactive wastes in repositories might cause irreparable harm to future generations and to the environment, including water and farmland. To address these concerns, the Health and Energy Institute initiated a project in 1983 to examine the questions associated with high-level radioactive waste disposal. Our initial focus was on the high-level wastes generated by the nuclear weapons program and stored at the federal Hanford Nuclear Reservation in Washington State, the Idaho National Engineering Laboratory in Idaho (INEL), and the Savannah River Plant in South Carolina. This was mainly because most of these wastes are stored in liquid and sludge forms, which are particularly dangerous because they are mobile. In this connection, we examined a broad range of questions -- from the process which the U.S. Department of Energy has chosen to glassify the liquid wastes, to the problems associated with repository construction and operation, and the ability of such a scheme to protect the health and safety of our generation and future generations.

During the course of this wide-ranging effort, we examined much official and technical literature which revealed serious deficiencies in the repository site selection procedure which has been followed by the U.S. Department of Energy. In particular, we accumulated a considerable body of evidence regarding the possible problems that might arise if Hanford, Washington, was selected as the place for the high-level nuclear waste disposal.

We had planned to include an analysis of these matters as one part of a report on the Department of Energy's plans for disposal of the high-level radioactive wastes at Hanford, INEL, and the Savannah River Plant. Two events caused us to change course and opt instead to prepare a special report on the Hanford site.

The first was the discovery of a background report by Dr. Donald E. White, which he prepared for the Panel on Radioactive Waste Isolation

Systems of the National Research Council of the National Academy of Sciences. The second was the decision by the Department of Energy to include the Hanford site as one of the three prime candidates for high-level nuclear waste disposal, from among the nine it had announced earlier.

Dr. White, a member of the National Research Council Panel on Radioactive Waste Isolation Systems and an employee of the U.S. Geological Survey (full time 1939 to 1981, now a retired annuitant), prepared the paper on the Hanford site at the request of the panel, which, after due deliberation, incorporated the substance of the paper into its own report, A Study of the Isolation System for Geologic Disposal of Radioactive Wastes. In that report, the panel referred to the forthcoming publication of Dr. White's paper by the National Academy of Sciences. However, Dr. White's paper was never published. We obtained a copy and found it raised the possibly serious problems that may arise at Hanford in a forthright manner which the public had the right to know. In order to further that purpose, Dr. White has kindly consented that his entire paper be reproduced as an appendix to our report.

The selection of Hanford as one of the top three sites in the next to last stage of DOE selection has the clear implication that the Department and its contractor at Hanford, Rockwell, feel that this site, along with the other two selected in December, is likely to be better than many other possible sites, and may meet all the requisite performance standards. The information and analyses that we have examined tends to point to the contrary conclusion. Moreover, the Department of Energy and Rockwell have tended to minimize very serious concerns, including those of safety and adequacy of its testing plan. The Nuclear Regulatory Commission has gone so far as to state, in reference to a Rockwell-DOE analysis of site suitability, "No specific issues have been identified for the interval through permanent closure for either operational safety or retrievability" and that the DOE plan "did not exhibit a commitment" to address these issues.

It is this last factor, the failure to address crucial issues seriously enough, that is perhaps the most troublesome. Given the wide range of problematic information about the Hanford site, we decided to prepare and issue a report as soon as feasible for examination by the public and concerned governmental and technical institutions. The constraints of time and resources, as well as the fact that our initial plan was focused on a somewhat different report, make this report necessarily a preliminary one. New documents have been published since we began writing our report, and we have not been able to update all footnotes. Much of the information in this report has already been made public. We have added our analysis, raised issues that have only recently come to light, and organized the information into one accessible document. This report can be used in commenting on the Environmental Assessment, and DOE may be swayed to rethink its decision.

We have been helped in essential ways by many people. Most of all, we would like to thank Dr. Donald White for making his report available to us to be reprinted along with ours. He is an elected member of the National Academy of Sciences, and was the 1984 recipient of the highest award in American geology -- the Penrose Medal of the Geological Society of America. Don Hancock of the Southwest Research and Information Center kept us abreast of local events around the country with his excellent briefing papers and clipping service. J. Davitt McAteer, Director of the Occupational Safety and Health Law Center, provided useful insights into the mining aspects of the proposed repository.

Nina Bell, Larry Caldwell, Bernd Franke, Don Hancock, Pat Hastings, Dr. Harold L. James, Dr. Michio Kaku, Victor LaCourse, Linda Lehman, Ayn Lowry, Chuck Magraw, Davitt McAteer, Samuel Milham, Caroline Petti, Marvin Resnikoff, Dean Tousley, Dr. Donald E. White, and Laura Worby kindly reviewed the report at very short notice and provided useful suggestions. Dave Berick of the Environmental Policy Institute and Linda Lehman, consulting hydrogeologist, also provided many useful materials. Jon Pinkus helped with the research and typed the report. Bob Alvarez and Debbie Sheftz have helped with production, and John Kelly helped publicize it. Special thanks to Bernd Franke and Lesley Haas for access to and assistance with their computer.

We hope this report will make a contribution to helping raise the questions of health and safety associated with high-level radioactive waste disposal, for this and future generations, in a more concerted manner.

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CHAPTER 1

Summary and Recommendations

> The geologic and some hydrologic aspects of BWIP [Basalt Waste Isolation Project] (excluding geochemical relations) are unfavorable enough to raise serious questions about its eventual suitability as a repository. Most of these questions can either be resolved or intensified, perhaps fatally, prior to major construction commitments.
>
> -- Donald E. White, Ph.D.
> U.S. Geological Survey

> A major reason for considering basalt for repositories is its abundance in Federal land near Hanford, Washington, and the Idaho National Engineering Laboratory and not its overall favorable characteristics.
>
> -- Panel on Radioactive Waste Isolation Systems of the
> National Research Council of the
> National Academy of Sciences

The construction of a radioactive waste repository at Hanford and the subsequent placement of high-level wastes in it is likely to be a dangerous mining operation with possible high costs in lives and money. The geologic and hydrologic characteristics may be so adverse that the site could violate every one of the major performance standards required by the U.S. Nuclear Regulatory Commission (NRC). Moreover, the site may be so complex that it may be difficult to have reasonable confidence that it will contain the wastes, as required, even after long and expensive efforts at site characterization.

For these reasons, a number of people and institutions, including the National Academy of Sciences panel on Waste Isolation, have concluded that the choice of Hanford, among the three sites chosen as the most likely ones for the first repository, would appear to be more politically expedient than technically sound. One of the other two proposed locations, on the Nevada Test Site, is also on federal land.

The only private land site is in Deaf Smith County, Texas, one of the richest agricultural areas of the country. Examination of basalt and tuff was undertaken because DOE saw advantages in locating a repository on federal/DOE controlled land rather than on the inherent suitability of these rock formations.

Hanford, in south central Washington State, has been a principal center for federal nuclear activities since 1943. The plutonium for the Nagasaki bomb was made there. There is one large operating nuclear reactor (the N-reactor), a plutonium-fueled test reactor (FFTF), one nuclear fuel reprocessing plant, and a variety of research projects on the site. Fifty million gallons of high-level radioactive wastes are stored there, in addition to millions of cubic feet of other radioactive wastes. The Columbia River, one of the country's largest, flows through the site. The radioactive waste disposal repository would be about 5 miles from the nearest point on the river. Both surface water and groundwater are used for irrigation, which is widespread in the larger region.

The rocks in which the repository would be built are lava flows known as basalts. One of the thickest lava flows, which is part of a thick flow-complex comprising the Grande Ronde Basalt, more than 2,500 feet deep, would be the location of the proposed repository. The relatively thick and intact basalt layers under the site are interspersed with highly fractured, water-bearing layers and with sedimentary rocks. There are vertical fractures in the rock which may be partly sealed or open enough to permit some water flow between layers. The geology and hydrology are acknowledged to be exceedingly complex -- one of the principal conclusions so far of relatively intensive study of the Hanford site (compared to other potential sites).

The lava flows of the Grande Ronde Basalt are probably heavily stressed, with horizontal stresses being two or more times the vertical stresses. This high ratio of horizontal to vertical stresses is the likely cause of the severe fracturing of core samples into poker-chip shaped discs. According to Donald E. White, Ph.D., U.S. Geological Survey, this indicates that intense rock bursting may be encountered in the lava flows where the repository is to be located. Such bursting could have serious results:

- compromise safety of the mining operation and the workers
- cause the repository to encroach on adjacent aquifers
- compromise shaft stability
- make waste retrievability more difficult

Widespread and/or intense rock bursting could also compromise long-term performance by providing paths for more rapid flow of water between aquifers and the repository. As it is, even without this, the repository is expected to become filled with water ("resaturate") a few years or decades after permanent closure.

The potential for rock bursting may also create a conflict between repository safety and long-term repository performance. One of the principal methods used to prevent accidental rock bursts from injuring or killing people is to measure rock stresses and deliberately induce rock bursting by blasting the area. The use of this preventive technique could, however, increase the water flow between the repository and aquifers, providing more and faster routes for the escape of radioactive wastes into the environment.

Mine safety and health is likely to be further complicated by substantial seepage of hot water from the copious aquifers above it, by the high rock temperatures (more than 120 degrees F.), and by the release of methane gas contained in the water into the mine. (The presence of substantial quantities of methane in the groundwater was recently discovered by DOE.)

Dr. White has noted in his paper that these problems "may each be individually tractable, but all in combination may be intolerable in cost of money, time, energy, and loss of lives, especially if rock bursting is frequent and difficult to predict." (See appendix.)

Mine construction and operational safety may also come into conflict with water use in the region. According to the NRC, there are frequent "microearthquake swarms" in the area, which are roughly correlated with the use of irrigation, though no causal connection has been established as yet. While these microearthquakes are too small to affect surface activities, they may affect the stability of the mine shafts. If that proves to be the case, continued or expanded irrigation in the area would come into conflict with mine safety.

The long-term performance of the mine as a repository for the wastes also appears to be faced with serious difficulties and uncertainties. The NRC has established the following standards for the performance of the waste form and other "engineered barriers" which contain the wastes and the geologic repository:

- engineered barriers should contain the wastes essentially completely (containment should be substantially complete) for 300 to 1,000 years

- the leakage from the engineered barriers after that time should not be more than 1 part in 100,000 per year of the wastes still existing after 1,000 years

- the water travel time from the repository to the "accessible environment" should be more than 1,000 years

The U.S. Department of Energy (DOE) estimates water travel times to be 10,000 years or more. While this may be one reasonable inference from the data, Dr. White has noted that "[f]low patterns are very complex in detail . . . [and] cannot be modeled reliably. . . ." Using the same data as DOE, the Nuclear Regulatory Commission came up with estimates of water travel times ranging from 20 years to one million years.

DOE has not yet selected the waste form in which it will encapsulate spent nuclear fuel from civilian power plants. Hence, it is not possible to evaluate the ability of the repository to contain the radioactive wastes on the basis of scientific experimental evidence. However, DOE has selected borosilicate glass (essentially the same as the "pyrex" glass with which kitchenware is made) as the waste form to encapsulate the military high-level wastes. This waste may be put in the same repository as civilian waste.

Laboratory data from a DOE-sponsored program indicate that if water flow is slow, a protective layer of chemicals builds up on the surface of the glass, substantially slowing down dissolution of the waste form and of the radionuclides in it. If this same phenomenon also occurred in a repository, it would be reinforced by the favorable water chemistry of the groundwater in the repository location at Hanford.

This potentially favorable factor may, however, be nullified by the rapid water flow at Hanford. The same data indicate that no protective layer is built up if water flow is fast enough and that the glass is rapidly corroded. As much as 1 part per 1,000 to 1 part per 10,000 per year may be lost to the groundwater. This is ten to one hundred times the maximum loss from the engineered barrier system permitted by the NRC. Moreover, the repository will be wet, and rock bursting may put many waste packages into communication with aquifers. This means that substantial amounts of radionuclides may be leached into the water well before the 300 year minimum required for complete containment by the NRC. The possibility would be increased if rock bursting damaged some of the waste packages.

There is one other potentially favorable factor at Hanford. Some of the radionuclides may be deposited ("sorbed") onto the rocks from the water, slowing down their release to the environment. However, this favorable factor may be nullified by the presence, or formation from methane, of certain organic compounds in the water. Some of these compounds, known to be present in Hanford groundwater, may form "complexes" with radionuclides like plutonium. If that happens, the radionuclides would not be as strongly sorbed onto rock surfaces or by the soil, but tend to travel with the groundwater. Thus, discharges of substantial quantities may begin soon after repository closure or even before closure. The repository is expected to be open for receipt of wastes for about 30 years.

In sum, the Hanford site is confronted with an immense array of safety, cost, and technical problems. It is a complex site and very difficult to model. In spite of this, DOE has tentatively selected it as one of the top three candidates for detailed site characterization.

DOE's expedient methods, its tendency to downplay serious problems, and its lack of sensitivity to public concern have come under attack from public officials from the very first high-level waste disposal project it undertook at Lyons, Kansas. Perhaps for that reason, it has selected Hanford, where opposition is reported to be less than at other sites, and the Nevada Test Site, both of which are on federal land. It would be unfortunate, and an injustice to future generations, if a site for immense quantities of long-lived radioactive wastes were selected out of political expediency, rather than on the technical merits.

To help avoid that outcome, we recommend the following policies in relation to the Hanford site:

(1) DOE should prepare a detailed study showing how it would comply with the Mine Health and Safety Act of 1977, including the applicable regulations, at Hanford.

(2) Although not required by the Nuclear Waste Policy Act of 1982, the activities of site characterization at Hanford may have significant impacts which are likely to be extensive and costly, so DOE should prepare an environmental impact statement on the effects of site characterization at Hanford.

(3) DOE and its contractor, Rockwell International, should make available all the data on the Hanford site to the States of Washington and Oregon, and to a competent body such as the National Research Council of the National Academy of Sciences or the Congressional Office of Technology Assessment (in addition to the NRC, as already required by the Nuclear Waste Policy Act) to enable the preparation of an independent site characterization report.

(4) The site selection procedure has been challenged by several of the state governors involved. The site selection procedure used so far raises sufficient questions that it should be evaluated for technical adequacy by the National Academy of Sciences or the Office of Technology Assessment. If serious inadequacies are found, the whole process should be redesigned to assure the long-term safety of the ultimate repository.

(5) Hanford should be removed from the list of the nine possible sites being considered until the above studies are completed, at which time a re-evaluation of its status can be performed. (This in no way suggests that other proposed sites are necessarily adequate or better sites.)

CHAPTER 2

Scope of the Report

The U.S. Department of Energy (DOE) tentatively identified three "finalist" sites for site characterization and possible construction of the first long-term disposal repository for high-level radioactive wastes on December 19, 1984. Sites at Hanford, Washington; Yucca Mountain, Nevada; and Deaf Smith, Texas, were chosen from nine potential sites that were under consideration by the DOE. Davis Canyon, just outside Canyonlands National Park in Utah, and Richton Dome, a salt dome near Richton, Mississippi, were chosen as alternates.

The DOE site selection enabled the agency to meet one of the first deadlines established under the Nuclear Waste Policy Act of 1982, which sets the schedule for developing a high-level radioactive waste repository by 1998. The schedule established by the Nuclear Waste Policy Act of 1982 calls for identification of five sites by January 1985, and presidential approval of three of those sites by July 1985. Site characterization studies are to be conducted at the three chosen sites, with selection of the first repository by March 31, 1987. DOE is charged with submitting a construction application to the Nuclear Regulatory Commission (NRC), and the NRC must approve or disapprove the application by 1990. The repository is expected to be operational by 1998 under the proposed schedule. (See Figure 2-1). DOE has already recognized that the time allowed for site characterization is too short and that the earliest that the first repository site could be chosen is 1990.[1]

The DOE chose one site from each of three different rock types under consideration in the first phase of site selection for deep mine excavation for a nuclear waste repository. The three geologic formations

[1] Draft Mission Plan for the Civilian Radioactive Waste Management Program, DOE/RW-0005 DRAFT, Vol. I, p. 3-A-40.

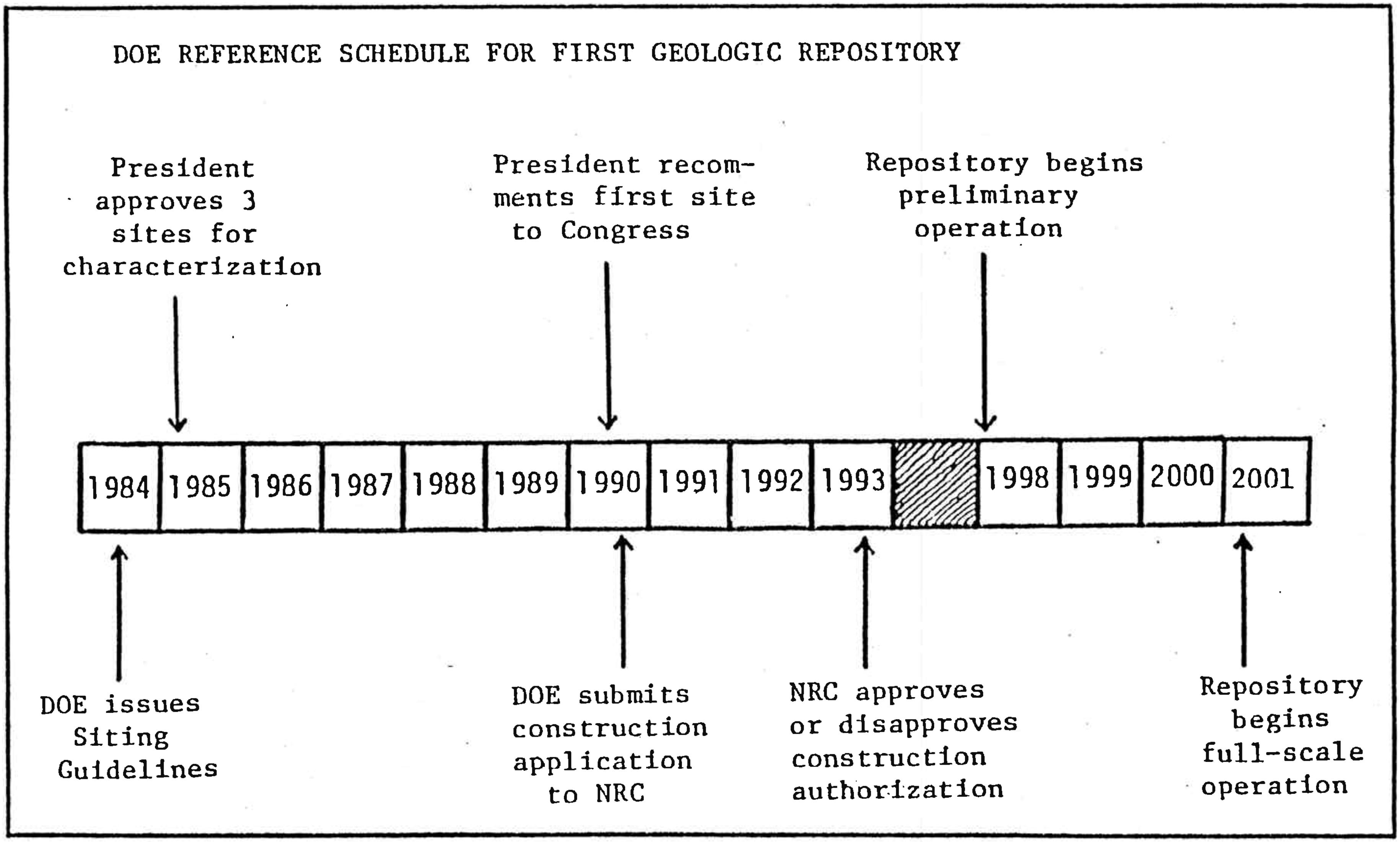

FIGURE 2-1 DOE REFERENCE SCHEDULE FOR FIRST HIGH-LEVEL NUCLEAR WASTE REPOSITORY

Source: Worby, Laura D. THE CITIZEN'S NUCLEAR WASTE MANUAL, Nuclear Information and Resource Service, Washington, D.C., p. II-10 (1984).

under consideration are salt, tuff (explosively erupted volcanic rocks), and basalt (lava flows).

Salt formations were the first proposed geologic formations for long-term storage of radioactive wastes, and the first site promoted for a repository by the Atomic Energy Commission was a central Kansas salt mine. Seven of the nine sites currently under review by DOE were salt formations. Salt domes were formed by a process called diapirism. Salt formations were chosen because they are believed to be geologically stable.[2]

The other two geologic formations are volcanic in origin. Tuff is the term used for explosively erupted volcanic rocks. Basalt is a rock formed by the cooling of volcanic lava flows. (See Table 2-1 for the nine sites screened by DOE for site characterization, and Figure 2-2 for a map noting these sites.)

TABLE 2-1

POTENTIAL SITES CONSIDERED BY DOE FOR THE FIRST HIGH-LEVEL NUCLEAR WASTE REPOSITORY

Salt formations:	1. Cypress Creek Dome, Mississippi
	2. Richton Dome, Mississippi
	3. Vacherie Dome, Louisiana
	4. Deaf Smith County, Texas
	5. Swisher County, Texas
	6. Davis Canyon, Utah
	7. Lavender Canyon, Utah
Tuff:	8. Nevada Test Site, Nevada
Basalt:	9. Hanford Nuclear Reservation, Washington

[2] Worby, Laura D. The Citizen's Nuclear Waste Manual, Nuclear Information and Resource Service, Washington, D.C., p. VI-28 (1984).

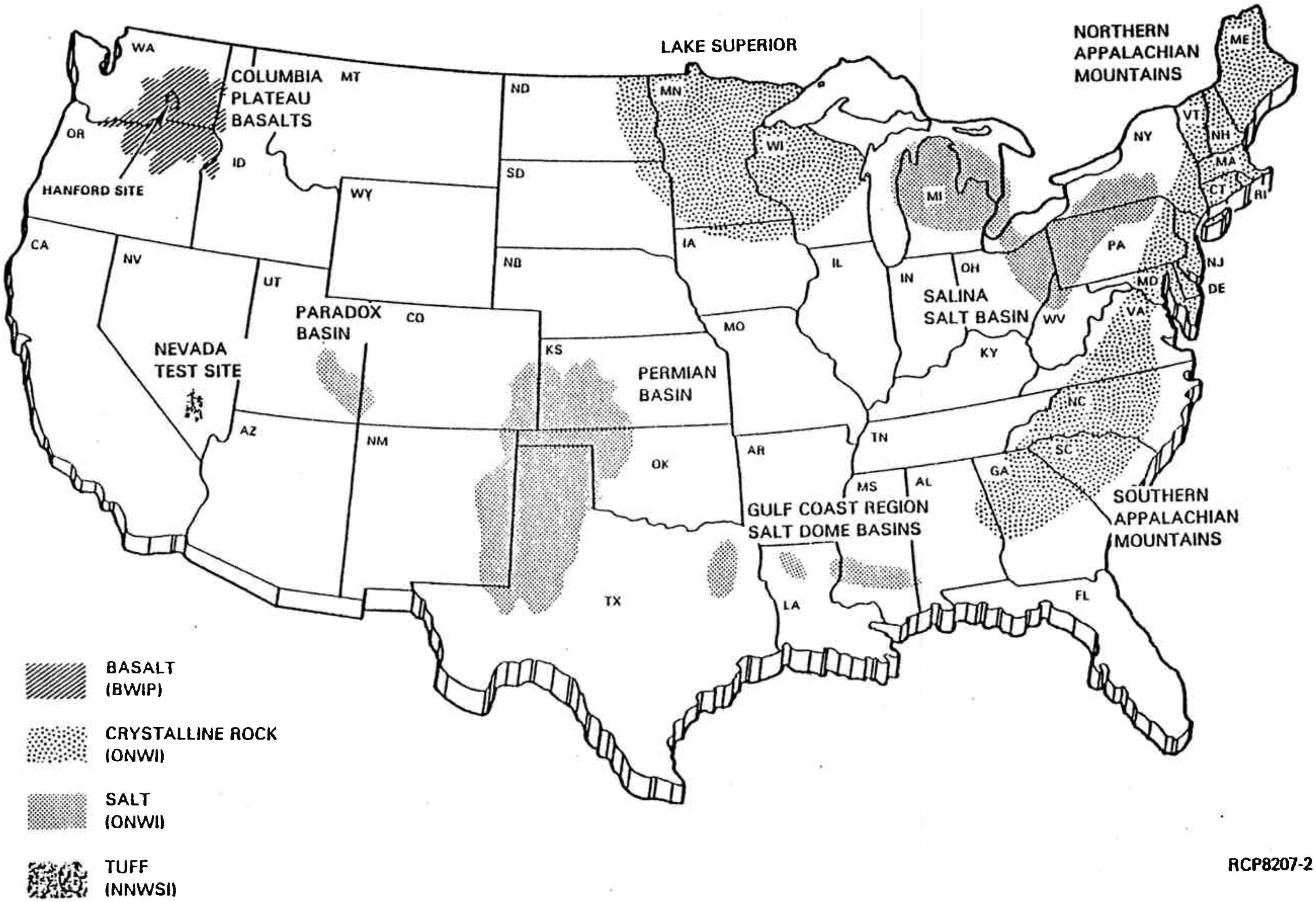

FIGURE 2-2 Regions That are Being Considered for Geologic Disposal of Radioactive Waste.

Source: U.S.DOE, SITE CHARACTERIZATION REPORT FOR THE BASALT WASTE ISOLATION PROJECT, DOE/RL 82-3 1.2-3 (Nov. 1982).

There are other possible rock types, but DOE is currently not considering them as possible candidates for a first repository. Notable among these are granite and many granite-like rocks called granitoids. The latter underlie much of the United States near the surface and at shallow depths,[3] and could be superior to the three being considered in several respects.[4]

The site ultimately selected is expected to handle 70,000 tons of high-level nuclear waste that will remain hazardous for hundreds of thousands of years. This will include the bulk of the current high-level commercial radioactive wastes, primarily spent fuel rods from nuclear power plants. Nearly all of the 10,000 metric tons of spent fuel are currently stored underwater at spent-fuel storage pools, most at the reactors where it was used. Around 2,000 tons of spent fuel are generated every year.[5]

The site could also receive high-level radioactive waste from the nuclear weapons program. More than 300,000 cubic meters (80 million gallons) of high-level wastes from the nation's nuclear defense programs are stored at three sites: Hanford, Washington; the Savannah River Plant near Aiken, South Carolina; and the Idaho National Engineering Laboratory in south central Idaho. Figure 2-3 demonstrates that 61 percent by volume of the military related high-level wastes, are located

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[3] Panel on Radioactive Waste Isolation Systems, National Research Council, A Study of the Isolation System for Geological Disposal of Radioactive Wastes, National Academy Press: Washington, D.C. (1983).

[4] Ibid., pp. 157 and 190-194; White, Donald E., "Background Paper for Generic Assessment of Granitoid Repositories," prepared for A Study of the Isolation System for Geologic Disposal of Radioactive Wastes, National Research Council of the National Academy of Sciences, Unpublished (1983); and White, Donald E., "Background Paper for Granitoid Repository Overlain by a Regional Sedimentary Aquifer," prepared for A Study of the Isolation System for Geological Disposal of Radioactive Wastes, National Research Council of the National Academy of Sciences, Unpublished (1983).

[5] Zurer, Pamela S., "U.S. Charts Plans for Nuclear Waste Disposal," Chemical and Engineering News, 20 (July 18, 1983), p. 23.

DOE DEFENSE HIGH-LEVEL WASTE INVENTORY STORED IN UNDERGROUND TANKS (12/31/81)

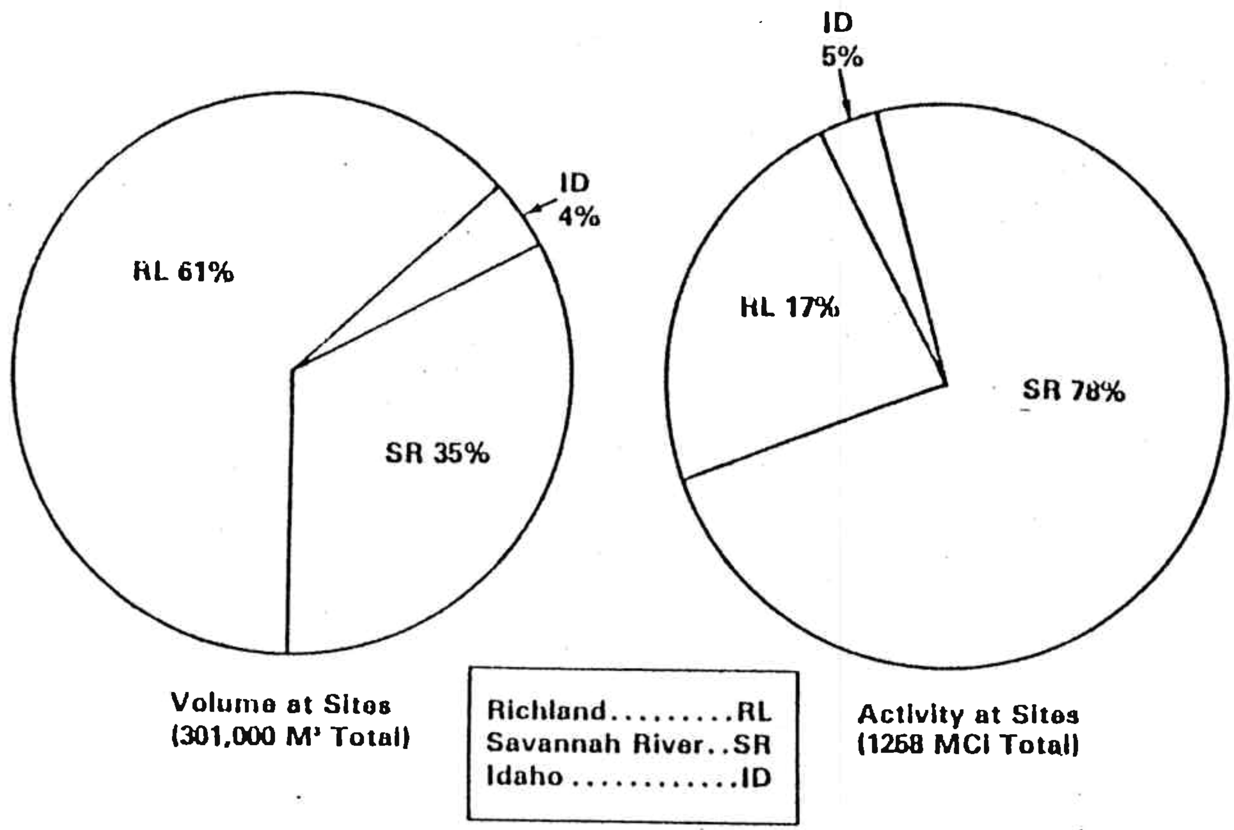

FIGURE 2-3 SOURCE: Hearings on H.R. 2496 [H.R. 2797] DOE National Security and Military Applications of Nuclear Energy Authorization Act of 1984 before the Procurement and Military Nuclear Systems Sub-comm. of the Comm. on Armed Services, 98th Congress, First Session 158 (March 1 and 2, 1983).

at the Hanford site. Transportation of these wastes off the Hanford Reservation will not be necessary if the government is allowed to bury them on-site.[6]

The goal of geologic disposal has been described as the:

> permanent isolation of HLW [high-level wastes] from portions of the environment accessible to present and future humans so as to minimize the threat to public health and safety and the environment.[7]

This is the purpose of the Nuclear Waste Policy Act insofar as it applies to geologic disposal. Pursuant to that Act and complementary to it, the Environmental Protection Agency and the Nuclear Regulatory Commission have issued many standards and regulations in draft form, but only the NRC has issued final regulations. Critics of the site selection process point out the problems of choosing a site before the rules are established.

The EPA and NRC regulations and standards are meant to regulate the selection, construction, and operation of the repository as well as to set limits on release rates of radionuclides to the environment and resulting doses to people from such releases. There is considerable controversy over the adequacy of these regulations, and over the lack of final EPA standards on which to base selections. We will not discuss these controversies in the present preliminary report. Rather, we have chosen to focus on the specific merits and demerits of the Hanford site in relation to the regulations already in place and to the goals of protecting the health and safety of present and future generations.

The period of operation of the repository, during which wastes are emplaced, may last as long as 50 years. We will also address the health and safety of the workers who will build and operate the

[6] Hearings on H.R. 2496 [H.R. 2797] DOE National Security and Military Applications of Nuclear Energy Authorization Act of 1984 before the Procurement and Military Nuclear Systems Subcommittee of the Committee on Armed Services, 98th Congress, First Session (March 1 and 2, 1983).
[7] Worby, Citizen's Manual, p. II-3.

repository. There are a variety of construction dangers that have not been adequately discussed by the appropriate agencies.

The Department of Energy is the federal government agency responsible for overseeing the selection, construction, operation, and closure of the nuclear waste repository. Thus, DOE must:

- ensure that releases of radionuclides from the repository do not exceed limits set by the Environmental Protection Agency. (Although these regulations should have been promulgated January 7, 1984, they have not yet been established.)

- "comply with all the requirements of the Nuclear Regulatory Commission (NRC) for the siting, development, construction, and operation of a repository"[8] and obtain a license to operate it from the NRC.

In practice, DOE has been hiring corporations which act as the contractors for specific jobs which the DOE oversees. The contractor for the Hanford operation is currently Rockwell International.

[8] Nuclear Waste Policy Act of 1982, Sec. 8(b)(3), Public Law 97-425, codified at 42 U.S.C.A. Sec. 10101 et seq.

CHAPTER 3

The Hanford Site

The federal Hanford Nuclear Reservation lies in a shrub-steppe, semi-arid area in the south-central portion of Washington State. The Columbia River, which is one of the largest in the United States, flows through the Hanford site. Hanford has been a major location for DOE nuclear activities since 1943. During World War II, the plutonium for the bomb dropped on Nagasaki, Japan, was produced there. Currently, it has a number of military-related and commercial nuclear activities. About 50 million gallons of military high-level radioactive wastes are stored on the site.[9]

If the Hanford Reservation is selected as the repository site, the repository would be located in the basaltic lava flows beneath it. The geologic area of the Columbia Plateau in which the proposed repository would be located is known as the Pasco Basin region of the Yakima Fold Belt.[10]

The basaltic rocks are basically layers of lava flows formed into fractured rocks as the lava cooled. Interspersed irregularly with the basalts are rocks formed from various sources such as ashfalls from the Cascade Mountains to the west and sedimentary deposits from erosional processes and glaciation.[11]

Groundwater is plentiful under the Hanford Reservation and eventually communicates with the Columbia River. Thus, the basaltic

[9] Oak Ridge National Laboratory, Spent Fuel and Radioactive Waste Inventories, Projections, and Characteristics, DOE/RW-0006, U.S. Department of Energy, Washington, D.C., September 1984, p. 66.
[10] Rockwell Hanford Operations, Site Characterization Report for the Basalt Waste Isolation Project, DOE/RL 82-3, U.S. Department of Energy, Washington, D.C., November 1982, Chapter 2.
[11] Office of Nuclear Material Safety and Safeguards, Draft Site Characterization Analysis of the Site Characterization Report for the Basalt Waste Isolation Project, NUREG-0960, U.S. Nuclear Regulatory Commission, March 1983, p. 22.

portions underneath the site, which form irregular layers relatively impermeable to water, are interspersed with water-bearing layers where water is plentiful and the flow is relatively rapid. There is general agreement that the geology and hydrology of the area is exceedingly complex. As a result there are large uncertainties about critical parameters like water travel times from the repository to the "accessible environment." Figure 3-1 shows the location of the proposed repository site in Washington State.

Both groundwater and river water are currently used for irrigation in the area, and irrigation is quite widespread. The irrigation is roughly correlated with microearthquake swarms. (See Figure 3-2.) While microearthquakes are, by definition, too small to present serious dangers to surface activities, they may affect repository operations, thus posing a possible conflict between continued or increased irrigation for farming and repository safety. (See Chapter 5.)

The proposed repository is likely to be in one of the older, deep layers of basalt lava flows under the Hanford site, as a group called the Grande Ronde Basalt. DOE has identified four lava flows within the Grande Ronde Basalt as

- Rocky Coulee flow
- Cohassett flow
- McCoy Canyon flow
- Umtanum flow

The Cohassett flow is currently the preferred site,[12] though all four continue to be considered as options.[13] The top of the Cohassett flow is about 900 meters (about 3,000 feet) below the surface of the site. Figure 3-3 shows a schematic of the various geologic layers beneath the Hanford site.

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[12] Office of Civilian Radioactive Waste Management, Draft Environmental Assessment: Reference Repository Location, Hanford Site, Washington, DOE/RW-0017, U.S. Department of Energy, December 1984, p. 2-60.
[13] Ibid., p. 6-153.

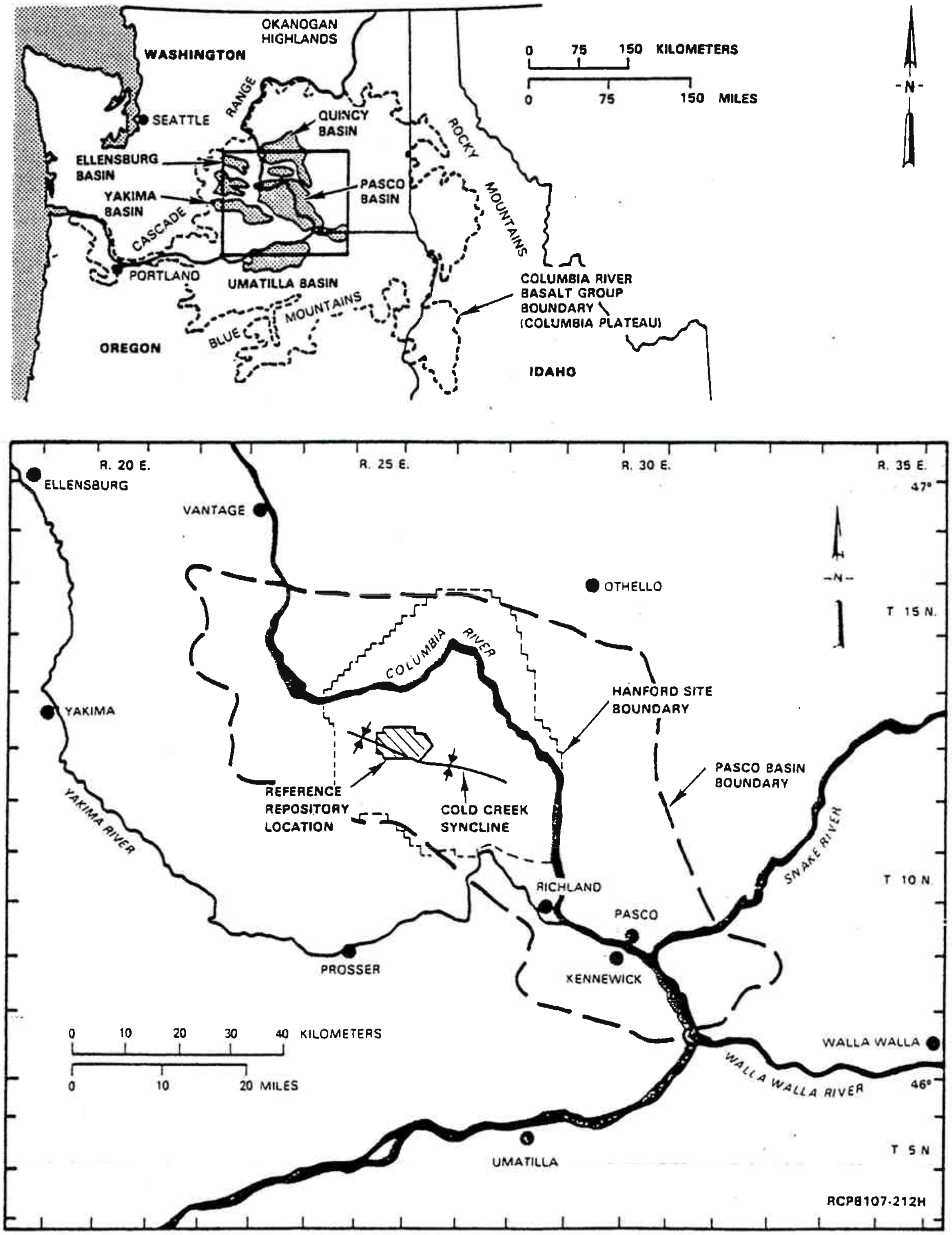


Figure 3-1. Location of the Hanford Site, southeastern Washington State.

SOURCE: U. S. DOE, DRAFT ENVIRONMENTAL ASSESSMENT DOE/RW-0017, p. 2-2 (Dec. 1984).

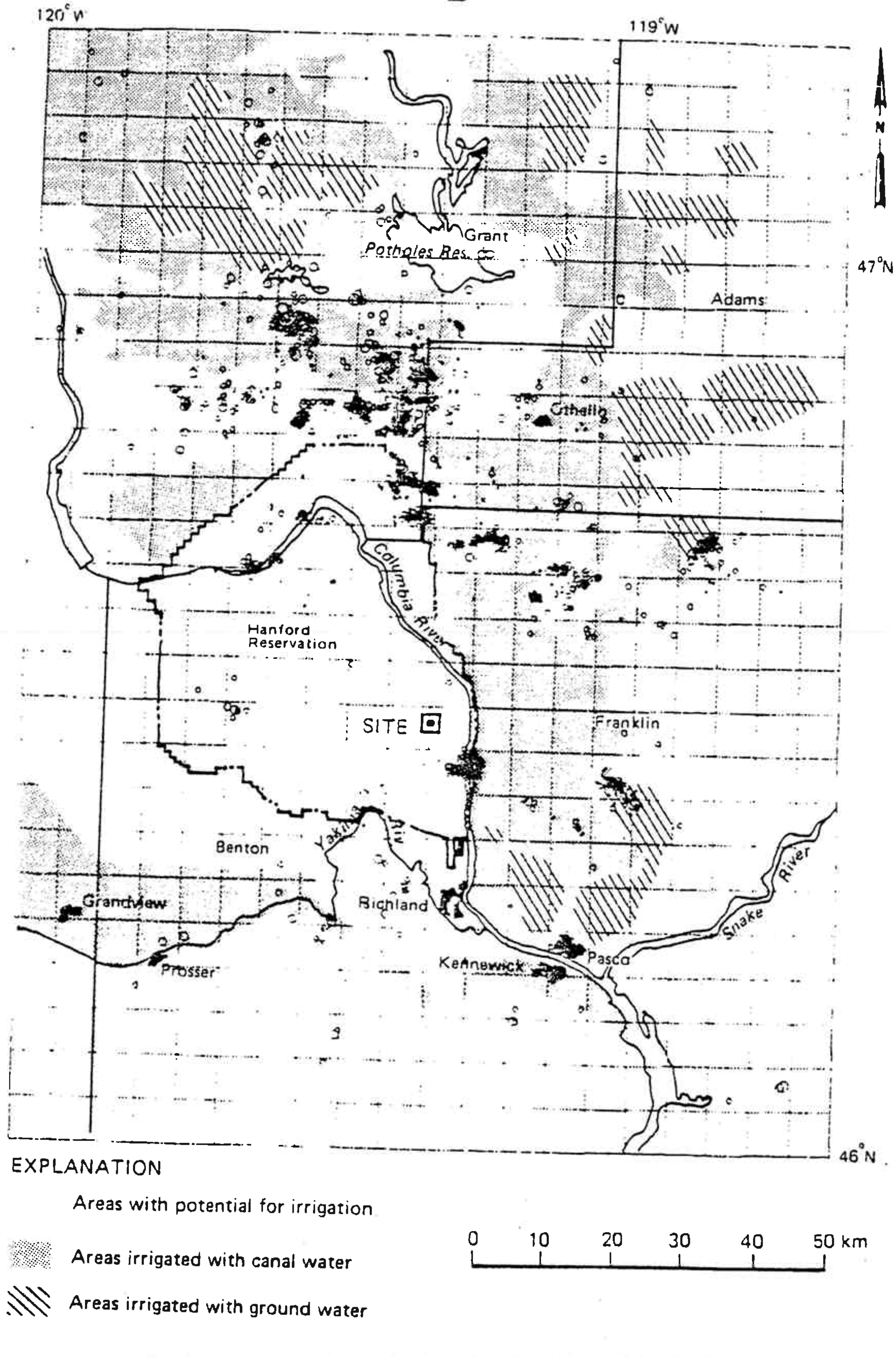
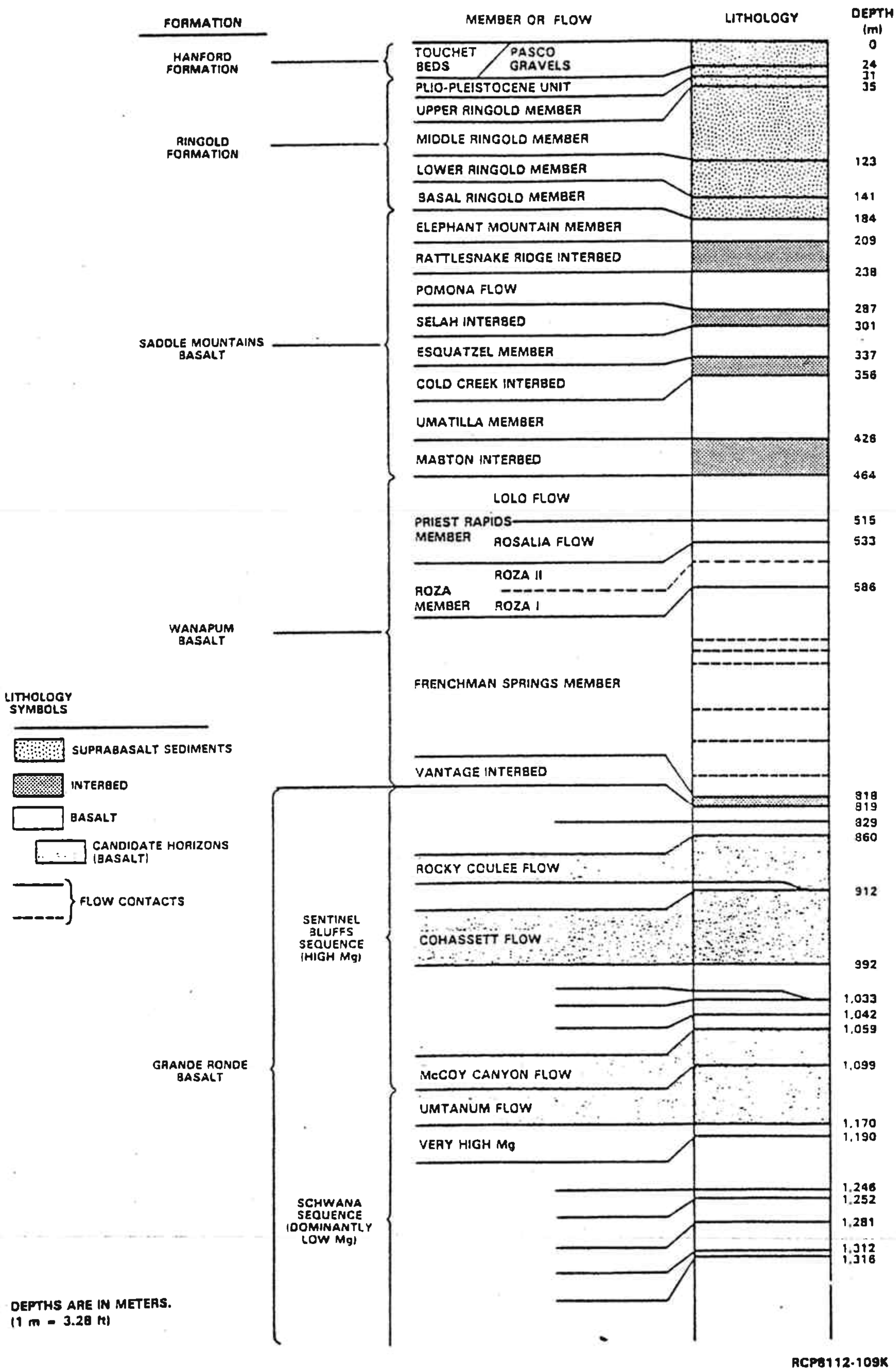


Figure 3-2 Swarm seismicity and areas of irrigation (Source: Washington Public Power System, Amendment No. 18)

Source: U. S. DOE, SITE CHARACTERIZATION REPORT FOR THE BASALT WASTE ISOLATION PROJECT, DOE/RL 82-3, Vol. 2, N-6 (Nov. 1982).



SOURCE: U. S. DOE, SITE CHARACTERIZATION REPORT FOR THE BASALT WASTE ISOLATION PROJECT, DOE/RL 82-3, p. 2-58 (Nov. 1982).

Figure 3-3 General stratigraphy of the reference repository location showing position of the candidate horizons. Depths are from borehole RRL-2.

At the time Dr. Donald E. White prepared his background paper for the National Research Council, the preferred location for the proposed repository was the Umtanum flow. This has since changed to the Cohassett flow. Some of the specific data in Dr. White's paper (see appendix), like temperature values, are related to the Umtanum flow, while most of his analysis applies to the Grande Ronde Basalt, in which all four lava flows are located, and to the Hanford site as a whole. We have used the data applicable to the Cohassett flow in the main text, and indicated when significantly different data relating to the Umtanum flow are discussed in the appendix. The two areas where this seems most pertinent are (1) temperature (the Cohassett flow appears not to be as hot on the average as the Umtanum flow), and (2) proximity to a permeable, water-bearing layer (the Cohassett flow is significantly closer to a water-bearing layer than the Umtanum flow).

Since the Hanford site is located on federally-owned land already used for nuclear purposes, it has been relatively more studied than the other sites. A considerable amount of field data exists to provide some indication of what might be expected. However, the Nuclear Regulatory Commission, and others, have concluded that there are large uncertainties about several factors that will eventually affect repository performance.[14]

[14] Nuclear Regulatory Commission, Draft Site Characterization Analysis of the Site Characterization Report for the Basalt Waste Isolation Project, NUREG-0960, Summary, U.S. Nuclear Regulatory Commission (March 1983).

CHAPTER 4

Repository Construction and Operation

> No specific issues have been identified [by the Department of Energy] for the interval through permanent closure for either operational safety or retrievability.[15]
>
> -- Nuclear Regulatory Commission

> Effects from rock bursting . . . , inhomogeneities in the Umtanum's control zone [one of the proposed locations of the Hanford repository] . . . , and construction of repositories at such high initial temperatures . . . may each be individually tractable; but all in combination may be intolerable in cost of money, time, energy, and loss of lives, especially if rock-bursting is frequent and difficult to predict.[16]
>
> -- Donald E. White, Ph.D.
> U.S. Geological Survey

Some of the most severe problems associated with locating the repository for radioactive wastes at the Hanford site may occur well before any waste is emplaced in it. These problems have to do principally with the danger, complexity, and unpredictability of the immense mining operation that will be required to ready the repository location for the receipt of wastes. Additional problems will be faced during the placement of wastes, which will last for decades. This will require further mining, as well as handling, movement, and placement and sealing of highly radioactive wastes in specially-prepared boreholes.

The proposed repository will be 3,000 to 4,000 feet underground, about one mile wide and 2 miles long (1.75 km by 3.35 km). Sketches of

[15] Office of Nuclear Material Safety and Safeguards, Draft Site Characterization Analysis of the Site Characterization Report for the Basalt Waste Isolation Project, NUREG-0960, U.S. Nuclear Regulatory Commission, March 1983, p. 9-16.

[16] Donald E. White, "Background Paper for Assessment of Basalt Lava Flows (BWIP), Washington," prepared for the National Research Council of the National Academy of Sciences, June 1983, p. 27. While the quote specified the Umtanum flow, the same general conditions appear to exist in all four of the proposed locations.

the proposed plan and cross-sections are shown in Figures 4-1 and 4-2. The working tunnels would be about ten feet high and twenty feet wide to accommodate the workers and machines needed for excavation, construction, and waste movement and emplacement. The waste itself will be placed in long (61 meters or 200 feet) holes off the main tunnels (Figure 4-3).

Site characterization activities involve more than drilling a few tiny holes in the ground. Site characterization will involve clearance of about 45 acres of land, and the construction of two shafts which will require constant blasting operations and heavy water consumption for drilling and excavation.

Just the excavation will be an immense operation requiring the cutting, fracturing, and lifting out of millions of tons of rock. It will require drilling through several copious water-bearing layers. Some of these will have to be sealed. Large amounts of water may have to be pumped out.

DOE acknowledges that unexpectedly large quantities of water may flow into the repository and cause hazardous conditions.[17] A 1983 Environmental Assessment estimated that up to several thousand gallons per minute of water will have to be sealed off from the shafts or pumped out if it leaks into them.[18]

Deep mines are, in general, more dangerous to build and operate. Extraordinary precautions would be required even in less critical mining operations involving non-radioactive materials. An ad-hoc panel of geologists co-chaired by Dr. Bruno Giletti of Brown University and Dr.

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[17] Office of Civilian Radioactive Waste Management, Draft Environmental Assessment, DOE/RW-0017, December 1984, p. 6-201.
[18] Office of Civilian Radioactive Waste Management, Draft Environmental Assessment, DOE/EA-0210, February 1983. Laura Worby has cited an estimate provided by Rockwell of up to 173,000 gallons per minute, which amounts to 100 billion gallons per year (about a quarter of a million acre-feet per year). Laura Worby, Citizens Nuclear Waste Manual, Nuclear Information and Resource Service, Washington, D.C., 1984, p. II-28.

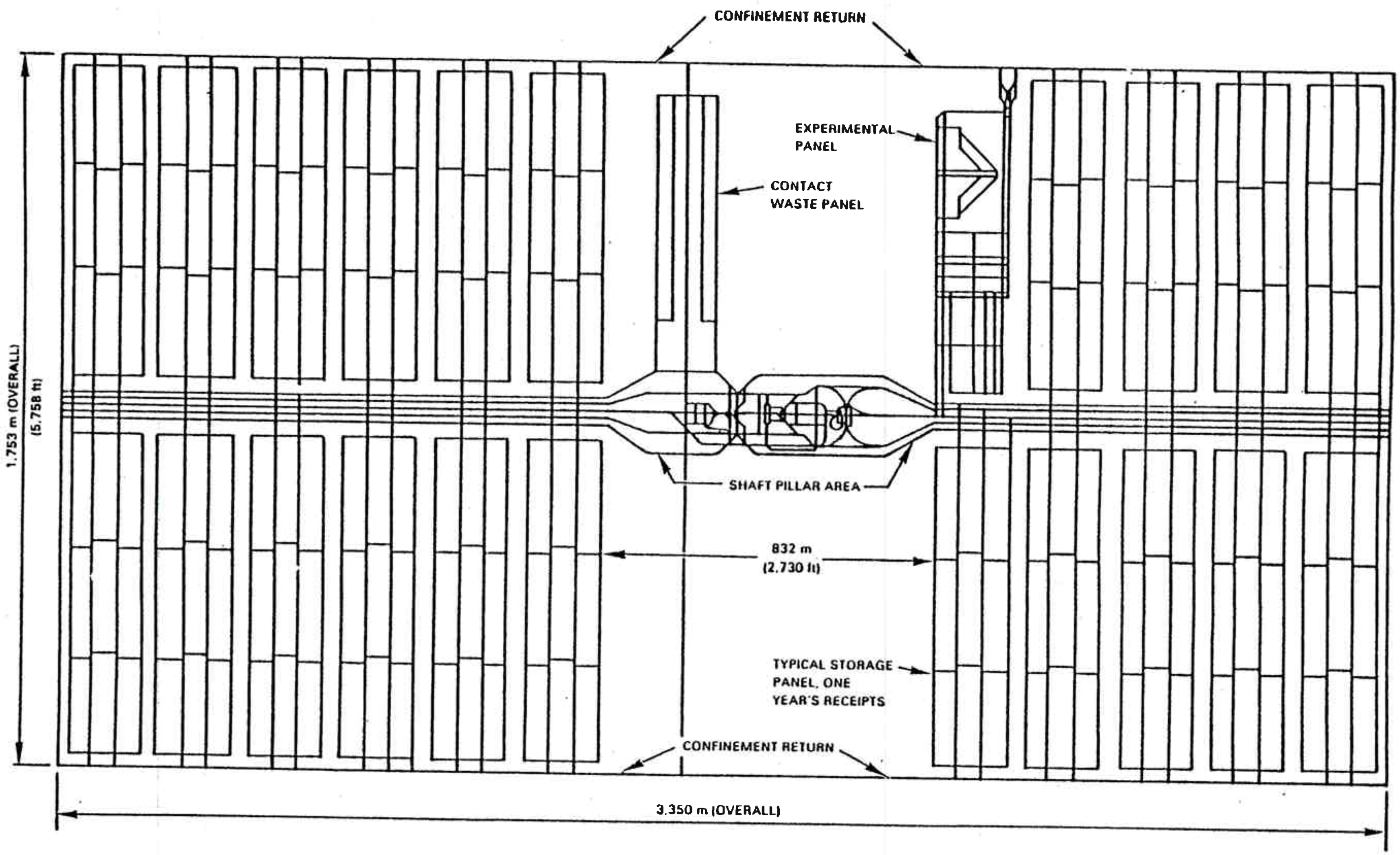

Figure 4-1 Subsurface facilities layout (bow-tie) arrangement

SOURCE: Nuclear Regulatory Commission, DRAFT SITE CHARACTERIZATION ANALYSIS OF THE SITE CHARACTERIZATION REPORT FOR THE BASALT WASTE ISOLATION PROJECT, NUREG-0960, p. A13 (March, 1983).

SOURCE: Nuclear Regulatory Commission, DRAFT SITE CHARACTERIZATION ANALYSIS OF THE SITE CHARACTERIZATION REPORT FOR THE BASALT WASTE ISOLATION PROJECT, NUREG-0960, Vol. 1, p. A-14 (March, 83).

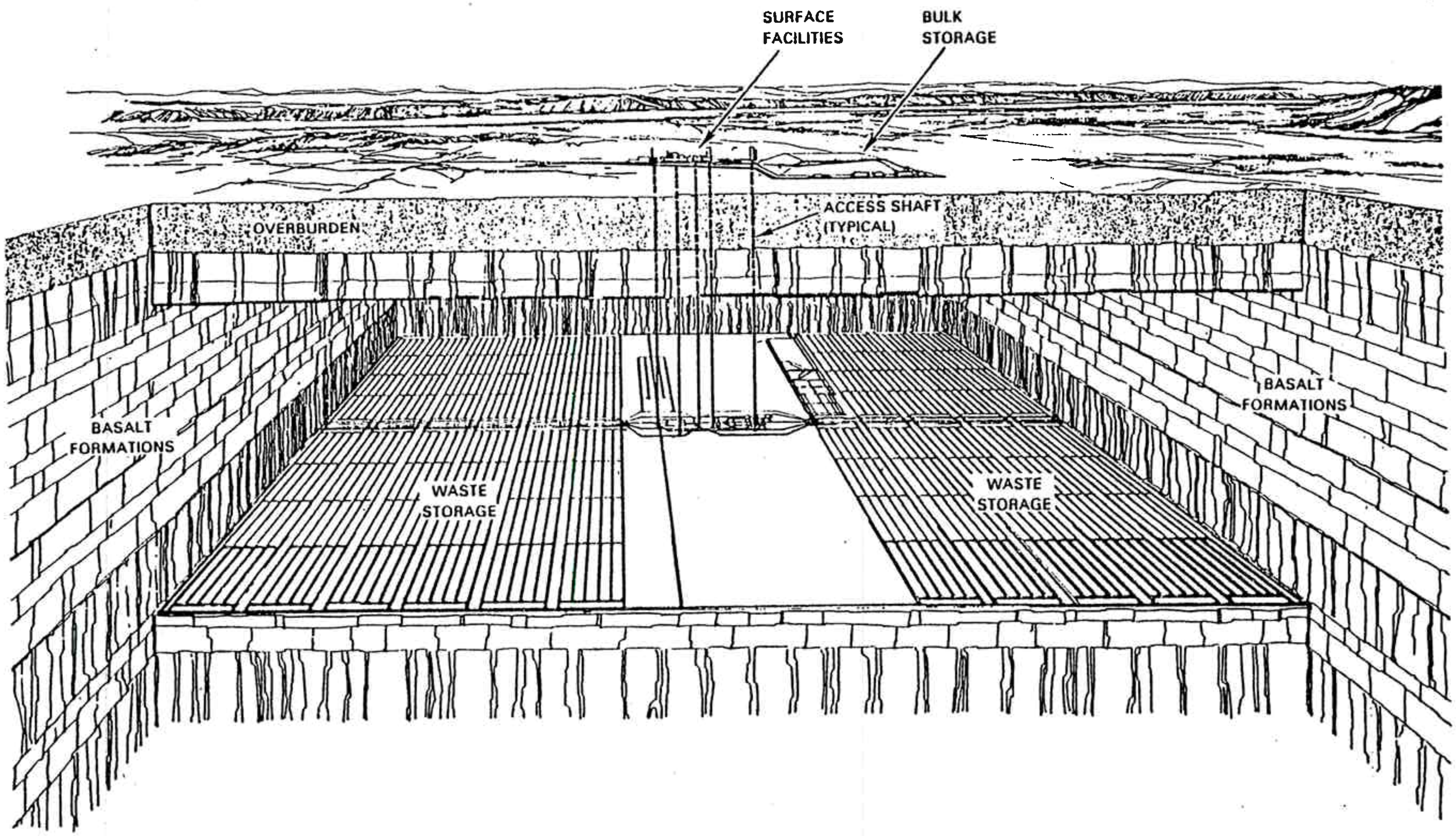

Figure 4-2 Repository cutaway

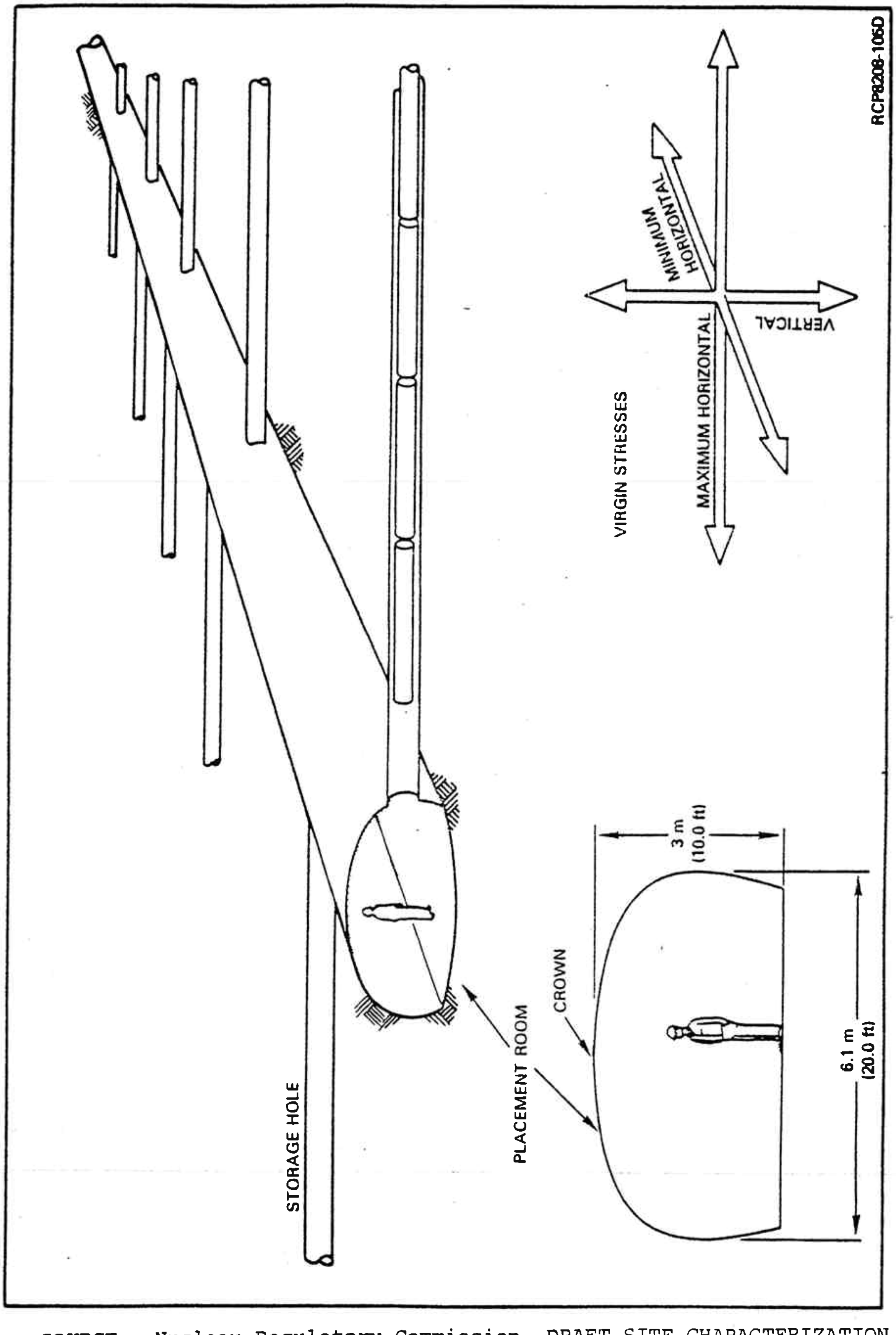

Figure 4-3 Orientation of rock stresses and excavations

SOURCE: Nuclear Regulatory Commission, DRAFT SITE CHARACTERIZATION ANALYSIS OF THE SITE CHARACTERIZATION REPORT FOR THE BASALT WASTE ISOLATION PROJECT, NUREG-0960, p. A-18 (March 1984).

Raymond Siever of Harvard University, convened by the EPA, warned that the hazards of deep mining would be complicated by inexperience in the case of nuclear wastes and the necessity of maintaining retrievability of such wastes for some time:

> Here again we are faced with lack of experience, for in ordinary mining operations, openings are usually abandoned after working with no thought of returning. Though there has been some reworking of mines in a few places, these are highly hazardous because of the dangers of roof-falls in a deteriorated mine. It is well known that keeping any underground mine open and clean requires constant maintenance and checking of rooms and entries. The deeper the mine, the greater the danger of rock bursts and floor heaving, the more so because accumulated strain in surrounding rock may build up over a long period of time and then suddenly give way by failure.[19]

In the same year that the EPA geologists' panel made the above observations, a National Research Council panel on rock mechanics issued a report on Rock Mechanics in Energy Resource Recovery and Development. This panel included a sub-panel concerned with rock mechanics as it affects nuclear waste repositories. That sub-panel expressed similar general concerns:

> Rock mechanics relates to four aspects of nuclear waste disposal: (1) The identification of geologic formations. . . . (2) The structural, hydrologic, and stress-field characterization before massive excavation. (3) The site-specific design of nuclear waste facilities. . . . This design must ensure that the facility will remain stable during its operational life . . . and that the ground will remain mineable beyond the waste emplacement phase to make waste retrieval possible. . . . (4) Establishment of geologic and hydrologic data prior to mining, as well as monitoring of the waste repository to evaluate the long-term effects of mining and waste emplacement to define safe retrievability periods.[20]

According to technical criteria proposed for the repository in 1983, a site would "be disqualified if the applicable safety criteria of the

[19] U.S. Environmental Protection Agency, "State of Geological Knowledge Regarding Potential Transport of High-Level Radioactive Waste from Deep Continental Repositories: Report of an Ad Hoc Panel of Earth Scientists," EPA/520/4-78-004 (1978).

[20] National Research Council, Limitations of Rock Mechanics in Energy-Resource Recovery and Development, National Academy of Sciences, Washington, D.C., p. 29 (1978).

DOE and NRC cannot be met."[21] The NRC is to issue or deny a license to construct and operate the repository depending on whether DOE's license application meets all the relevant criteria, including mine safety criteria.

The NRC regulation applicable to mine safety is 10 CFR 60.132, which states:

> To the extent that DOE is not subject to the Federal Mine Safety and Health Act of 1977, as to the construction and operation of the geologic repository operations area, the design of the repository shall nevertheless include such provisions for worker protection as may be necessary to provide reasonable assurance that all structures, systems, and components important to safety can perform their intended functions.[22]

The regulation further requires the DOE to comply with mine design regulations which were issued pursuant to the Mine Health and Safety Act of 1977.[23] In spite of these laws and regulations, and in spite of the existence of a number of potentially serious problems at Hanford, the NRC has noted that the DOE did not identify any "specific issues . . . for the interval through permanent closure for either operational safety or retrievability." Nonetheless, several such issues exist, and we discuss them below.

Rock Stability

> . . . the unusual degree of intense spalling [breaking into small pieces] of hard drill core into 'discs' or 'poker chips' as thin as 0.5 cm . . . has not been adequately recognized in previous BWIP studies and has not been recognized in other basalts, at least to this extreme degree. The discing is probably a forewarning that 'rock bursting' (sudden collapse of rock margins during excavation) may be difficult or even impossible to control at reasonable costs.[24]

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[21] Office of Civilian Radioactive Waste Management, Draft Environmental Assessment, DOE/EA-0210, p. 3-39 (February 1983).
[22] Code of Federal Regulations, 10 CFR Part 60.132, Sec. (9), Federal Register, June 21, 1983, p. 28226.
[23] Ibid.
[24] White, "Background Paper for Assessment of Basalt Lava Flows," June 1983, p. 27.

There are several possible features of the Hanford site which could cause rock-bursting, shaft instabilities, and similar events leading to mine accidents.[25]

- high horizontal to vertical rock-stress which is the probable cause of the severe fracturing of core samples into discs (called "core discing").[26] See Figure 4-4.

- existing fractures in Hanford basalt.[27]

- earthquakes.[28]

The fracturing of core samples into poker-chip shaped discs was discussed in a Rockwell report as long ago as 1979:

> The most widespread and least understood fractures observed in core are the subhorizontal, closely spaced fractures that form small discs perpendicular to the core axis known informally as 'poker chips.' They are . . . different from normal cooling joints, which invariably contain some secondary mineralization or alteration, and occur at various angles to the core axis. . . . Study of poker-chip fractures is under way.[29]

The Rockwell report considered stresses in the rock, which were released by drilling, to be the "most probable cause of poker-chip fractures."[30] Geologist Donald E. White later came to the same conclusion (see Appendix), as did the National Research Council:

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[25] The long-term implications of rock-bursting for radionuclide containment are discussed in Chapter 5.

[26] White, "Background Paper for Assessment of Basalt Lava Flows," June 1983; and National Research Council, A Study of the Isolation System for Geologic Disposal of Radioactive Wastes, National Academy Press, Washington, D.C., 1983, p. 164.

[27] Draft Site Characterization Analysis of the Site Characterization Report for the Basalt Waste Isolation Project, NUREG-0960, March 1983, p. 6-3.

[28] Ibid., p. 4-7.

[29] C.W. Myers and S.M. Price, Geologic Studies of the Columbia River Plateau -- A Status Report, RHO-BWI-ST-4, Rockwell Hanford Operations, Richland, Washington, 1979, pp. III-142 and III-150.

[30] Ibid., p. III-150.

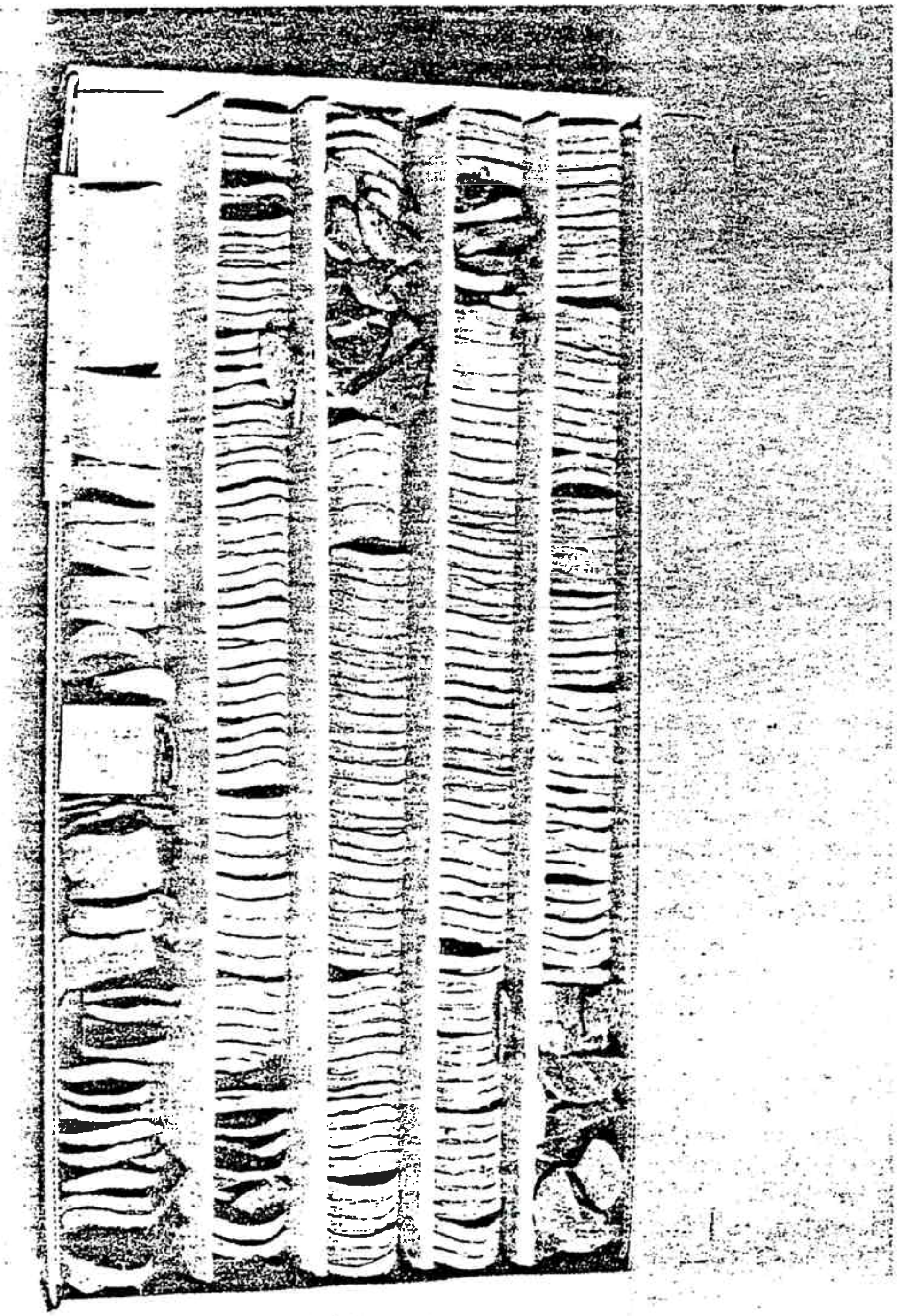

FIGURE 4-4 Basalt core from Hanford–intense discing. Source: Courtesy of Rockwell International.

SOURCE: National Research Council, A STUDY OF THE ISOLATION SYSTEM FOR GEOLOGIC DISPOSAL OF RADIOACTIVE WASTES, National Academy Press, Washington, D.C., p. 117 (1983).

> Strong horizontal compressive stress, probably at least twice the vertical stress, is the likely cause of a phenomenon called core-discing. . . . [C]ore discing is an indicator of high in-situ stress, with potential for rock bursting from the surfaces of mined openings...[31]

While DOE has not discussed rock bursting as an issue in mining safety and repository integrity in the detail it deserves, it has implicitly acknowledged the great importance of this issue by proposing a technical criterion for repository siting which would eliminate certain sites with high stresses:

> A very preliminary estimate is that average maximum principal stress magnitudes greater than 80 Megapascals [about 800 atmospheres] or average stress ratios (greater than 3) (maximum horizontal to vertical) are the upper limits beyond which construction of a repository could be economically unattractive.[32]

Rockwell and DOE have as yet only limited data on actual stress values and ratios at or near the proposed repository location. All of these measurements have stress ratios of greater than 2.0 and ranging up to 2.7, according to the DOE-Rockwell Site Characterization Report.[33] Yet, the same report makes a statement in its Executive Summary that "the ratio of maximum horizontal stress to the vertical stress is approximately 2."[34] This is very misleading since the critical value for this ratio in DOE's own judgment quoted above is 3.

The maximum ratio obtained in the limited tests performed by Rockwell was 2.7 and the average was 2.33. This average is only about 25 percent less than the DOE disqualification figure of 3 cited above. The average maximum pressure measured was 61.5 Megapascals, also about 25 percent less than DOE's maximum permissible pressure. The maximum pressure was 71.5 Megapascals.

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31 National Research Council, A Study of the Isolation System for Geologic Disposal of Radioactive Wastes, p. 164.
32 Draft Environmental Assessment, DOE/EA-0210, February 1983, p. 340.
33 Rockwell Hanford Operations, Site Characterization Report for the Basalt Waste Isolation Project, DOE/RL 82-3, U.S. Department of Energy, Washington, D.C., November 1982, Table 4-11.
34 Ibid., p. 5.

There is also the problem of the method used to obtain the measurements and its accuracy. The technique used is called "hydrofracturing." This method assumes that the "borehole direction is one of the principal stress directions."[35] This assumption cannot currently be verified since the only technique available for stress measurements in deep boreholes, hydrofracturing, depends on this assumption. DOE and Rockwell have a "Near-Surface Test Facility" where another method can be used. However, the conditions at repository depths differ considerably from those near the surface, particularly in regard to the horizontal to vertical stress ratio which appears to be the principal cause of core-discing. The intensity of core-discing increases with depth at the Hanford site, being particularly intense at repository depths of more than 2,700 feet (800 meters).[36]

Tests that DOE has conducted at the Near-Surface Test Facility are themselves problematic and are difficult to interpret:

> The high fracture frequency . . . caused serious difficulties in conducting the tests and in interpreting the results. . . . In these tests there was general agreement on stress orientations. Stress magnitudes varied widely enough to be of little value in defining the exact state of stress at the Near-Surface Test Facility.[37]

Thus, when two methods of measurement were used,[38] the quantitative results were so widely divergent that DOE and Rockwell admit that they are of "little value" so far as stress magnitudes were concerned. Even in regard to orientation, the measurements differed by more than 10 degrees in each case cited in the DOE-Rockwell Site

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[35] Ibid., p. 4.6-10.

[36] A Study of the Isolation System for Geologic Disposal of Radioactive Wastes, 1983, p. 164.

[37] Rockwell Hanford, Site Characterization Report for the Basalt Waste Isolation Project, p. 4.6-10.

[38] Ibid. DOE used the "Overcoming method" of the U.S. Bureau of Mines and the "Hydrofracturing method" to measure stresses in the Near-Surface Test Facility.

Characterization Report.[39] The same situation may occur in case more than one method is applied to deep underground stress measurements.

With so much uncertainty as regards stress measurements, 25 percent below the DOE-suggested maximum value can hardly be considered safe or prudent. Moreover, the technical criterion suggested by DOE which would disqualify a site if the horizontal to vertical stress ratio is greater than 3 is itself highly questionable.

The evidence from the core samples shows that intense core discing is frequent when the stress ratio is greater than 2, as it is in every measurement taken at repository depths.[40] We have already quoted Donald E. White's conclusion at the beginning of this section that the discing "is probably a forewarning that 'rockbursting' (sudden collapse of rock margins during excavation) may be difficult or even impossible to control at reasonable costs." He has also noted that the nature of the fractures of the core shows that they are "fresh surfaces that did not exist prior to drilling. They are exceptional phenomena rarely observed in drill core."[41]

The panel on geologic waste isolation of the National Research Council of the National Academy of Sciences concluded that "potential rock burst phenomena" are among the "most critical problems related to the Hanford repository."[42] It arrived at this conclusion despite an assurance to the contrary in a personal communication from D.J. Brown of Rockwell to the chairman of the panel, Professor T.H. Pigford of the University of California at Berkeley.[43]

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[39] Ibid., Table 4-12.
[40] Draft Site Characterization Analysis of the Site Characterization Report for the Basalt Waste Isolation Project, NUREG-0960, March 1983, p. 6-11.
[41] White, "Background Paper for Assessment of Basalt Lava Flows," June 1983, p. 5.
[42] Panel on Radioactive Waste Isolation Systems, National Research Council, Study of the Isolation System for Geologic Disposal of Radioactive Wastes, 1983, p. 164.
[43] Ibid.

J. Davitt McAteer, Director of the Occupational Safety and Health Law Center, has reviewed the site especially with regard to rock-bursting. After discussions with the Mine Health and Safety Administration and reviewing the DOE proposal, McAteer expressed reservations, noting:

> [T]he Polish mining community has the most experience with rock bursting problems. In those mines, bursting has in fact resulted in the death of a number of individuals, killed for the most part by the explosion of the rock out from the face. Whether there would be secondary implications from such bursting, such as disruption of ventilation, roof falls, etc., is unclear. What can be said, is that the bursting potential creates possibilities of unstable and unsafe working conditions. With regard to the question of whether these bursts can be contained or prevented, little is known in this country or abroad regarding means of prevention; there simply is insufficient experience to be able to realistically speak of concrete means of avoiding these outbursts. Preemptive blasting of pressurized rock is one technique currently employed. Of course, this preemptive blasting of the rock bursts themselves may create problems, especially with the aquifer formations.[44]

In the case of radioactive wastes, these dangers are likely to be greater, and worker protection more problematic. Rock bursting could also complicate the already serious problems posed by waste retrievability. The National Academy of Science's report implicitly expresses a frustration with the lack of significant Rockwell attention to a problem which "has been known for some time"[45] in the following terms:

> Data are presently inadequate for a full evaluation of core discing. . . . During two years of panel deliberations, Rockwell has been urged to study the potential problem intensively by recognized experts in stress measurements, but definitive data are not yet available.[46]

> The Nuclear Regulatory Commission not only noted the limited nature of the data available, but criticized the DOE test

[44] J. Davitt McAteer, personal communication, Occupational Safety and Health Law Center, Washington, D.C., January 16, 1985.

[45] Panel on Radioactive Waste Isolation Systems, National Research Council, Study of the Isolation System for Geologic Disposal of Radioactive Wastes, p. 115.

[46] Ibid., p. 174.

> plan to obtain more data as one "which does not exhibit a commitment to perform necessary and sufficient testing to resolve key issues before license application is made.[47]

Subsequent to this intense criticism, the DOE appears to have decided at least to acknowledge the problem of rock bursting. In its Draft Environmental Assessment issued in December 1984, it claims on the basis of theoretical calculations that mine conditions are "expected to minimize the violence and extensiveness of potential rock-bursts...."[48] It plans to pursue rock-bolting or "destressing by drilling and small-charge blasting."[49]

In response to widespread criticism and the advice reportedly given to DOE by the Mine Health and Safety Administration (see quote above), DOE has conceded the importance of the problem. Its proposed guidelines require it to disqualify a site if "rock characteristics are such that the activities associated with repository construction, operation, or closure are predicted to cause significant risk to the health and safety of personnel. . . ."[50] DOE continues to insist that with "mitigating measures that use reasonably available technology . . . the evidence does not support a finding that the reference repository location is disqualified."[51] But it has at least conceded that this is a tentative judgment: "A final conclusion on this disqualifying condition is not possible at this time."[52]

The stability of the mine openings at Hanford could also be adversely affected by pre-existing rock faults and fractures. Yet according to the NRC, the DOE-Rockwell Site Characterization Report uses "a single value of rock strength . . . in the conceptual design

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[47] Draft Site Characterization Analysis of the Site Characterization Report for the Basalt Waste Isolation Project, NUREG-0960, p. 6-11.
[48] Office of Civilian Radioactive Waste Management, Draft Environmental Assessment: Reference Repository Location, Hanford, Washington, DOE/RW-0017, U.S. Department of Energy, December 1984, p. 6-185.
[49] Ibid., p. 6-187.
[50] Ibid., p. 2-72.
[51] Ibid.
[52] Ibid.

[which] corresponds to the strength of intact basalt specimen tested in the laboratory, and not to rock mass strength, which is affected by discontinuities [fractures]."[53] The NAS panel went further, noting that new fractures formed due to excavation as well as pre-existing fractures could cause the "deformed rock mass within the immediate vicinity of the opening . . . [to] be susceptible to collapse."[54] It also cautioned that high horizontal stresses could cause additional rock fallout problems and that "[a]ppropriate tunnel design can reduce but not necessarily eliminate the adverse effects of unfavorable in-situ stress conditions."[55] The problems from large stresses in the intact rock evidenced by core discing have been discussed above.

Finally, mine stability can also be affected by earthquakes. Besides the microearthquakes of magnitude less than 4 on the Richter scale which occur in the area, several earthquakes "measuring modified Mercalli intensity VII to VIII have occurred in the surrounding region."[56] Such earthquakes are of sufficient magnitude to shake buildings and cause some damage. In contrast to DOE, the NRC concluded that such earthquakes "may impact shaft stability."[57]

Drainage Problems

> . . . even a thick basalt flow may be much too thin for simple, efficient, low-cost repository construction. Intolerable rates of water flow may result from encroachment of permeable faults and flow margins.[58]
>
> -- Donald E. White, Ph.D.
> U.S. Geological Survey

[53] Draft Site Characterization Analysis of the Site Characterization Report for the Basalt Waste Isolation Project, NUREG-0960, March 1983, p. 6-3.
[54] National Research Council, Study of the Isolation System for Geologic Disposal of Radioactive Wastes, p. 123.
[55] Ibid., p. 124.
[56] Draft Environmental Assessment, DOE/EA-0210, p. 2-18.
[57] Draft Site Characterization Analysis of the Site Characterization Report for the Basalt Waste Isolation Project, NUREG-0960, p. 4-7.
[58] White, "Background Paper for Assessment of Basalt Lava Flows," June 1983, p. 6.

There are copious aquifers located in the permeable layers above the proposed repository locations at Hanford. Some of the water is expected to seep into the shafts and into the repository. This could give rise to a number of safety concerns:

- non-uniformity of lava flows could create serious drainage problems[59]

- the water is partially saturated with methane, which will be released into the repository[60]

- the water is hot (over 50 degrees C.) and contact with it could cause burns[61]

DOE plans to seal water bearing zones or to "draw down the water source to assure the excavation would not be flooded."[62] However, given the large volumes of water involved -- perhaps over 170,000 gallons per minute (see above) -- considerable seepage into the repository may occur.

This seepage of water must be continuously pumped out. By itself this would not pose a problem, unless there were accidental flooding of the repository. However, the expected seepage may pose problems for a geologic repository for radioactive wastes.

The current design of the repository calls for horizontal bore-holes in which the waste will be emplaced. The lava flow is inhomogeneous and the boundaries of the waste emplacement zone may rise or decline. According to Donald E. White, "a decline in altitude of zone boundaries as related to folding and faulting would create serious

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59 Ibid.

60 Draft Environmental Assessment: Reference Repository Location, Hanford, Washington, DOE/RW-0017, p. 6-187.

61 Ibid., p. 6-191.

62 Ibid., p. 6-184.

drainage problems."[63] The suitability of a relatively thick lava flow may be jeopardized by irregularities in the flow and consequent drainage problems. (See Appendix for further details.)

Water inflow into the mine would also result in the release of methane. The groundwater samples around the Cohassett flow "are partially saturated (approximately 50 percent) . . . with methane gas."[64] Expected water seepage could result in the release of about 60 cubic feet per minute of methane. DOE ventilation plans project dilution of this to well below required safety standards.

The dilution plans may not be sufficient in case local high concentrations of methane occur due to localized large seepages. Accidental releases of water into the mine could also create dangerous levels of methane. These also pose the danger of burns. According to DOE:

> An additional concern is the groundwater temperature of 51 degrees C. (124 F.) at the depth of the Cohassett flow. Sudden inrushes of water could cause injury in the form of body burns. Water inrushes or inundation would be mitigated by exploratory pilot hole drilling in advance of excavation. Protective clothing would be provided to workers at all times to prevent body burns.[65]

Mine Temperature

> As mine temperatures rise above 70 degrees F., sickness and death also rise.[66]
>
> -- J. Davitt McAteer in Miner's Manual

> Rock temperatures at RRL [the Reference Repository Location in the Umtanum flow] are likely to be at least 57 degrees C [about 135 degrees F.] and may be considerably higher. Precise data are

[63] White, "Background Paper for Assessment of Basalt Lava Flows," June 1983, p. 6.
[64] Draft Environmental Assessment: Reference Repository Location, Hanford, DOE/RW-0017, December 1984, p. 6-187.
[65] Ibid., p. 6-188.
[66] J. Davitt McAteer, Miner's Manual, Crossroads Press, Washington, D.C., 1981, p. 90.

> not yet available. A full-sized repository with a network of tunnels and rooms distributed over an area of several square kilometers, especially if remaining open for decades for possible waste recovery, will require refrigeration on a scale not yet attempted elsewhere in the world.[67]
>
> -- Donald E. White, Ph.D.
> U.S. Geological Survey

Rockwell estimates that the temperature in the Umtanum lava flow ranges from 125 degrees F. (52 degrees C.) to 150 degrees F. (66 degrees C.).[68] DOE has cited a temperature of 124 degrees F. (51 degrees C.) for the Cohassett flow, now its preferred repository location.[69] These values are for temperatures prior to waste emplacement.

The ventilation and cooling requirements for the repository will be costly both in terms of money and electrical power consumption. There are many examples of mines in high temperature environments. The highest figure cited by DOE is 140 degrees F. at a mine in Butte, Montana.[70] DOE plans to design facilities so as "to provide a continuous moderate workload environment for individuals according to standards adopted by the American Conference of Industrial Hygienists."[71]

These plans may, however, be complicated by several factors. Inhomogeneous temperatures in the repository may require different quantities of cooling in different parts of the repository. The necessity of wearing protective clothing as a precaution against burns (see above) will further increase cooling requirements and/or necessitate reduced workloads. Rock bursting may also have the potential of cutting cooling and ventilation to parts of the mine. Emergency cooling and evacuation in such circumstances may be difficult.

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[67] White, "Background Paper for Assessment of Basalt Lava Flows," June 1983, p. 21.
[68] Ibid., p. 4.
[69] Draft Environmental Assessment: Reference Repository Location, Hanford, DOE/RW-0017, December 1984, p. 6-188.
[70] Ibid., p. 6-190.
[71] Ibid., p. 6-188.

Hanford Contamination

Activities are expected to increase levels of total suspended particulates, making it easier for radioactive particulates deposited by other Hanford operations to be blown off site.[72] One of these radionuclides is plutonium, which remains dangerous for hundreds of thousands of years and is a known carcinogen. The average quantity of plutonium in the northern hemisphere is 6.3 micrograms per acre, due to atmospheric nuclear weapons testing. A town close to the western border of Hanford and downwind of it, contains 65 micrograms of plutonium per acre, according to research at Battelle.[73] That's ten times the average rate, and presumably most of the extra came from plutonium operations at the Hanford site.

According to Dr. Alan Benson, a Spokane chemistry professor, measurements taken near the Hanford reservation show plutonium accumulations in soil of 12 to 69 micrograms per acre. Measurements taken on the reservation go up to 1,700 micrograms per acre. Thus, site characterization activities could increase off-site plutonium contamination. Other radioisotopes could also be dispersed.

There are several important reasons to take a closer look at Hanford before initiating site characterization activities. They involve the complexity of the site and the technical problems arising from it. The technical problems which we have addressed and which Dr. White has outlined make it clear that difficulties encountered in the site characterization might lead to events which subsequently make the site unusable. The problems involve heavy water flow and drainage difficulties, rock instability (rock bursting and high stress ratios), high mine temperatures, and the presence of contamination on-site.

[72] Department of Energy, Draft Environmental Assessment Overview: Reference Repository Location, Hanford, DOE/RW-0017, December 1984, p. 11.

[73] Melissa Laird, "Radiation on the Rocks," Clinton St. Quarterly 12 (1984), p. 16.

An environmental impact statement (EIS) is only required by law once the final repository site is selected.[74] However, the shafts and chambers to be constructed for site characterization appear to be the same as some of those needed for the actual repository. (See Figure 4-5). Construction of the site characterization facilities is really the same as the first stage of the construction project. Preparing an environmental impact statement on a project which is already well underway with a multi-million dollar budget creates a momentum which is difficult to halt. It is like deferring a construction permit application until the basement and first floor are already built, and therefore not the soundest way to proceed. It will be difficult to have better, safer sites receive consideration if a poor site is already well under construction.

[74] Nuclear Waste Policy Act, Sections 112(3) and 113(d).

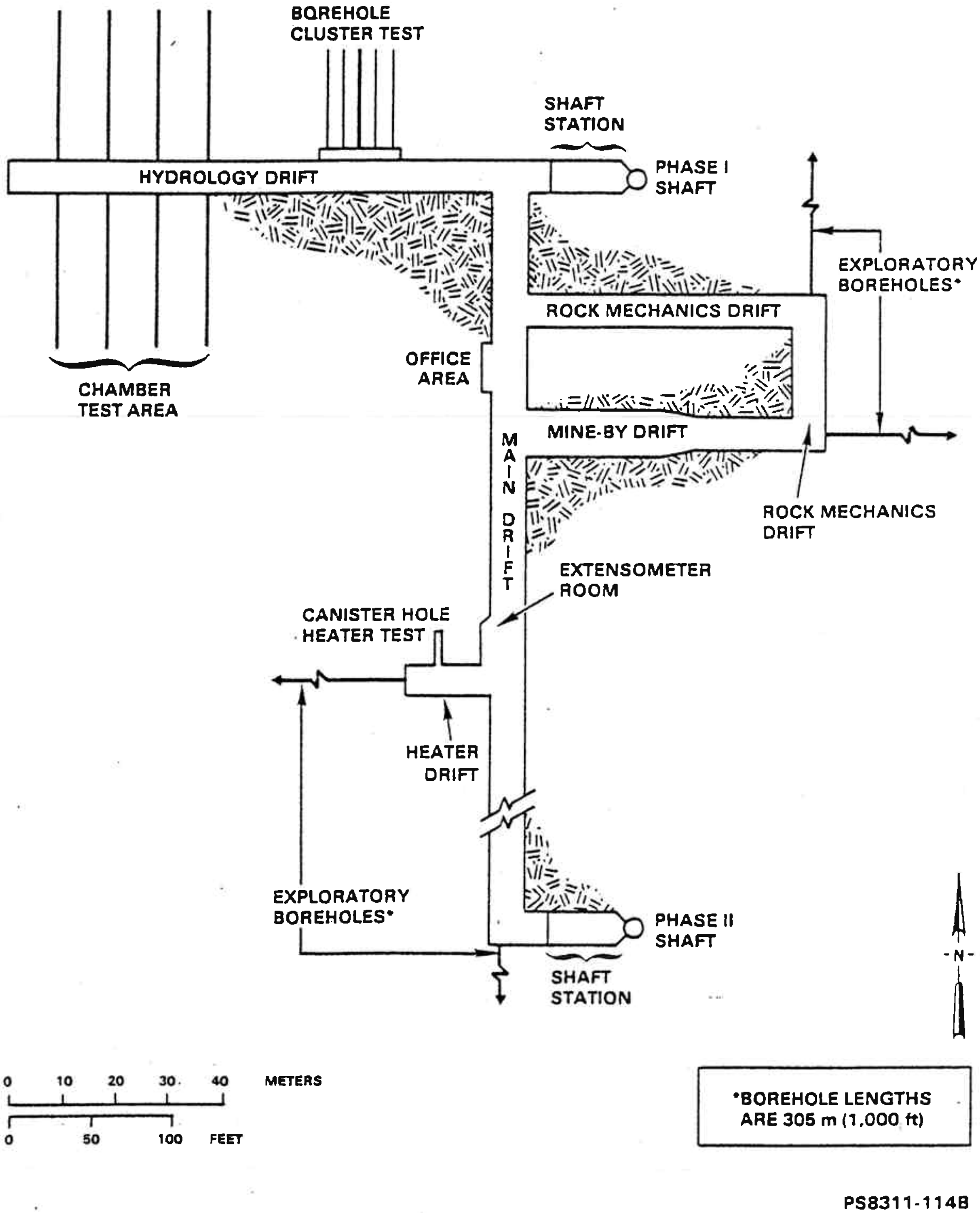

Figure 4- 5 Conceptual arrangement of the exploratory shaft underground facilities.

SOURCE: U. S. DOE, DRAFT ENVIRONMENTAL ASSESSMENT DOE/RW-0017, p. 4-13 (Dec. 1984).

CHAPTER 5

Repository Performance

The [Hanford] area is not geologically favorable relative to some other sites.[75]

-- Donald E. White, Ph.D.
U.S. Geological Survey

. . . the Umtanum host rock [at Hanford] is physically much less favorable than some other repository types considered in this report.[76]

-- National Research Council

Any geologic repository for high-level radioactive wastes will be required to meet a number of criteria and regulations issued by the Environmental Protection Agency and the Nuclear Regulatory Commission. Some of these relate to the construction and operation of the repository, which we have discussed in Chapter 4. Others apply to monitoring the repository, to retrievability in case it does not perform as desired, and to the actual long-term performance requirements.

The Environmental Protection Agency has issued criteria for repositories in draft form, but has not yet issued a final standard. The draft standard proposed by the EPA would prescribe limits on releases of radioactivity to the accessible environment for 10,000 years. These limits would be based on the "fundamental premise . . . that there should be no more than 1,000 fatalities ['health effects'] in the next

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[75] White, "Background Paper for Assessment of Basalt Lava Flows," June 1983, p. 26.

[76] National Research Council, Study of the Isolation System for Geologic Disposal of Radioactive Wastes, 1983, p. 166 (emphasis added). The Umtanum lava flow was the proposed location of the repository at the time the National Research Council report was written. While it is still one of the options, the Cohassett flow is now the proposed location. (See Chapter 3.) The context of the National Research Council's judgment makes it clear, however, that it applies to the conditions prevailing at the Hanford site, which are qualitatively similar in both flows, compared to some other possible sites.

10,000 years resulting from radioactive releases from a full-scale geologic repository. . . ."[77]

The Nuclear Regulatory Commission has issued performance criteria and other regulations based on "an assumed EPA standard" like the proposed one cited above. Strangely, while the EPA standard is still in draft form; the NRC has already issued its final rule. (It has retained some flexibility in this rule to make amendments in light of changes in EPA standards or other factors.) It has four principal performance criteria after closure:

- retrievability during waste emplacement and after closure until "significant uncertainties . . . have been resolved, thereby providing greater assurance that the performance objective will be met."[78]

- complete "containment of HLW [high-level waste] within the waste packages . . . for a period . . . not less than 300 years nor more than 1,000 years after permanent closure of the geologic repository."[79]

- the release rate from the "engineered barrier system" of all radionuclides remaining in significant quantities after 1,000 years "shall not exceed one part in 100,000 per year of the inventory of that radionuclide calculated to be present at 1,000 years following permanent closure."[80]

- the "pre-emplacement" travel time of groundwater along the fastest likely path "shall be at least 1,000 years or such other travel time as may be approved or specified by the Commission."[81]

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[77] Ibid., p. 220.
[78] Code of Federal Regulations, 10 CFR 60, Federal Register, June 21, 1983, p. 28197.
[79] Ibid., Sec. 113, p. 28224.
[80] Ibid.
[81] Ibid.

Our resources do not permit an evaluation of these EPA and NRC performance standards at this time, though they have been severely criticized by the National Research Council. The Council concluded that:

> EPA release limits can result, in some cases, in expected health effects for real candidate sites that are far lower than in the health effect goal basic to the EPA calculation, and in other cases population exposures and numbers of health effects much greater than the EPA objective seem likely. . . . We conclude that the EPA has not proposed a useful or meaningful way of obtaining its goal of limiting population risks from a geologic repository.[82]

The Council also seriously criticized the NRC standards saying that it had "not presented adequate evidence" that there would be no "unreasonable risk" to the public, that EPA and NRC standards have apparently contradictory assumptions, that the NRC criteria have not been technically justified, and that performance cannot be verified.[83]

We shall limit ourselves to discussing the merits, or lack thereof, of the characteristics of the Hanford site in meeting the NRC performance standards.

There are a number of factors which will affect repository performance as it concerns the NRC standards. Some of them are:

- the characteristics of the radioactive waste package and the material used to backfill the emplacement hole (which together are called the "engineered barrier system")

- groundwater chemistry, temperature, and velocity

- nature of groundwater-waste package interaction

- ability of the rock to selectively retain radionuclides (known as "sorption")

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[82] National Research Council, Study of the Isolation System for Geologic Disposal of Radioactive Wastes, pp. 224-225.
[83] Ibid., Chapter 8, pp. 227-232.

- possibility and effects of "human intrusion"

- volcanism, earthquakes, or other large-scale geologic phenomena

- the problems of monitoring the release of radionuclides after closure so as to validate performance

- difficulty of retrievability in the post-closure phase

- ease or complexity of site characterization

Hanford has two potentially favorable characteristics which could help it meet the NRC standards, provided there are no complicating circumstances. These two factors are (1) favorable water chemistry, which tends to slow down dissolution of the waste package, and (2) good sorption capabilities for many radionuclides on rock fracture surfaces. (See Appendix for further discussion.) However, as we shall see below, both these potentially favorable factors may be nullified by other unfavorable characteristics of the site and of certain waste forms.

Hydrologic Conditions

> Calculations by NRC of pre-emplacement groundwater travel time vary from 20 years to more than one million years, based on current BWIP [Basalt Waste Isolation Project] data.[84]
>
> -- Nuclear Regulatory Commission

The groundwater in or near the proposed Hanford repository will be quite close to the Columbia River. Estimates of groundwater path length vary from 6 to 80 kilometers.[85] Questions relating to groundwater velocity and to the containment of wastes within the

[84] Draft Site Characterization Analysis of the Site Characterization Report for the Basalt Waste Isolation Project, NUREG-0960, March 1983, p. xiv.

[85] White, "Background Paper for Assessment of Basalt Lava Flows," June 1983, p. 14. The discussion in the Appendix relates generally to Grande Ronde Basalt where all the proposed repository sites are located, but on some specifics relate to the Umtanum lava flow, not currently the preferred repository location.

engineered barrier system take on an even greater importance than they might in another location away from such a major source of water for people.

Since the Hanford site has long been the location of numerous Federal nuclear activities, it has been relatively more studied than the other sites. The data obtained from the field investigation have revealed that the site is exceedingly complex, as the Basalt Waste Isolation Project Overview Committee has pointed out:

> We anticipate and emphasize the possibility that the complexity of the proposed BWIP site geology and hydrology may preclude highly definitive characterization of the hydrologic regime for any reasonable -- or even heroic -- expenditure.[86]

DOE estimates that "median preemplacement water travel times to the accessible environment along pathways of likely radionuclide travel are expected to be greater than 10,000 years."[87] With many qualifications, an estimate of travel time of 10,000 years may not be unreasonable. (See Appendix for detailed discussion.) However, the complexity of the site, inadequacies of the model, and uncertainty of the data are such that the Nuclear Regulatory Commission was able to come up with an enormous range of estimates from 20 years to one million years for water travel time using the same data. The complexity of the site may preclude reliable measurements of performance after closure. In that case, the performance data would not reliably indicate whether wastes should be retrieved or not, thus defeating the purpose of waste retrievability required by the NRC.

As noted above, the NRC requires a site to be disqualified if the water travel time to the "accessible environment" is less than 1,000 years. Even while claiming that it expects water travel time to be greater than 10,000 years, the DOE has now admitted that it cannot certify at this time that the site will not be disqualified because of

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[86] BWIP Hydrology and Geological Overview Committee, Report and Responses from BWIP, Informal Report, RHO-BWI-LD-50.

[87] Draft Environmental Assessment: Reference Repository Location, Hanford, DOE/RW-0017 (December 1984), p. 6-63.

short water travel time. According to its Environmental Assessment of December 1984:

> A final conclusion on this disqualifying condition for pre-emplacement water travel time [of less than 1,000 years] is not possible at this time.[88]

That the extensive investigations at Hanford have led to data which allows for such a wide range of conclusions as to water travel times underlines the complexity of the Hanford site. It means that we may not be able to achieve a reasonable level of confidence in hydrologic estimates. It is for this reason that complexity could by itself be a disqualifying factor for a site, according to a DOE Environmental Assessment published in 1983:

> A site shall be disqualified if the characteristics that influence radionuclide transport are too complex to allow reasonable confidence of compliance with the proposed 40 CFR 191.13 [EPA proposed standards] when considered in conjunction with state-of-the-art engineered systems. . . .[89]

Strangely, while admitting that the "geologic setting, site geometries, and radionuclide-transport characteristics . . . are extremely difficult to characterize and model,"[90] DOE goes on to take credit for "groundwater travel times of more than 10,000 years" under the same system guideline![91]

The estimate by the NRC of a water travel time as low as 20 years is not the lowest value we have come across. Christopher Earle, a geologist, stated at a conference about the Hanford site that the travel time to the accessible environment could be as small as one week:

> A point which was not mentioned by other critics of the Rockwell report but which our research uncovered, is that springs which occur in the south side of the Columbia River a few miles north of the proposed repository location, are found to flow out of the Vantage Interbed. The Vantage Interbed is a layer of very

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[88] Ibid., p. 6-79.

[89] Office of Civilian Radioactive Wates Management, <u>Draft Environmental Assessment</u>, DOE/EA-0210, U.S. Department of Energy, Washington, D.C., February 1983, p. 3-7. According to Dean Tousley, this guideline was later dropped for reasons we do not know. 49 Fed. Reg. No. 236, 47715 (December 6, 1984).

[90] Ibid., p. 3-8.

[91] Ibid., p. 3-7.

> porous, 'leaky' rock through which groundwater flows only a couple of hundred feet above the Cohassett Flow, which is where Rockwell proposes to store the nuclear waste. The deep groundwater circulation created by the hot waste containers will carry waste upward into this Vantage Interbed, at which point the waste could reach the Columbia River in as little as one week. . . .[92]

We do not know if this analysis has been confirmed by others. So far as we know, DOE and Rockwell have not substantively and directly addressed the specific issue it raises.

The general question of vertical flows of water at the Hanford site is unresolved and constitutes one of the most important uncertainties about water flow at the site. (See Appendix for detailed discussion of the uncertainties.) A significant upward component to the water flow may mean substantially faster travel times than those computed assuming horizontal flows. In a 1981 study done for the Nuclear Regulatory Commission, Linda L. Lehman and Ellen J. Quinn noted that, "[w]ith the exception of [an] in-house RHO [Rockwell Hanford Operations] report" all other "studies show a predominantly upward groundwater flow component which travels through the repository stratum and discharges at or near the Columbia River."[93]

In a later study done for the Yakima Indian Nation, Linda Lehman concluded that chemical data pointed in the same direction of vertical water flow:

> Data from 17 wells located on the Hanford Reservation . . . were analyzed. . . . The results . . . indicate vertical mixing is occurring. The analyses do not permit determination of the rate of mixing.[94]

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[92] Christopher Earle, statement at WASHPIRG Hanford Conference.

[93] Linda L. Lehman and Ellen J. Quinn, Comparison of Model Studies: The Hanford Reservation, Internal NRC Document, 8204200365-820330 PDR Waste, WM-1, PDR (1981), p. 2.

[94] Linda Lehman, Hanford Reservation: Analysis of Chemical Data Released by DOE on February 15, 1983, Harmon and Weiss, Washington, D.C., March 27, 1983, p. 1.

The controversies surrounding vertical conductivity assume even greater importance when we consider that the Hanford repository would fill up with water relatively soon after closure. According to Dr. White:

> Resaturation starts when the water drainage system is shut off and the repository is sealed. Water levels rise slowly as the repository rooms saturate, and then rise rapidly as the limited volume shafts are filled. . . . The time required for resaturation probably ranges from a few years to decades. . . .[95]

This means that the engineered barrier system will come into contact with the water soon after the repository is closed. Unlike a repository in which a substantial period of isolation from water is possible, radioactive waste packages at the Hanford site would be susceptible to attack by groundwater and its constituents without substantial delay. This means that a much greater degree of confidence in the integrity of the engineered barrier system will be required compared to sites where isolation from water for a long period is probable. In particular, the NRC standard that there be essentially no releases from 300 to 1,000 years after permanent closure may be more difficult to meet.

Chemical Factors

Were it not for complicating factors, the favorable groundwater chemistry at Hanford (see Appendix) may have compensated for the resaturation of the repository, at least to some extent. However, this is by no means assured since several adverse factors tend to nullify its advantage of favorable water chemistry.

First, rock bursting during and after waste emplacement may physically damage the integrity of one or more of the engineered barriers. (At the present time, it is uncertain what these might be, but typically 3 barriers are being considered -- a 'waste form' such as glass to encapsulate the waste, a container for the waste form, typically of metal, and the use of special backfill materials in the emplacement hole.) The NRC requires each of the barriers to "make definite

[95] White, "Background Paper for Assessment of Basalt Lava Flows," June 1983, p. 23.

contribution" to waste containment, and not only to the "bottom line" of an overall performance standard.[96] However, a common mode failure of at least two engineered barriers (the backfill and metal container) is a possibility for a number of waste packages due to rock bursting. This may violate the spirit of the NRC regulations.

Under the circumstances of the Hanford repository, it is conservative and reasonable to assume that the water will be in contact with the waste form soon after closure of the repository, or perhaps even during it. The latter possibility could arise if rock bursting established communication between waste emplacement boreholes and sources of water seepage into the repository.

We should also note at this point a possible conflict between mine safety and waste containment. One way to promote safety and prevent unanticipated rock bursting is to relieve rock stresses by deliberate blasting.[97] This could aggravate containment problems by increasing the permeability of the repository and hence water flow through it. Donald E. White has noted:

> Data are especially inadequate for assessing the significance of core discing, with its implications of extreme rock bursting that could encroach on adjacent aquifers. . . .
>
> . . .
>
> Special studies of present stress environment by recognized experts are needed to establish the magnitude of the problems. Direct communication with permeable local aquifers may become established.[98]

In its most recent Environmental Assessment (December 1984), DOE has conceded the possibility that repository construction may decrease groundwater travel times, but claim that existing data and analyses "do not support a finding that the reference repository location is likely to

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[96] 10 CFR 60, June 21, 1983, p. 28196.
[97] Draft Environmental Assessment: Reference Repository Location, Hanford, DOE/RW-0017, p. 6-187.
[98] White, "Background Paper for Assessment of Basalt Lava Flows," June 1983, p. 25.

have this potentially adverse condition."[99] Thus, the response of DOE to the possibility of adverse conditions is to continue to insist on the non-conservative values for water travel times.

The final decision on the waste form for civilian high-level radioactive wastes currently in the form of spent fuel has not yet been made. Detailed studies on the interaction of spent fuel with water under repository conditions have not yet been made, so far as we know. However, DOE plans to encapsulate the military high-level wastes at the Savannah River Plant in South Carolina in glass. Westinghouse Corporation is under contract to do the same to the mostly civilian high-level wastes currently stored at West Valley, New York. These glassified wastes may be put in the same repository as spent fuel.

Recent experiments on glass indicate that under the conditions of high water flow that may occur at Hanford, the glass may disintegrate rapidly (relative to requirements).

A two-year program from 1982 to 1984 to study leaching mechanisms for radioactive waste from glass under diverse conditions was "sponsored by DOE's High-Level Waste Technology Program Office at the Savannah River Laboratory."[100] Glass was tested under varying water chemistry, temperature, and flow conditions. It was found that when water flow is slow enough, a protective layer of chemicals forms on the glass surface, substantially slowing down dissolution of the glass, at least under laboratory conditions.[101] If the same phenomenon occurred in a repository, as might be reasonable to expect without other complicating factors, it would substantially limit the releases of radionuclides to low values.

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[99] Draft Environmental Assessment: Reference Repository Location, Hanford, DOE/RW-0017, December 1984, p. 6-76.
[100] J.E. Mendel (compiler), Final Report of the Defense High-Level Waste Leaching Mechanisms Program, PNL-5157, prepared for the U.S. Department of Energy, Pacific Northwest Laboratory, Richland, Washington, August 1984, p. v.
[101] Ibid., pp. 1.28-1.33

Under laboratory conditions of relatively high water flow velocity, the protective layer of chemicals is either not formed or destroyed as it is being formed:

> . . . at high [water] flow rates . . . the surface layer is depleted with respect to all these elements [silicon, boron, sodium, etc.] and . . . a dealkalized silica-rich protective layer is not built up.[102]

Dissolution of the glass was found not to be the major mechanism for the destruction of the waste form under high water flow conditions, at least under laboratory conditions. The glass is simply mechanically corroded by the water flowing past it, according to the analysis of these experiments.[103] One of the principal advantages of the Hanford site -- favorable water chemistry limiting dissolution of the waste form -- may therefore be nullified by high water flow velocities.[104]

The Department of Energy estimates water flow times of 10,000 years or more. Using a figure of 10,000 years with a water path length on the lower side of about 10 kilometers yields a water velocity of roughly one meter per year. At this water flow rate, a number of glass constituents, including silica, would leach rapidly into the water -- at rates of 0.1 gram per square meter per day if the glass becomes exposed to the flowing water. This is roughly equal to a fractional loss of one part in 10,000 per year.[105]

<u>This loss rate is 10 times the maximum loss rate permitted by NRC standards</u>. Moreover, it may start occurring soon after emplacement in those cases where engineered barriers are damaged by rock bursting.

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[102] Ibid., p. 1.25

[103] Ibid., p. 1.26.

[104] There is considerable controversy over the mechanisms of radionuclide transport from the surface of the waste form. The National Research Council Panel on Radioactive Waste Isolation Systems has criticized the DOE-sponsored analysis for not taking diffusion mechanisms into account adequately, though these may tend to slow radionuclide transport. It is our impression that this controversy relates primarily to low water velocities. However, it is beyond the scope of this preliminary report to address it. We have relied on the DOE-sponsored analysis for this brief discussion.

[105] Derived from data in ibid., Figure 1.16.

Thus, the other NRC criterion for containment -- essentially complete containment for 300 to 1,000 years -- may also be violated.

In the cases when the outer engineered barriers are not subject to violent failure, the water may stay out of contact with the glass for a longer, though as yet uncertain, period. However, we should note that these calculations are based on a non-conservative value of water velocity. Higher values of water velocity (and glass surface area relative to volume) could result in loss rates up to one part in 1,000 per year. Water velocity and flow patterns could also be significantly affected by the heat generated by the radioactive waste placed in the repository.

It is, of course, not possible for us to predict water velocity in the repository. The water flows in intact basalt are normally very small, since the intact basalt consists of lava flows isolated from aquifers, by definition. However, it is known that there are vertical fractures in the basalts of the Grande Ronde Basalt where the repository is to be located, though the extent and character of vertical water flows is largely unknown, as discussed above. In addition, the construction of the repository will necessarily destroy the integrity of the lava flow and put it into communication with aquifers. The repository will be saturated as a result. Water flow velocity may also increase as a result of rock bursting, as noted above. Thus, a number of factors indicate that water flow of one meter per year or faster may prevail in the repository.

The waste form may also be adversely affected by high temperatures. The leaching program did not consider in detail the possible effects of steam on glass. Due to the high water temperature and the lowering of water pressure to approximately atmospheric pressure,[106] steam may be generated near the waste form if the water comes into contact with the waste form -- since the waste form will be generating heat. This will depend in part on the design temperature

[106] White, "Background Paper for Assessment of Basalt Lava Flows," June 1983, p. 23.

and the extent to which ambient conditions are accurately taken into account in the design. Steam may destroy the waste form much more rapidly than hot water -- a phenomenon which was experimentally found in the case of glass at Argonne National Lab.[107]

The final barrier between the radionuclides and the "accessible environment" would be the rock through which the water water would flow. Radionuclides may be selectively deposited ("sorbed") on the rock fracture surfaces under certain favorable physical and chemical circumstances. The state and chemistry of the rock fractures at Hanford indicate that many radionuclides could be sorbed by the rock, thereby substantially reducing their release to the environment (see Appendix for details). However, this favorable factor may be nullified by other unfavorable factors of the Hanford site.

It has been found that certain organic compounds form "complexes" with radionuclides. These complexes are not well sorbed and tend to travel at approximately the speed of the groundwater. Thus, for instance, the DOE estimated the sorption capacity for plutonium of the soil at the Savannah River Plant site to be very high. However, in the presence of an organic solvent, tributyl phosphate, plutonium traveled through the soil and reached the groundwater, tens of feet below the surface, in only twenty years.[108]

Recently, small but significant quantities of complexing compounds (fulvic acids) were found in a single sample of water from the Grande Ronde Basalt in which the repository is proposed.[109] DOE does not as yet consider this "a major problem" but has at least recognized the need for further investigation.[110] It takes on great significance,

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[107] J.K. Bates et al., "Hydration Aging of Nuclear Wastes," Science, Vol. 218, 1 October 1982, pp. 51-53.
[108] Arjun Makhijani et al., Deadly Crop: Growing Curies on the Tank Farm, Environmental Policy Institute, Washington, D.C., February 1985, Chapter 6.
[109] Draft Environmental Assessment: Reference Repository Location, Hanford, DOE/RW-0017, p. 6-94.
[110] Ibid.

however, in the context of possible rapid waste-form corrosion and short water travel times, which DOE does not as yet acknowledge.

Methane gas has also recently been discovered to be present in Grande Ronde water samples in concentrations up to 700 milligrams per liter. Under highly radioactive conditions, the methane in the water could form complexing compounds of high molecular weight. However, DOE claims that these are not found in the presence of basalt and thus that this factor may not be an adverse one.[111] However, the waste form and container will probably not be in contact with basalt, but with the backfill material.[112] The possibility of significant quantities of complexing compounds being formed cannot be ruled out as easily as DOE has done.

In sum, the complexing of wastes with organic compounds may occur in the repository and could nullify the effects of high sorption of many radionuclides from the groundwater.

Long-Term Geologic and Climatic Stability

> We can be much more confident of the stability of old granites on a pre-Cambrian shield [older than 570 million years] than of young basalts in a tectonically active continental margin such as the Pacific coastal regions of the U.S.[113]
>
> -- EPA Ad Hoc Panel

> Future melting of polar ice caps, with consequent rise in sea level close to the altitude of the Columbia River Gorge, raises questions of the time and extent of possible flooding due to downstream changes. These could also occur unpredictably from volcanic damming of the Columbia River.[114]
>
> -- National Research Council

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[111] Ibid., p. 6-95.

[112] Backfill may contain basalt and bentonite in combination, according to Dean Tousley, but this issue still needs to be resolved.

[113] EPA Ad Hoc Panel, 1978.

[114] National Research Council, Study of the Isolation System for Geologic Disposal of Radioactive Wastes, p. 171.

The Department of Energy claims climatic stability, which it predicts should extend "over the next 100,000 years, except for a colder drier climate associated with a postulated glacial advance."[115] It has not considered in depth the possibility of polar ice cap melting as posited by the National Research Council. Moreover, contrary to the DOE statement that the climate could only become drier, the EPA Ad Hoc panel raised the possibility that it might become substantially wetter.[116]

DOE has acknowledged that there is evidence of "active folding, faulting, diapirism, uplift, subsidence, or other tectonic processes" in the Hanford region.[117] It has also noted the presence of volcanism in the Columbia River Basalt Group and in the area where this "onlaps the Cascade Range."[118] At the same time it claims to have calculated that there is "less than one chance in 10,000 over the first 10,000 years after closure of leading to releases of radionuclides to the accessible environment."[119] On this basis the "nature and rates of igneous activity and tectonic processes" are claimed as a "favorable condition" for the Hanford site.[120] This characterization is being challenged, and more research is clearly needed.

There are many difficulties associated with such calculations. It is beyond the scope of this preliminary report to discuss these in detail, but we mention some of them. First, the complex nature of the site, the difficulty of modeling combined with the very short period over which reliable data are available raises the possibility that calculations in which we can have high confidence cannot be done. Second, it is not a conservative procedure to calculate the risk from catastrophic events by multiplying a probability with its calculated consequences.[121]

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115 Draft Environmental Assessment: Reference Repository Location, Hanford, DOE/RW-0017, p. 6-117.
116 EPA Ad Hoc Panel, 1978.
117 Draft Environmental Assessment: Reference Repository Location, Hanford, DOE/RW-0017, p. 6-129.
118 Ibid., p. 6-130.
119 Ibid., p. 6-127.
120 Ibid.
121 While this is a common procedure in the nuclear industry, it is not based on practical social reasoning. For a discussion, see Makhijani, Deadly Crop: Growing Curies on the Tank Farm, Chapter 5.

Third, there are many radionuclides with half-lives greater than 10,000 years, and these are ignored by the DOE calculations, since it covers only 10,000 years. This approach has also been criticized by the National Research Council.[122]

Finally, the DOE notes that no faults have been identified within the proposed repository location. However, Donald E. White has noted that this does not exclude the possibility that they exist since such faults "could not be recognized easily below the cover of young sediments, especially considering the wide spacing of drillholes."[123]

Social Factors

Official publications discuss conflicts of economic activities with repository performance as "human intrusion" or "human interference." We will not discuss the many general schemes that have been suggested to prevent "human intrusion" after a repository has been built, since these are rather speculative. The issue is far better addressed by not building a repository where radionuclides are likely to interfere with or cause serious harm to substantial economic activities.

There are four areas of economic activity which may be affected by the construction of the repository at Hanford:

- the use of surface waters and groundwater for domestic and industrial purposes
- irrigation
- the production of hydrocarbons, particularly natural gas
- the production of geothermal energy

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[122] National Research Council, Study of the Isolation System for Geologic Disposal of Radioactive Wastes, pp. 226-231.
[123] White, "Background Paper for Assessment of Basalt Lava Flows," June 1983, p. 2.

The first item is of general concern in case the repository does not contain the radionuclides adequately, rendering it dangerous to use the waters that would be contaminated as a consequence. While this criterion applies to all sites, it has special significance at Hanford. The Columbia River is one of the largest in the country, Hanford operations have already contaminated the river with radionuclides, and its further contamination could result in great economic and social dislocation and deprivation.

Besides the possibility of water pollution, there may be a potential conflict of the use of water for irrigation with repository performance. According to the NRC:

> . . . it appears that the [microearthquake] swarms are not occurring randomly. However, no mechanism has been found which can explain the cause of all the swarms. . . . Various investigators have suggested that groundwater level changes may be a triggering mechanism for the swarm seismicity. . . . [A] visual inspection [of a map] reveals that the majority of swarm events have occurred in areas of irrigation or in areas bordering (within 5 kilometers) irrigation. However, this does not explain all the swarms because some swarms have occurred in non-irrigated areas.[124]

Microearthquakes, being relatively small events by definition, do not affect normal surface activities. However, according to the NRC, repeated occurrence of microearthquake swarms "could result in the degradation of the mine openings or damage mining equipment."[125] Thus, in case irrigation is found to be a cause of or aggravating factor in the occurrence of microearthquake swarms, there could arise a conflict between repository integrity and irrigation (which is widespread in the region), which would be very difficult to resolve. The dilemma would essentially be between the economic interests of the farmers and their products' consumers and the safety and integrity of the repository which is essential to protecting workers and future generations.

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[124] Draft Site Characterization Analysis of the Site Characterization Report for the BWIP, NUREG-0960, March 1983, Appendix N, p. N-2.

[125] Ibid.

The Department of Energy recognizes the potential for natural gas production in the area. There was a small natural gas field in the area which produced gas between 1929 and 1941.[126] There has recently been exploration in the area by major oil companies. But DOE postulates that

> [the] mineral industry within 100 kilometers (62 miles) of the Hanford Site, including the reference repository location, is a relatively insignificant component of employment, personal income, and governmental revenue derived from all mineral resources.[127]

This is an inappropriate conclusion since we do not know the extent of the natural gas resources in the area. (Note that methane, the main constituent of natural gas, is present in the Grande Ronde Basalt groundwater.) Moreover, the area does contain substantial geothermal resources in the form of hot water which could be used for non-electrical purposes, such as space heating (see Appendix). Finally, comparison of the potential with "governmental revenue from all mineral resources" may be irrelevant if local economic considerations favor exploitation of local resources at some future time.

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[126] Draft Environment Assessment: Reference Repository Location, Hanford, DOE/RW-0017, p. 6-139.
[127] Ibid., pp. 6-140 - 6-141.

CHAPTER 6

Politics of Repository Siting and Recommendations

The first years of atomic development in the 1940s focused on developing an atomic bomb, rather than on handling the new radioactive wastes being produced in the crash program to be the first to create atomic fission. Scientists seemed confident that technologies could later be developed to deal with the problem. Over the next two decades, various proposals were offered for long-term waste disposal, and the growing nuclear power industry added impetus to the need to develop a plan.

The Atomic Energy Commission decided to pursue underground disposal of these wastes in the 1960s, and initiated Project Salt Vault to conduct tests in a salt mine near Lyons, Kansas. Lyons was chosen by the AEC in 1970 for an initial salt mine repository for the demonstration of long-term storage of solid high-level and long-lived low-level wastes. The Project Salt Vault manager, Oak Ridge National Laboratories, announced in 1971 that "most of the major technical problems pertinent to the disposal of highly radioactive wastes in salt have been resolved."[128]

However, the State Geological Survey of Kansas reached a different conclusion regarding the safety of salt beds for storing radioactive wastes. A 1970 State Geological Survey report raised serious questions about interactions of heat and radiation on salt, noted that transportation plans for wastes to the burial site were completely inadequate, and warned that there were no plans at all for removing the wastes if something went wrong.[129]

AEC plans to begin placing waste at Lyons in 1975 were thwarted by local opposition and further revelations of problems with the Lyons

[128] "The Nuclear Legacy -- How Safe Is It?" 8 The Workbook, Nos. 4 and 5, p. 151 (July-October 1983).
[129] Ripley, Anthony, "Kansas Geologists Oppose a Nuclear Waste Dump," New York Times, 27 (Feb. 17, 1971).

site. The Lyons area had been the site of numerous natural gas mining wells, which left unplugged drill holes through which wastes might escape. AEC scientists eventually claimed that they could seal all but two of the unplugged drill holes in the area. Rep. Joe Skubitz, a Kansas Republican, charged that the AEC solution was somewhat akin to fixing all but two holes in a flat tire and then claiming one could drive to California on it. In 1971 Rep. Skubitz asked Governor Robert B. Docking to join him in opposing a $3.5 million appropriation requested by the AEC from Congress to purchase 2,000 acres of land for the waste site.

"The fact is," Rep. Skubitz wrote the Governor, "that however the Atomic Energy Commission may phrase it semantically, a part of Kansas is proposed as a dump for the most dangerous garbage in the knowledgement of mankind. A dump is a dump no matter how the garbage is packed."[130] Governor Docking joined Rep. Skubitz in opposing the plan.

Representative Skubitz wrote to the AEC later in 1971, charging that in Kansas the AEC acted:

> . . . to carry out a previously adopted decision to install the waste dump regardless of the scientific facts that might be developed to alter or modify such a decision; to use legal technicalities and scientific verbiage in an effort to confuse and mislead non-scientifically educated persons. All in all, yours has been a shabby endeavor in this instance, not befitting any Federal agency, much less one supposedly dedicated to the scientific truth and therefore not afraid to face facts. Of course, I am disappointed and dissatisfied with the AEC and I am far from alone in the Congress in so believing.[131]

The AEC was forced to start looking anew for a nuclear dump site. It initially attempted drilling into the Salina Basin salt beds, without seeking support of Michigan officials. Michigan's Governor William Milliken informed the AEC that it was not welcome to explore the salt beds of that state, so the AEC turned to New Mexico, where it was

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[130] Ibid.
[131] "Nuclear Legacy," p. 151.

actually welcomed by various state government officials, the Mayor of Carlsbad, and some business interests.[132]

In 1975 work began at the New Mexico bedded salt site, called the Waste Isolation Pilot Plant (WIPP). To avoid any NRC licensing requirements, in 1979 Congress decided that the WIPP site would only be used for military waste storage. President Carter attempted to cancel WIPP in 1980, having decided that public policy required that all wastes be disposed of in repositories licensed by the NRC. Further, disposal of both commercial and military wastes at one site would be more cost effective. In 1981, under the Reagan administration, DOE announced that it would dispose of defense transuranic waste and small volumes of high-level waste at the WIPP site. Despite three lawsuits (including one instituted by the State of New Mexico) and opposition from the state's governor, DOE reaffirmed its plans on July 1, 1983, to construct WIPP as a permanent waste disposal site to be in operation by 1988, though no commercial or high-level military waste would be disposed at the site.[133]

Concerns raised by the Interagency Review Group on Radioactive Waste Management,[134] the U.S. Geological Survey,[135] and the Environmental Protection Agency[136] by the 1970s forced the DOE to expand its program, focussed on salt domes and salt beds, to consider other locations and other geologic media. DOE identified three approaches for preliminary site selection: (1) host rock approach, (2) review of potential sites already held by the federal government, and (3) province screening.[137] Under the second approach, two sites

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[132] Ibid., p. 152.

[133] Ibid., pp. 152-153.

[134] Interagency Review Group on Radioactive Waste Management, Subgroup Report on Alternative Technology Strategies for the Isolation of Nuclear Waste, TID-28818 (Draft), October 1978.

[135] U.S. Geological Survey Circular 779, Geologic Disposal of High-Level Radioactive Wastes -- Earth Science Perspectives, 1978.

[136] U.S. Environmental Protection Agency, State of Geological Knowledge Regarding Potential Transport of High-Level Waste from Deep Continental Repositories, EPA/520/4-78-004 (1978).

[137] Department of Energy, Draft Environmental Assessment for Characterization of the Hanford Site Pursuant to the Nuclear Waste Policy Act of 1982, (Public Law 97-425), DOE/EA-0210 (February 1983).

already contaminated with radioactive materials were added to the federal list:

> Hanford, Washington -- home of the nation's first plutonium production facilities, a reprocessing facility, storage of 50 million gallons of high-level nuclear waste, a plutonium fueled test reactor (FFTF), a variety of other federal nuclear projects, and a low-level nuclear waste burial ground.
>
> Yucca Mountain, Nevada -- near the Nevada Test Site where nuclear weapons have been tested since 1951.

Both sites are among the three which DOE has placed at the top of its list for site characterization.

In 1982, Dr. Frank Coffman became DOE's deputy assistant secretary for waste management and fuel cycle programs. Pledging to move the waste construction selection process on the "fast-track," Dr. Coffman stated,

> Make no mistake about it, I want this program to get off the ground. I want the public to know that we are very clear about what we have to do about wastes, and that we are going to implement a sound policy with all reasonable speed.[138]

Coffman stated his intention "to sit down with state and local officials and do a lot of straight talking. . . . We will tell state and local officials that we are creating jobs, improving roads and schools with an endeavor that will not produce emissions or effluents. We are talking about siting a small set of facilities and a mine. And this can be a very positive thing." He claimed that DOE would do everything it could "to avoid the kind of misunderstandings that have hurt us in the past."[139]

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[138] "DOE Plans to Fast-Track First National Repository," Nuclear Waste News 74 (May 20, 1982).
[139] Ibid., p. 76.

Only a year later, one state official was less than charmed by the DOE performance. Writing to DOE Secretary Donald P. Hodel on December 22, 1983, Governor Scott Matheson of Utah charged:

> In its efforts to meet deadlines established in the Act, minimize the costs of this program and enhance public confidence in the nuclear power industry, DOE appears to be shortcutting the steps prescribed by Congress to assure careful judgment based on full information. I am also concerned that this rush to judgment is proceeding in disregard of other important values protected by law. It is my judgment that the DOE's site selection process is seriously flawed, both procedurally and substantively, requiring immediate reexamination and change of course.[140]

Governor Matheson directed Utah agencies to terminate any cooperative activities with the DOE and its contractors which would further the existing schedule and approach. He also sought changes in the Nuclear Waste Policy Act of 1982 regulations so that guidelines would protect National and State Parks, and he demanded responses to earlier information requests made to DOE.[141]

The following year Governor Mark White of Texas wrote a similar letter to DOE Secretary Hodel:

> . . .[I]t is my judgment that the screening and candidate site selection process . . . is sufficiently flawed to have the strong likelihood of leading to a repository site recommendation that cannot demonstrate a requisite level of protection of human health and safety, and environment. I strongly recommend for your consideration that, in the interest of the nation's ultimate success in resolving the need to finally dispose of existing and accumulating high-level wastes, the current site selection decision activities for a first repository be abandoned, and that a new and full and competent national screening process be instituted under the Nuclear Waste Policy Act. <u>I make this recommendation of serious consequence in view of my having lost faith in the integrity of the ongoing DOE site selection activities. . . .</u>[142]

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140 Letter to The Honorable Donald P. Hodel, Secretary, Department of Energy, from Governor Scott Matheson, Utah (Dec. 22, 1983).

141 Ibid.

142 Letter to Secretary Donald Hodel, Department of Energy, from Governor Mark White of Texas, October 9, 1984. Emphasis added.

Governor White pointed out the refusal of DOE staff to disclose the specific methodology by which sites were to be recommended for site characterization, and noted that the guidelines not yet finalized by DOE appeared to have been designed with the sites already nominated in mind. Governor White, like Governor Matheson, also felt that state officials' questions were being left unanswered and that state concerns were not being adequately addressed.

The State of Texas filed suit in the Fifth U.S. Circuit Court of Appeals on December 19, 1984, challenging the legality of the federal selection process. State Attorney General Jim Mattox charged that DOE ignored the importance of prime farmland in the Texas Panhandle, as well as the danger to the Santa Rosa and Ogallala aquifers supplying water to residents of West Texas.[143]

The Texas Department of Agriculture conducted a scientific survey of Texas Panhandle people to evaluate the impact of the proposed siting of a nuclear waste respository in the region. Agriculture Commissioner Jim Hightower stated:

> We've demonstrated with scientific methods and hard numbers that people in Deaf Smith and Swisher counties don't want the dump because they fear it would ruin their health, their land, their livelihoods, and their way of life. More than 80 percent would reject the dump if it were up to them. More specifically, this opposition is extremely broad-based and cuts across age, gender, ethnic, and occupational groupings. But it is particularly strong among farmers. They know how the dump would threaten their land and water and the outstanding reputation of the vast array of agricultural products grown in this fertile farm country.[144]

After Deaf Smith County was chosen as a DOE finalist, Governor White declared, "Here in Texas, we are not about ready to roll over and let the federal government shove this program down our throats."[145]

[143] Yance, Matt, "Washington State, Nevada, Texas on N-Dump List," The Arizona Daily Star, December 20, 1984, p. 1.

[144] "Results Show Nuke Dump Plans Hurt Panhandle," 76 The Tulia Herald (44) 1 (Nov. 1, 1984).

[145] Reed Parsall, "Governor States Opposition to Dump," Hereford Brand, p. 1 (December 23, 1984).

He also warns, "Before the people of Deaf Smith County will glow in the dark, sparks will fly."[146]

Governor Richard Bryan of Nevada joined the Utah and Texas governors in criticizing the whole DOE process. Bryan charged that DOE ". . . has consistently ignored its Congressional mandate" to get sound data regarding the facility. Governor Bryan stated:

> Instead, the site selection process has been tainted by politicking and the real issues of geological suitability and which state bears proper responsibility have been lost. . . . In sum, the process is flawed, its credibility seriously -- if not totally -- eroded, and I strongly urge Congress to reexamine the entire site selection process.[147]

Governor Bill Allain of Mississippi also found state officials facing too many unanswered questions and requests made to DOE. In early December, 1984, he warned residents not to be "lulled into a false sense of hope on the nuclear waste issue. . . . We are not home free. If we sit down after December 20, we may well wake up in February and see that we're number one."[148]

Allain was referring to the projected announcement by DOE of the three final sites chosen for characterization by December 20, 1984. The City of Biloxi, Mississippi, opposed the proposed Mississippi waste sites so strongly that it provided office space and administrative help to the activist group Citizens Against Nuclear Disposal. Biloxi Mayor Gerald Blessy called the nuclear waste site issue "one of our high public safety priorities."[149]

The State of Louisiana reached an agreement with the DOE under the Carter administration that acceptance of a strategic petroleum reserve site in the mammoth underground salt domes would eliminate

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[146] The Oregonian, p. 1 (December 20, 1984).

[147] "Bryan: Re-evaluate nuclear dump site," Reno Gazette, October 11, 1984, p. 1-A.

[148] "Allain urges residents to keep fighting dump," Clarion-Ledger, December 8, 1984.

[149] Cauchon, Dennis, "Biloxi joins fight against waste site," Clarion-Ledger, August 14, 1984.

Louisiana from the list of finalists for the long-term nuclear waste disposal repository. The DOE agreement provides that the government "will not construct any nuclear waste repository in Louisiana if the state objects."[150] Presidential candidate Ronald Reagan pledged to uphold this agreement in a telegram to Louisiana Governor David Treen while on the campaign trail in 1980.[151] With strong opposition to the site from four out of five of the remaining states, the political climate at Hanford, Washington, appeared to offer DOE the most hope of political success.

After the December 19, 1984, announcements of the top three sites and two alternatives, Texas and Nevada officials affirmed their opposition to locating the site in their states. Outgoing Governor John Spellman of Washington declined immediate comment, but the Mayor of Richland, Washington, John Poyner, said the selection of the Hanford Reservation would be "a real shot in the arm for the city of Richland. . . . We have been looking forward to this, and it is a real positive step for us."[152]

According to physicist Dr. Michio Kaku of City College of New York:

> The choice of Hanford runs counter to the thrust of scientific thinking for the past 20 years, when arid, geologically stable conditions were sought by our scientists. Hanford is right next to a river, near the Pacific, where one expects seismic activity and where rock formations may be unstable. I think it was more a political decision -- a politically expedient choice rather than a scientifically honest one.

The more politically favorable climate at Hanford has been viewed as the major reason for studying that site by a variety of responsible groups. The DOE Hydrology Overview Committee stated in June, 1980:

> There is really only one solid justification for studying this site [the Hanford Nuclear Reservation] and it is the sociopolitical fact that the land is a U.S. nuclear reservation. From a hydro-

150 Telegram from Ronald Reagan to Governor David Treet of Louisiana (September 9, 1980).
151 Ibid.
152 Kurtz, Howard, "A-Waste Grave Site Narrowed to 3 States," <u>Washington Post</u>, December 20, 1984, p. A-3.

geologic perspective, the Columbia River Basalt Group as a whole is not well suited for a high-level waste repository.[153]

The National Academy of Sciences warned in 1983:

> A major reason for considering basalt for repositories is its abundance in Federal land near Hanford, Washington, and the Idaho National Engineering Laboratory, and not its overall favorable characteristics.[154]

Hanford was the only basalt formation included by the DOE in the final list of nine candidates. The Hanford Reservation was developed in Washington state in the early 1940s as a secret federal facility to produce plutonium for the first plutonium atomic bomb, the bomb eventually dropped on Nagasaki. The communities that arose near the facility grew to supply the needs of workers at the Hanford site, the chief employer in the region. A variety of federal nuclear projects were established at the site over the next decades, including eight plutonium production reactors, a low-level nuclear waste burial ground, a reprocessing facility, the N-reactor which produces both saleable steam and plutonium, a plutonium fueled test reactor (FFTF), and a variety of other nuclear research projects. The regional nuclear dependence helps account for the more favorable view of a possible nuclear waste dump expressed by the Richland mayor, and the recent cancellations of nuclear power plants under construction (WPPS IV and V) and the mothballing of two others (WPPS I and III) by the Washington Public Power Supply System left a job shortage which the mayor hopes site characterization and repository construction might help alleviate.

However, the climate in the rest of the state may be changing, as nuclear accidents could have more than local consequences. Nuclear waste accidents have abounded, and the world's worst nuclear accident occured in Kyshtym, in the Ural mountains of the U.S.S.R. Analysts

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153 Hydrology Overview Committee, Report on Hydrologic Studies Within the Columbia Plateau, Basalt Waste Isoloation Project, RHO-BWI-LD-50, p. III-3 (June 1980).

154 National Research Council, A Study of the Isolation System for Geological Disposal of Radioactive Wastes, National Academy Press: Washington, D.C., p. 155 (1983).

report that at least 50 square kilometers of land was made totally uninhabitable after an explosion believed to have occurred where nuclear wastes were stored.

At least 430,000 gallons of caustic, highly radioactive liquids have already leaked at the Hanford Reservation. About 115,000 gallons leaked over a 50-day period in 1973.[155] Hanford windstorms carry radioactive dust east, and radiation that gets into the water seeps into the Columbia River which marks the border between Washington and Oregon, eventually emptying into the Pacific Ocean. Ultimately, everyone along the Pacific Coast may be at risk from radioactive leakage at Hanford.

Outgoing Washington Governor John Spellman had been promoting a contract between the State of Washington and DOE, called a C & C Agreement (Consultation and Cooperation), and public hearings had been scheduled for January of 1985. Incoming Governor Booth Gardner asked that action be postponed on the C & C Agreement until he had an opportunity to review the proposal. A 90-day moratorium was established for action, and the proposed hearings were cancelled.

When the DOE announced that Hanford was one of the three finalist sites on December 19, Governor-elect Gardner stated that serious questions still needed to be resolved. "I don't believe there has been adequate work done on the threat of earthquakes in the area," Mr. Gardner said, "and I still have concerns about possible groundwater contamination."[156]

On January 7, 1985, the City Council of Spokane, Washington, and the mayor of Spokane went on record criticizing DOE for its failure to schedule hearings in Spokane on the proposed siting of a high-level nuclear waste dump at Hanford. Ellensburg and Moses Lake, Washington, north of the Hanford site, have sent letters of concern to their Congressional representatives regarding the proposed waste

[155] Anna Gyorgy and Friends, No Nukes: Everyone's Guide to Nuclear Power, South End Press: Boston, Mass. (1979).
[156] "U. S. Names 3 Sites for Atomic Study," New York Times (December 20, 1984).

repository plans.[157] In early January, five local citizen organizations filed suit against the proposed action on the C & C Agreement and demanded an environmental impact statement. The groups include Washington Public Interest Research Group (WASHPIRG), the Hanford Oversight Committee, Washington Physicians for Social Responsibility, the Federation of Western Outdoor Clubs, and Save the Resources Committee.[158]

Three Indian Tribes have been designated as affected tribes in the area: The Confederated Tribes and Bands of the Yakima Indian Nation, the Nez Perce Tribe, and the Confederated Tribes of the Umatilla Reservation. Watson Tatus, chairperson of the Yakima Tribal Council, warned that the establishment of a high-level waste repository threatens contamination of natural food sources and area waters.[159]

At the Hanford site, the contractor for the site evaluation and testing is the same as the likely contractor for building the repository, which will involved an estimated 16 billion dollars in contracts.[160] Rockwell International is the prime contractor at the Hanford site. Rockwell-Hanford, its subsidiary, has already handled site evaluation contracts totaling about 300 million dollars since 1976.[161]

"If I were in a position of federal authority," stated State Senator Al Williams (D-Seattle), Chairperson of the Senate Science and Technology Committee, "I don't think I would allow the same contractors to evaluate the site and build the project. There's a credibility problem, a temptation not to be objective."[162]

According to Caroline Petti of the Environmental Policy Institute:

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157 Phone calls to city governments of Ellensburg and Moses Lake, Washington, February 1, 1985.

158 The Oregonian, January 10, 1985.

159 Melissa Laird, "Radiation on the Rocks," Clinton St. Quarterly 12 (1984).

160 Fern Shen, "Lines Drawn Over Radioactive Waste Storage Plan," The Oregonian, p. B-2 (December 16, 1984).

161 Fern Shen, Richard Read, and Spencer Heinz, "Hanford Among 3 Sites Eyed as Nuclear Dumps," p. 1 (December 20, 1984).

162 Shen, "Lines Drawn Over Radioactive Waste Storage Plan."

> DOE's implementation of the high-level nuclear waste program thus far would indicate the Department, first and foremost, has the interest of the nuclear utilities at heart. Yet, it's highly unlikely DOE's past and present conduct of the program, driven as it is by expediency considerations and political allegiances, will yield environmentally suitable sites for repositories. No site more clearly illustrates that this is the case than the Hanford site. I believe it is neither in the interest of the nuclear industry nor in the interest of the public and environmental health, to have a shoddy federal nuclear waste effort.[163]

The tremendous health hazards posed by high-level nuclear wastes demand the most stringent protections possible to preserve the environment and to protect future generations. Final decisions on siting the first high-level nuclear waste repository must be based on scientific evidence, gathered by disinterested parties, and reviewed by a variety of responsible agencies. If the current process cannot provide the scientific assurances needed, the system for site selection should be reevaluated. It is more important to place the high-level wastes in a truly secure site that can protect the environment for the hundreds of thousands of years that the wastes are hazardous than it is to meet the 1998 deadline now in place.

In view of the tremendous technical problems posed by the Hanford site, the potentially exorbitant costs associated with developing the site, and the safety problems expected in working in an area subject to rock bursts, a reevaluation of the site's viability is in order. DOE's expedient methods, its tendency to downplay serious problems, and its lack of sensitivity to public concern have come under attack from public officials from the very first high-level waste disposal project it undertook at Lyons, Kansas. If DOE is to survive charges that Hanford was selected out of political expediency, it must present a better case on the technical merits.

We recommend that the following actions be undertaken in relation to the Hanford site:

[163] Personal communication, February 4, 1985.

1. DOE should prepare a detailed study showing how it would comply with the Mine Health and Safety Act of 1977, including the applicable regulations, at Hanford.

2. DOE should prepare an environmental impact statement on the effects of site characterization. Although not required by the Nuclear Waste Policy Act of 1982, the activities of site characterization at Hanford may have significant impacts which are likely to be extensive and costly.

3. DOE and its contractor, Rockwell International, should make available all the data on the Hanford site to the States of Washington and Oregon, and to a competent body such as the National Research Council of the National Academy of Sciences or the Congressional Office of Technology Assessment (in addition to the NRC, as already required by the Nuclear Waste Policy Act) to enable the preparation of an independent site characterization report.

4. The site selection procedure has been challenged by several of the state governors involved. The site selection procedure used so far raises sufficient questions that it should be evaluated for technical adequacy by the National Academy of Sciences or the Office of Technology Assessment. If serious inadequacies are found, the whole process should be redesigned to assure the long-term safety of the ultimate repository.

5. Hanford should be removed from the list of the nine possible sites being considered until the above studies are completed, at which time a re-evaluation of its status can be performed. (This in no way suggests that other proposed sites are necessarily adequate or better sites.)

Supplement by Donald E. White, Ph.D.

AN APPENDIX TO

HEAT, HIGH WATER AND ROCK INSTABILITY AT HANFORD

FOREWORD TO THE APPENDIX

by

Donald E. White, Ph.D.
U.S. Geological Survey

This foreword is an addendum to the following "Background Paper for Assessment of Basalt Lava Flows, Hanford, Washington," (for radioactive waste disposal), June 1983. It was written as a back-up supplement to the National Research Council of the National Academy of Sciences report, "A Study of the Isolation System for Geologic Disposal of Radioactive Wastes," National Academy Press, Washington, D.C., 1983.

For reasons beyond my control, the National Research Council did not follow through with original plans to publish the "Background Papers" in the same volume as the panel report. Instead, informal arrangements were made for the Council or the original author (myself) to supply copies upon request. In October, 1985, such a request was made by Ms. Kathleen M. Tucker of the Health and Energy Institute, but she was informed by someone at the National Research Council that the request should be made directly to me -- the latest of no more than around ten previous requests.

I then became completely aware that my concerns about Hanford's suitability as a high-level radioactive waste repository were not becoming widely known. This was soon confirmed when DOE included Hanford in its three most favorable sites for U.S. evaluation efforts. DOE either did not know about Hanford's serious problems, or had not been impressed by my rationale. I was therefore delighted when the present opportunity became available for a broader dissemination of my reasons for questioning Hanford's suitability.

My 1985 concerns are nearly identical to those expressed in my earlier 1983 "Background Paper," but detailed comparison is made difficult by the following:

DOE's intended "R.R.L." (Reference Repository Location) had not yet been precisely defined by area or depth, so it was not identified as such on my figure 2, 1983. The only detailed data supplied to our study panel concerned the Umtanum lava flow, indicated in the Makhijani-Tucker report (figure 3-1) of February, 1985. Also, locations of the Cold Creek syncline and the Cle Elum-Wallula deformation zone had been requested by me but not yet supplied in suitable form to be shown in my figure 2, 1983 report.

The most significant difference between the two reports was caused by DOE-Rockwell's decision to change their favored repository lava flow from the Umtanum (my 1983 text) to the Cohassett flow (Makhijani-Tucker figure 3-3, 1985). The 1983 study panel was not even aware that the Cohassett flow was being considered, and no data were supplied for this flow. The relative positions of these two thick flows is best shown in Makhijani-Tucker figure 3-3, 1985. The important consequences of this change are:

(1) The shallower depth of about 170 meters for the Cohassett indicates slightly lower mining costs and especially a lower in-situ temperature of about 5 degrees C. (seemingly minor, but perhaps very important).

(2) The Cohassett flow is consequently also about 170 meters nearer to the major hydrologic hazard, the permeable Vantage Interbed (not shown as such on my 1983 figure 3, but indicated clearly on the Makhijani-Tucker figure 3-3. The dangers of increased proximity to this regional aquifer cannot be assessed from available data, but may be more significant than the depth-temperature factors.

(3) Other significant differences between the two thick flows may exist but are presently unknown to me.

Other confusing differences between the 1983 and 1985 manuscripts probably exist, but I hope they can be overcome by interested readers.

Donald E. White, Ph.D.
Menlo Park, California
February 5, 1985

BACKGROUND PAPER FOR ASSESSMENT OF BASALT LAVA FLOWS (BWIP), WASHINGTON

by Donald E. White

June 1983

CONTENTS

INTRODUCTION

Thick basaltic lava flows of the Hanford area of the Pasco Basin in south-central Washington have been studied for more than 10 years for suitability for radioactive waste disposal. This assessment is focused on the Basalt Waste Isolation Project (BWIP). Other basaltic areas of Washington, Oregon, and Idaho may also have repository possibilities, but are considered less favorable from BWIP studies to date.

GEOLOGIC CHARACTERISTICS

Regional Setting

Surface geology, drilling, and seismic data (Basalt Waste Isolation Project Staff 1981b) indicate that the Pasco Basin is underlain, in succession, by shallow sediments, three thick flood basalt formations (probably 2 to 3 km thick, in total, with interbedded sediments in the upper basalts, decreasing in proportion downward), pre-Tertiary sedimentary rocks, and basement rocks, probably metamorphosed. The thickness of the crust (to the mantle) is about 27 km, which is relatively thin for the western United States, generally 34 to 40 km (Basalt Waste Isolation Project Staff 1981a). The underlying mantle is anomalously low in seismic velocity (7.7 km/sec instead of the "normal" 8.1 km/sec, probably because of high temperatures and/or partial melt). These characteristics of a thin crust and low upper mantle seismic velocity are generally viewed as indicating high upper mantle temperatures, rocks that may be partly molten, and above-average crustal conductive heat flow.

Repository Host

The presently favored repository host of BWIP is the Umtanum flow, which is one of the thickest flows in the thick ($>$ 1,370 m) Grande Ronde

Basalt formation of the Pasco Basin (Basalt Waste Isolation Project Staff 1981a, 1981b). As shown in Figure 1, the Umtanum flow is 65 ± 5 m thick near the axis of the favored Cold Creek syncline at a general depth of 1110 ± 30 m below ground level. Its rather uniform dense central zone (the "entablature" zone) is generally 47 ± 5 m thick (Basalt Waste Isolation Project Staff 1981b), its flow-brecciated top is 8 m to 30 m thick, and its columnar-jointed base is ~5 m thick. However, its central zone varies considerably in thickness and internal structures, so continuity must not be assumed.

The Umtanum central zone consists of fracture-bound, commonly hexagonal columns that, under normal low-stress conditions, are probably tightly interlocking, strong, and favorable for maintaining mined openings without other engineered support (judging from nearly vertical exposures adjacent to the Columbia River). However, under the highly-stressed conditions that may exist near 1 km depth, favored for the Reference Repository Level (RRL) indicated in Figure 1, and with clay-bordered fracture blocks, this zone may have extreme rock-bursting tendencies, possibly yielding readily in bulk (National Researach Council 1983, Chapter 6).

Important subdivisions of the thick Pasco Basin basalt series, decreasing upward in age (Basalt Waste Isolation Project Staff 1981b) are: (1) Grande Ronde Basalt, > 2600 m thick and containing the Umtanum flow in its upper part, age ~16 million years; flows are thick and were erupted so frequently that interbedded sediments are rare; (2) Wanapum Basalt (~350 m thick, with some thick flows and several sedimentary interbeds); age ~14 million years; (3) Saddle Mountains Basalt, ~275 m thick, with only a few flows but numerous sedimentary interbeds; age ranging from 13.6 million years at its base to 8.5 million years or less at its top; and (4) several overlying units of sedimentary rocks and alluvium without lava flows, averaging ~0.4 km in total thickness.

Tectonic Environment

Regional north-south compression has warped the rocks into a series of west and northwest-trending folds, with the synclines (down-folds) generally having gently dipping flanks, as in the Cold Creek syncline of Figure 1, and with sharply flexed anticlines (up-folds). The latter are in part broken by faults on their sharply flexed anticlinal crests. Related tectonic fractures and faults are superposed on the early cooling joints (including columnar and entablature joints). Steeply dipping northwest-trending shear zones are abundant in the region in many areas of outcropping basalts, occurring every few hundred meters or less, and apparently independent of local folding (Basalt Waste Isolation Project Staff 1981c). Known faults commonly strike northwest and are mainly restricted to the broken anticlines, but other faults cut across the folds. No faults have been identified within RRL, but they could not be recognized easily below the cover of young sediments, especially considering the wide spacing of drillholes.

A major northwest-striking deformation zone (the Cle Elum-Wallula zone) lies 8 to 10 km southwest of RRL (see Figure 1). No young fault

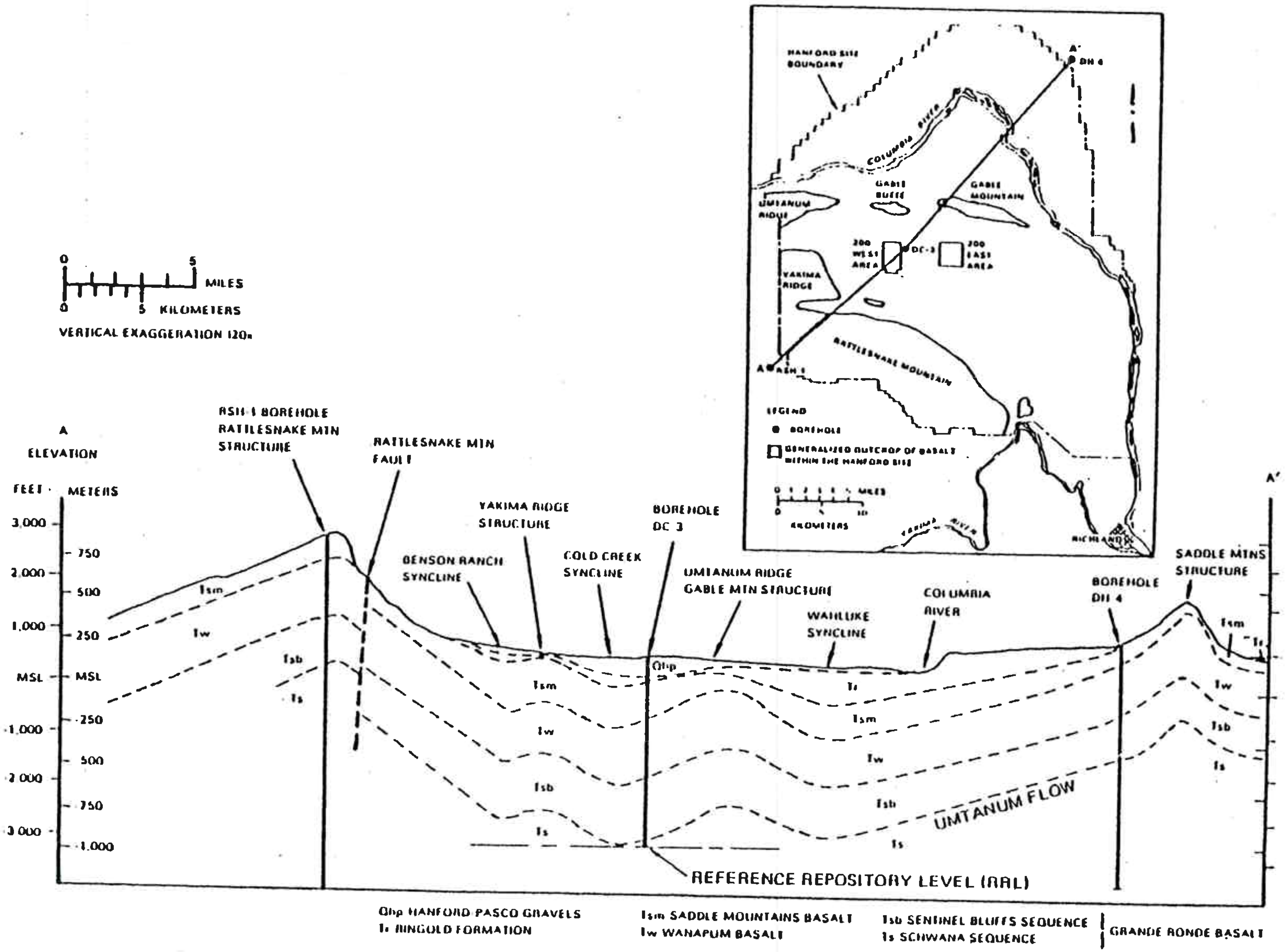

FIGURE 1 Generalized geologic cross section of the Pasco Basin, Washington. Source: Basalt Waste Isolation Project Staff (1981a).

offsets are known in the Hanford reservation, but a minor displacement younger than ~12,000 years has been recognized 25 km to the southeast, and others are west of RRL (D. Swanson, U.S. Geological Survey, personal communication to D. E. White, July 1981).

Thickness and distribution of basalt flows indicate uplift of 0.03 to 0.7 mm/yr for the past 15 million years (Basalt Waste Isolation Project Staff 1981b). Present-day north-south compression rates of approximately 0.03 mm/yr are indicated by preliminary data (Savage et al. 1981), but the time span of these measurements is too short to be of certain significance.

Present seismic activity is relatively low, and is scattered throughout the Hanford area; most of the earthquakes are unusually shallow (Savage et al. 1981). A moderately strong earthquake of uncertain location and intensity occurred a few km north of RRL on November 1, 1958, and a shallow series occurred near the Cold Creek syncline west of RRL on September 8, 1979. Thus, tectonic activity is continuing.

The youngest dated volcanic rocks in the Hanford area are 8.5 million years old (Basalt Waste Isolation Project Staff 1981b), but somewhat younger basalts seem likely to exist but exposed at the sufrace or not yet recognized by age-dating. Even though new volcanic eruptions could occur, the possibility seems remote; the known eruptions of the past few million years in the region are localized near the Cascade volcanic belt 100 km and more to the west of RRL.

Conductive heat flow of the Pasco Basin is stated to be "normal to slightly above normal" (Basalt Waste Isolation Project Staff 1981b). However, the mean thermal gradient in Hanford boreholes is 41.6°C/km, which is considerably above "normal" (< 30°C for water-saturated bedrocks). For present purposes, the thermal gradient is far more significant than conductive heat flow. The thin continental crust and low mantle seismic velocities under the Pasco Basin are normally associated with high regional conductive heat flows and high thermal gradients. The mean annual surface temperature near Hanford is about 12°C; if added to an expected temperature gradient increase of ~46°C (1.1 km depth x 41.6°C/km) to RRL, ~58°C is indicated at the proposed repository depth. Temperatures projected by Rockwell (Basalt Waste Isolation Project Staff 1981b) to RRL range from 52°C to 66°C, and an average of 57°C is preferred by Rockwell.

Proximity to Natural Resources

No fossil fuel or mineral resources are known near the Hanford site. Thick continental flood basalts are notably unfavorable for oil, gas, and mineral resources. However, natural gas has been produced in the past from shallow depths, and the petroleum industry has explored for fluid hydrocarbons in underlying sedimentary rocks (Basalt Waste Isolation Project Staff 1981b). Because of past and present high temperatures below the basalt, natural gas is much more likely to occur as organic degradation products than petroleum. Only in very recent years has natural gas alone perhaps justified deep exploration, so the mild interest of the past seems likely to increase. Metallic and non-metallic mineral resources, even if existing in underlying rocks, are unlikely to be identifiable at such depths (2 km or more) and high temperatures would prevent mining by presently known methods. Thus, any other resources are not near-future targets unless discovered by accident while exploring for fluid hydrocarbons. Temperature gradients are high enough for possible future interest in low-temperature, non-electrical geothermal energy (Sorey and Reed in press). In this on-going assessment of low-temperature geothermal resources by the U.S. Geological Survey, 47°C at a depth of 1 km and 72°C at 2 km are the lower temperature limits required for present consideration in south-central Washington. Thus, nonelectrical geothermal heat at the Hanford site (~ 57°C at 1 km and ~ 96°C at 2 km) is a potential resource, especially if the thermal waters are sufficiently low in objectionable constituents for domestic and agricultural uses. Even if the waters are too high in some chemical constituents, they could be utilized for heating and then diluted by surface waters for other uses.

Adequacy of Data

Geologic data from BWIP are adequate for some but not all purposes. Outstanding inadequacies in order of importance are:

o Present state of stress, especially of the Umtanum flow at RRL, shows the area had been undergoing north-south compression and folding. Thick competent lava flows may have stored excessive localized stresses that could cause the observed "discing" of drill core, perhaps being indicative of "rock bursting" during and after repository construction (National Research Council 1983, Chapter 6). These fractures have new fresh surfaces that did not exist prior to drilling. They are exceptional phenomena rarely observed in drill core. Logging of the core revealed discing in all holes cored to depths of 278 m (884 ft) and deeper (Basalt Waste Isolation Project Staff 1981a). Three degrees of discing were recognized. The most intense, type C, had fracture spacings of 0.5 cm or less. This intense discing characterized much but not all of the Umtanum flow at depths greater the 870 m (2800 ft).

o The Umtanum flow may not be sufficiently thick or homogeneous enough in its central portion for an extensive repository. This central part has an average thickness of 47 m (see geology section, above); proposed tunnel and storage rooms are 6.1 m high and storage holes 6.4 m deep for a total thickness of 12.5 m (National Research Council 1983, Chapter 6). Thus, a perfectly centered repository would be bounded above and below by only 17 m of central-zone material. Even if emplacement holes are horizonal rather than vertical, a perfectly-centered repository would be bounded by ~ 20 m of homogeneous material. In a horizontal flow in an unstressed environment, this could be adequate. However, the zone boundaries will normally <u>not</u> be horizontal but will rise or fall unpredictably as construction progresses, relative to the synclinal axis and in response to faults and to flow inhomogeneities. A slight rise of the contacts (up-dip) as in

Figure 1 is easily accommodated, but a decline in altitude of zone boundaries as related to folding and faulting would create serious drainage problems. Inflowing seepage must then be pumped out or otherwise drained if the repository is to remain "centered" in the flow. The alternative of horizontal construction with dipping contacts must encroach on the permeable brecciated flow margins. Because of original internal flow inhomogeneities and possible caving by rock-bursting, the repository workings would then encroach on permeable flow margins. In other words, even a thick basalt flow may be much too thin for simple, efficient, low-cost repository construction. Intolerable rates of water flow may result from encroachment on permeable faults and flow margins.

o The abundance and tightness of faults and fractures at the repository depth are unknown and cannot be established reliably from widely spaced drillholes. Both permeable faults and fractures are especially likely to occur on broken anticlines, but are also likely to occur elsewhere independent of local folding (see previous section on tectonic environment).

o Temperatures at repository depths may range from 52°C to 66°C but are not yet known with desired precision near RRL; Rockwell favors 57°C but without adequate assessment of all data. The uncertainties may seem unimportant but are significant if canister/rock temperatures of $<$ 100°C are required. The problems of construction of a huge repository at temperatures near 60°C or even higher will be enormous and costly to control; for example, underground mining of high-grade ore deposits has seldom been successful at rock temperatures as high as 80°C (White 1955), thus illustrating the magnitude of the problem.

Most Critical Problems

All four problems discussed above are critical, with (1) probably being the most threatening for successful repository construction.

Outstanding Favorable Characteristics

None of the favorable characteristics is mainly geological (other than physical location on a dedicated federal reservation). However, see sections following on Geochemical Characteristics of Repository Host and Geochemical Characteristics of Natural Waters.

HYDROLOGIC CHARACTERISTICS

Near-Field and Regional Properties and Flow Patterns

The near-field hydrologic characteristics are not yet well known because of the scarcity of deep exploration, other than several nearby deep drillholes (Figures 1 and 2). Of these, detailed data are available only for holes DC-12, DC-14, DC-6, DC-15, and DB-15 (Basalt Waste Isolation Project Staff 1981d). Holes DC-3, DC-4, and DC-5, in or near RRL, have not been studied in detail. Regional flow patterns are very complex, as we shall see, and cannot yet be projected with confidence to the near-field. Representative hydraulic properties of flows and interbeds of the Saddle Mountains and Wanapum basalts are listed in a Basalt Waste Isolation Project staff report (1981b). The middle parts of individual flows are generally thickest and lowest in permeability. Flow-breccia tops and bottoms were initially highly permeable but permeability has decreased through time because of alteration and solution-redeposition of minerals (Keith et al. 1978). Representative hydraulic conductivities of flow central zones (Basalt Waste Isolation Project Staff 1981b) are 10^{-10} to 10^{-12} m/sec. In contrast, brecciated Grande Ronde flow-tops (interflows) typically range from 10^{-5} to 10^{-8} m/sec in hydraulic conductivity, which is 1 to 2 orders of magnitude lower than in the younger Wanapum and Saddle Mountain flows. No data have been supplied for the Umtanum flow top or bottom.

Vertical hydraulic conductivities are not yet known. Rockwell (Basalt Waste Isolation Project Staff 1981b) assumes insignificant cross-formational flow, but extensive faulting and fracturing of broken anticlines have been ignored. Also, other permeable steep faults and fractures are likely to occur elsewhere, thus making this assumption for vertical permeability of doubtful validity. BWIP's Hydrologic Overview Committee (Basalt Waste Isolation Project Staff 1981c) concluded that a major river, such as the Columbia, is normally a hydrologic sink for all groundwater of a region, including any cross-formational flow from the Pasco Basin basalts (Figure 2) of the Mabton interbed in the basal Saddle Mountain basalt. Significant cross-formational flow is also strongly indicated by data in hydrostratigraphic charts for the few deep wells measured in detail (Basalt Waste Isolation Project Staff 1981d). These charts are all too large and complex for reproduction here, but Figures 3 and 4 are representative of part of their data from DC-15. Major conclusions from analysis of available data are:

- Changes in horizontal and vertical potentiometric levels are much too complex to be explained solely by intraformational flow. Combinations of horizontal and vertical flow are essential, differing from well to well (Basalt Waste Isolation Project Staff 1981c, 1981d). The highest potentiometric levels of these test wells are in the upper basalts of DC-14 (Figure 2). Relatively low heads characterize parts of the Grande Ronde (DC-15, DC-14), and nearly uniform heads with little overall gradient with depth characterize DB-15 and DC-12. The complexity of changes in vertical heads with depth is clearly illustrated by well DC-15 (Figure 3), where three major reversals in head occur, one of which is in and below the basal Umtanum.
- Another puzzling example of changes in head with depth is evident in the drilling history of DC-5 (Basalt Waste Isolation Project Staff 1981d). At 3,340 feet (1,015 m), artesian water flowed from the hole at an estimated rate of 44 liters per minute and continued flowing for an unspecified time during later "trips and connections" (clearly

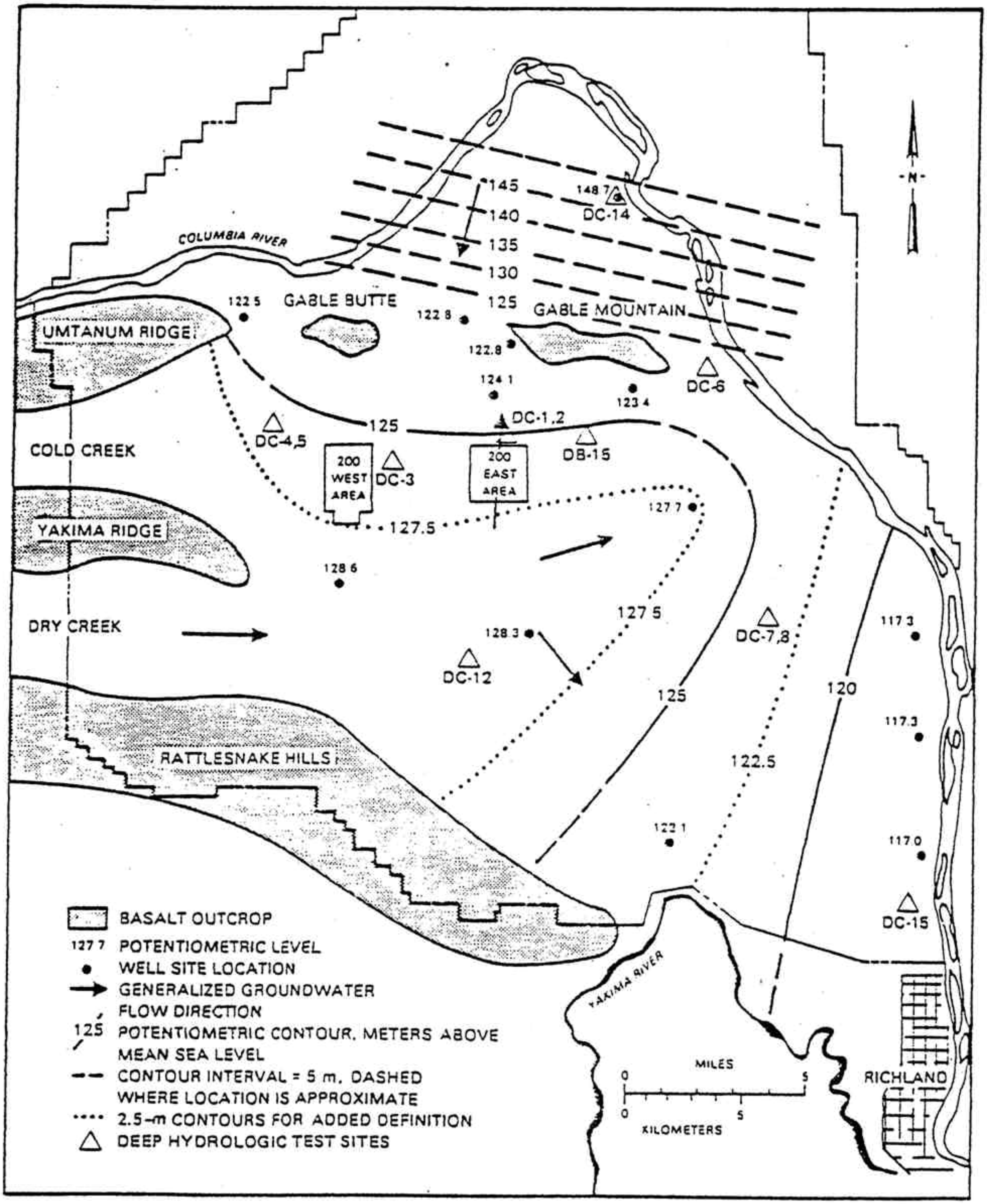

FIGURE 2 Potentiometric map and inferred flow direction of groundwater within the Mabton Interbed, one of the major aquifers of the Saddle Mountains basalt. This map also shows the locations of deep hydrologic test sites and the general area of the reference repository level. Source: Basalt Waste Isolation Project Staff (1981a).

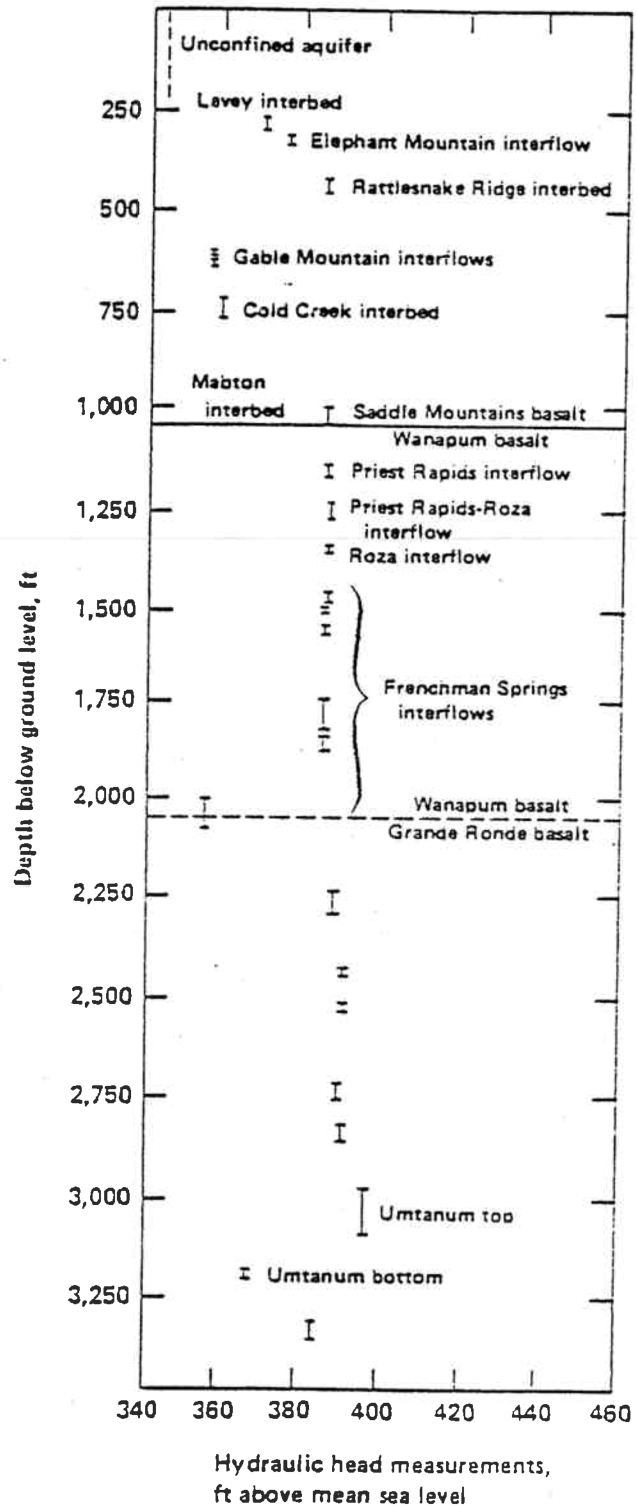

FIGURE 3 Hydraulic head measurements within the Columbia River basalt in borehole DC-15. Source: Basalt Waste Isolation Project Staff (1981b).

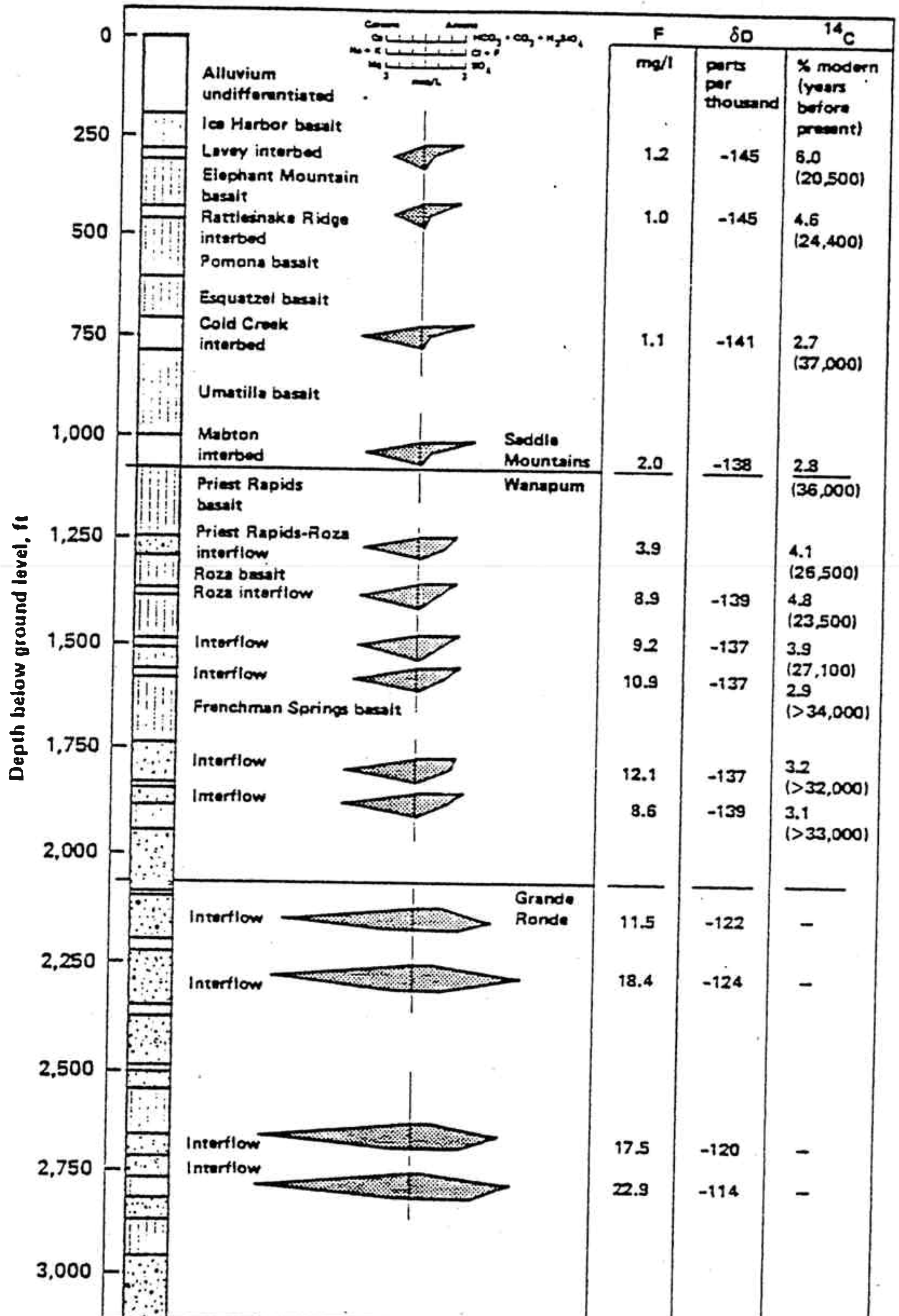

FIGURE 4 Selected hydrochemistry for borehole DC-15. Dashes indicate carbon source too small to obtain reasonable age date. Source: Basalt Waste Isolation Project Staff (1981b).

puzzling to the drillers). In contrast, water circulation was "lost" (drill water supplied but no water returned to the surface) at 3,954 feet (1,205 m), which is ~ 45 m below the Umtanum. Although quantitative data on hydraulic heads in DC-5 are lacking, this qualitative drilling record is reasonably interpreted as a downward vertical gradient through the Umtanum at this locality, with water flowing down to an underlying aquifer.

Additional insights into the complexities of regional flow patterns are gained from hydrogeochemistry, discussed here rather than in the section on Geochemical Characteristics of Natural Waters. The three major basalt formations tend to be characterized by different chemical water types (Figure 4 and Table 1). Saddle Mountains waters of the upper formation are relatively dilute sodium bicarbonate waters and very low in chlorine. Wanapum waters of the middle formation are moderately higher in salinity and dominated by sodium bicarbonate-chlorine water that is low in sulfates. Grande Ronde waters from the lowest formation are much higher in salinity, dominated by sodium, chlorine, sulfates, and bicarbonates, especially by chlorine and sulfates. However, the general pattern of chemical types and increasing salinity with depth,

TABLE 1 Mean Composition of Groundwaters in Pasco Basin Basalts, in Parts per Million

	Saddle Mountain	Wanapum	Grand Ronde
Na^+	58	96	257
K^+	11	14	6.5
Ca^{+2}	14	3.4	2.4
Mg^{+2}	4.2	0.8	0.04
HCO_3^-	180	128	57
CO_3^{-2}	4.2	18	21
Cl^-	12	43	169
SO_4^{-2}	15	11	125
F^-	1.3	8	30
OH^-	0.08	0.27	0.98
SiO_2 (total)[a]	63	62	109
pH	8.2	9.3	9.7

[a]All silica species converted to SiO_2.

SOURCE: Rockwell International (personal communication to T. H. Pigford, 1982).

generally changing most abruptly near formation boundaries, has exceptions in DC-14, where the Saddle Mountains type extends down through the underlying Wanapum to its basal Vantage interbed, and in DC-6, where analyses are lacking from the upper formations but the Grande Ronde is highest in salinity near its top and only half as saline below the Umtanum. In DC-12, essentially all waters from 300m to 1000 m depth have modest salinity, and "Wanapum"-type compositions extend down at least 300 m into the underlying Grande Ronde. Unfortunately, no chemical data from greater depths were provided from the Grande Ronde. These exceptions to "normal" distribution are all downwardly displaced by higher-level more dilute waters. This seems most reasonably explained by deeper-than-normal flushing by higher-level waters, utilizing cross-formational flow. The general pattern of upward decrease in salinity is likely to involve upward flow of saline waters and perhaps also intraformational dilution by recharge water. This probability of cross-formational flow is strongly supported by Figure 5, consisting of chemical data from the Priest Rapids member of the uppermost Wanapum basalts. Water compositions in the north and west parts of the area of this figure are similar to overlying Saddle Mountains waters (compare with Figure 4). The major increase in chlorine seems to occur rather abruptly near or east of RRL. Note that of all constituents, chlorine is the most soluble and easily leachable from rocks, as indicated by extensive geothermal literature. Local water/rock interactions are unlikely to explain the pattern of Figure 5, especially if the flow-rate pattern in the Priest Rapids is at all similar to that of the Mabton in Figure 2. Upward flow of deeper waters high in chlorine seems highly probable near and east of RRL.

Porosity of centers of basalt flows (Basalt Waste Isolation Project Staff 1981a), generalized from literature, are 0.1 to 6 percent; brecciated tops and bottoms, 6 to 12 percent; and interbedded sediments, 10 to 15 percent. Respective longitudinal dispersivities are 1.0 to 10.0 m, 1.0 to 20.0 m, and 1.0 to 20.0 m. Data from BWIP staff (1981b) indicate that effective porosities of Pasco Basin interbeds is $\sim$10 percent; of flow-breccia tops, $<$ 5 percent; and of columnar zones, including entablature, $<$ 1 percent.

The seemingly erratic differences in hydraulic heads discussed above cannot be explained by either a static nonflowing system or a dynamic system with uniform horizontal and vertical pressure gradients and flow patterns. Aquifers low in hydraulic head relative to adjacent units (assuming that measurements are reliable) are best explained by lower resistance and faster flow rates to discharge areas. Complex patterns of intraformational and cross-formational flow are indicated. If this explanation is correct, local decreases in head in or below the basal Umtanum of boreholes DC-15 (Figure 3) and DC-5 (qualitative heads, discussed previously), suggest downward pressure gradients and faster flow rates, at least locally, below the Umtanum. This possibility has not been recognized by Rockwell in its various modeling efforts (Basalt Waste Isolation Project Staff 1981b), and no measurements are provided to refute this possibility.

Unconfined water in the shallow sediments flows east to south from RRL to the Columbia River (Basalt Waste Isolation Project Staff,

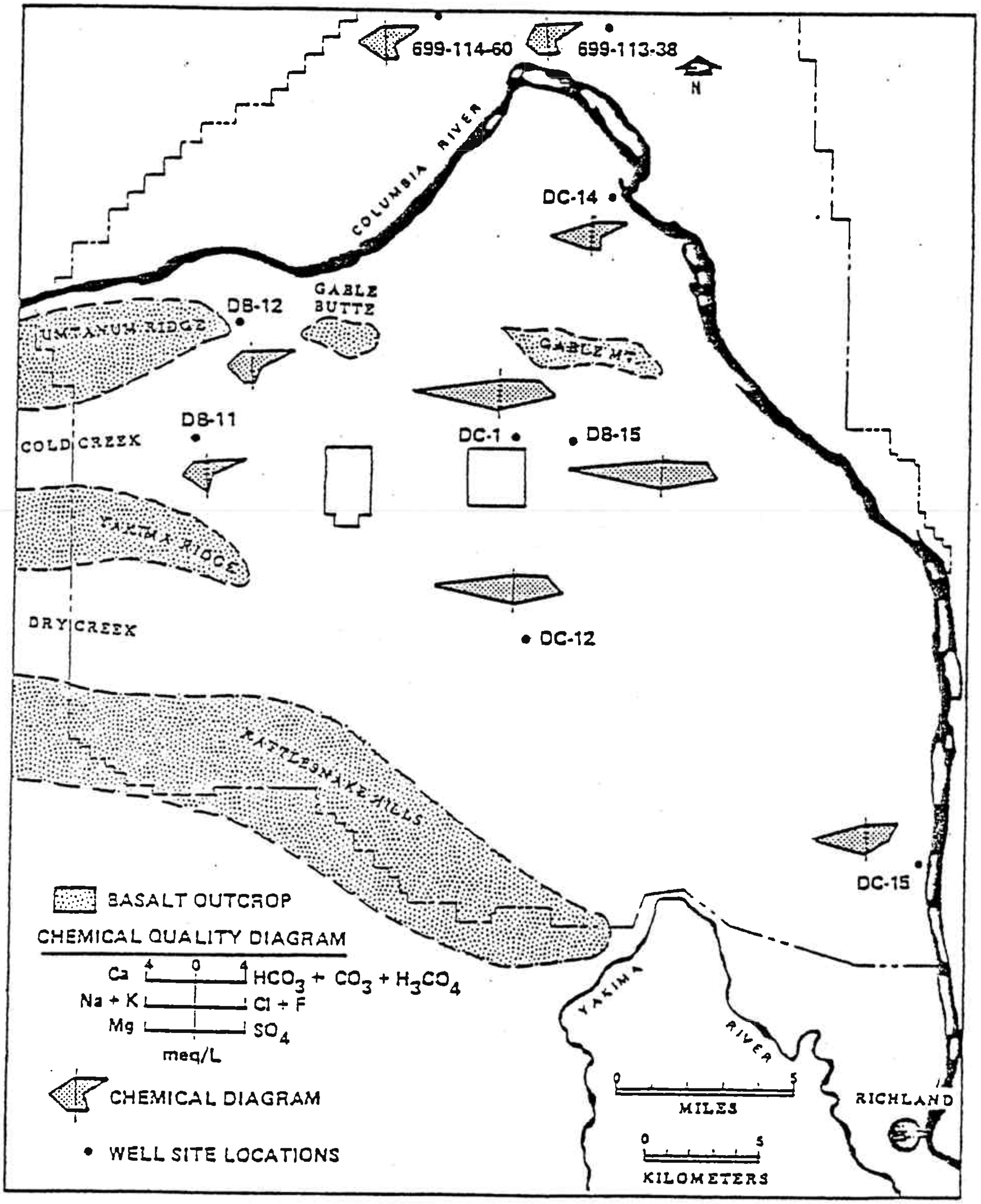

FIGURE 5 Hydrochemical facies map for Priest Rapids groundwater, uppermost Wanapum formation. Source: Basalt Waste Isolation Project Staff (1981b).

1981b). The reported hydraulic conductivity ranges from 20 to 600 ft per day in the middle sedimentary unit and from 0.1 to 10 ft per day in the lower unit.

Rates of deeper groundwater movement are still being studied. Complexities in flow paths and great uncertainties in fracture-controlled vertical hydraulic conductivity greatly complicate these efforts. Estimates of travel times by BWIP contractors to borders of the near-field and through the far-field to assumed discharge areas, as calculated by modeling, are listed in BWIP reports (Basalt Waste Isolation Project Staff 1981b, 1981c). Distances to assumed discharge areas are not yet well defined, but these estimates range from 6 to 80 km. Depending on the selected location of RRL and the favored discharge area (here assumed to be the Columbia River between wells DC-6 and DC-15 (Figure 2), 15 to 35 km seems most reasonable.

Carbon-14 contents, as measured in water samples from borehole DC-15, are shown in Figure 4. Indicated ages (in years before present) have no quantitative reliability because of probable cross-formational upflow of older waters low in carbon-14. Also of interest is the significant increase in δD in middle Saddle Mountains basalt and a major increase (less negative δD) below the Wanapum-Grande Ronde contact. These data are all qualitatively consistent with a considerably greater age for Grande Ronde waters since their recharge at unspecified distances to the west, relative to higher-level waters, and are also consistent with estimated travel times of 15,000 to 78,000 years. An exception is Rockwell's pathline D (Basalt Waste Isolation Project Staff 1981b), where discharge is assumed to occur near Wallula Gap on the Columbia River 60 to 80 km southeast of RRL, with travel times greater than 100,000 years. Both assumptions are probably too great.

We have no valid data on pore velocities in Grande Ronde basalts between probable recharge areas to RRL, or from RRL to their discharge areas along the Columbia River. Our only data concern the indicated carbon-14 ages and compositions of waters from DC-15 (Figure 4) established since their up-gradient recharge. The data are quantitatively unreliable, but their qualitative "great age" from carbon-14 (below limits of detection) is strongly supported by the δD (ratio of deuterium to hydrogen) contrasts with young groundwaters of the area. Our most reasonable estimate assumes that travel time from RRL to discharge points along the Columbia River (about 20 km) requires 10,000 years. A travel time one order of magnitude faster (1,000 years) is unlikely to explain either the carbon-14 or the δD data of Figure 4, and an order of magnitude slower (100,000 years) seems possible but unlikely. Our favored estimate of 20 km in 10,000 years indicates an average pore velocity of 2 m/yr with probable limits between 0.4 m/yr and 4 m/yr.

Topographic and Geomorphic Environment

The Pasco Basin is a structural and topographic basin within the Columbia Plateau. The Basin is largely sediment-covered, and is surrounded except on the east by anticlinal ridges of the Yakima fold belt. The Cold Creek syncline (with RRL) is one of several folds between the major anticlinal ridges (Figure 1). Ground elevation above this syncline ranges from 110 m above sea level near the Columbia River to 244 m on the highest late-Pleistocene flood bar recognized adjacent to the river. The landscape near the Cold Creek syncline (~200 m above sea level) is dominated by effects of huge late-glacial floods resulting from melting of ice dams in western Montana. These are among the earth's major geologically recorded floods (or series of floods). Extensive erosion (channelled scablands) occurred, while bars and other deposits were formed. Younger eolian deposits mantle or modify much of the area.

Climate

Present climate is semiarid, with average annual precipitation of 16 cm. Of this, 41 percent occurs in the three winter months, and only 11 percent from July through September. Nearly all precipitation returns to the atmosphere by evapo-transpiration from rather abundant sagebrush and cheat grass. A very small proportion seeps downward to the water table, with direct runoff to the Columbia River seldom occuring. Heavier precipitation on higher ground along the Cascade front to the west probably provides much of the recharge to the confined basalt aquifers. The mean annual temperature is 10°C to 15°C; an average of 12°C is assumed.

The last glacial stage terminated only 10,000 to 12,000 years ago when climate was colder and precipitation heavier. Multiple glaciations have occurred in the past, with major cycles roughly at 100,000-year intervals and with minor cycles, including the last, of shorter duration. Complete melting of present polar icecaps during an interglacial period would raise sea level by ~60 m, which would seriously affect the Columbia River near Hanford because of sluggish flow through the narrow Columbia River Gorge. A significant lake could form, especially during renewed volcanism near and in the gorge. Renewed upstream glaciation followed by ice-dam destruction would be far more serious, resulting in violent flooding and destruction of surface installations up to 240 m above present sea level, or approximately 130 m above present river level at Hanford.

Adequacy of Hydrologic Data

Much regional subsurface data have already been obtained--enough to demonstrate great complexities in flow patterns that cannot be projected reliably to the near-field. Horizontal flow within interbedded sediments and brecciated flow tops is clearly dominant, with hydraulic conductivities in general decreasing downward and being consistently low in the centers of thick flows. Inadequacies include:

o Vertical hydraulic conductivity in faults and fractures is clearly significant but inadequately known; most is probably controlled by broken anticlinal crests, but extensive vertical flow in other unrecognized faults and fractures may also be very important. No overall measurement of vertical hydraulic conductivity, nor its ratio to horizontal conductivity, has been made. Rockwell (Basalt Waste Isolation Project Staff, 1981b, 1981c) assumes a ratio of vertical/horizontal of 1 to 10, but without evidence.

o Discharge of deep groundwater from the Pasco Basin is inadequately known. The Columbia River is probably everywhere a hydrologic sink (Basalt Waste Isolation Project Staff 1981c), with deep discharge from RRL occurring largely to the east and southeast along the river for 30 km north of Richland (Figure 2), rather than much farther downstream near the confluence with the Snake River as favored by Rockwell. However, no detailed deep discharge patterns are yet known. A thorough study of chemical, thermal, and other data from shallow observation holes along the west bank of the Columbia River should clarify these uncertainties.

o The very irregular and as yet unpredictable changes in hydraulic heads with depth relate to 1 and 2 above. Data are especially scanty in and near RRL, where extensive drilling for adequate data might threaten the future integrity of a repository. However, drillholes DC-1 through DC-5 were drilled in and near RRL, but did not yield much critically needed data.

o Reliable travel times from RRL to the environment are not available. Apparent carbon-14 ages of the deep basalt waters are satisfyingly long and probably adequate, but real ages may be too low through a combination of "upstream" precipitation of $CaCO_3$ (from increasing pH as recharge water containing carbon-14 reacts with basalt), combined with upflow of older water with "dead" carbon. The real age of a water or of its mixture of components from recharge area to RRL is also critical in evaluating travel time or pore velocity from RRL to the discharge areas. Data on these travel times are urgently needed.

o Downward decrease in hydraulic heads in the few wells drilled below the Umtanum implies the existence of faster flow rates and escape paths below RRL. This possibility has not yet been recognized by Rockwell in its hydrologic modeling.

Most Critical Hydrologic Problems

All of the uncertainties listed above are important and interrelated. Other serious long-range problems concern future climatic changes that affect melting of polar ice caps, with consequent rise in sea level, renewed downstream volcanism to dam the river, or glaciation and catastrophic flooding, like that of $\sim$12,000 years and more ago.

Favorable Hydrologic Characteristics

The Grande Ronde basalts have low hydraulic conductivities, in general below 10^{-5} m/s. Ages of deep waters since recharge are probably

$>$ 10,000 years, which imply low flow rates from RRL to the environment, but actual ages and flow rates are not yet known. Marked contrasts in water types, with Grande Ronde waters having high contents of chlorine and sulfates relative to the shallower waters, are consistent with greater age and relative isolation from the shallow waters. Complexities in flow patterns, combined with low flow rates, may also be viewed as favorable for extensive mixing and dispersion.

GEOCHEMICAL CHARACTERISTICS OF REPOSITORY HOST

Whole Rock

Major element chemical composition of the Umtanum flow (M. J. Smith, Rockwell Hanford Operations, personal communication to D. E. White, 1982) consists of the following mean values in percent, excluding volatiles: SiO_2, 54.9; TiO_2, 2.17; Al_2O_3, 14.34; FeO, 13.10 [total iron as ferrous oxide (FeO); ferric hydroxide (Fe_2O_3) present, but greatly dominated by FeO]; MgO, 3.48; CaO, 7.30; Na_2O, 2.66; K_2O, 1.48; MnO, 0.21; and P_2O_5, 0.35. Individual flows have chemical differences that assist in their recognition throughout the area and also at depth from drill core (Basalt Waste Isolation Project Staff 1981b), but are unimportant with respect to waste containment. The great dominance of FeO (reduced iron) over Fe_2O_3 (oxidized iron) is especially significant. Much reactive Fe^{+2}, especially in glass, essentially guarantees that all groundwaters far from the recharge areas have little if any dissolved oxygen, and thus are strongly reducing--probably the most reducing of all repository rocks here considered (see National Research Council 1983, Chapter 7).

Primary Minerals

The rocks are dominated by silicates of calcium, aluminum, iron, magnesium, sodium, and potassium, as well as magnetite (Fe_3O_4) and other minor minerals. The thick central part of the Umtanum flow contains as much as 70 percent undevitrified glass (Basalt Waste Isolation Project Staff 1981b), which is the most reactive constitutent of the rock, probably followed by olivine, pyroxene, and calcic plagioclase. Abundant ferrous iron in glass, olivine, and pyroxene should effectively maintain reducing environments, as discussed above, and continuing cation exchange with H^+ of the water should maintain moderately high pH's.

Sorption Capacities

The primary minerals lack notable sorption capacities for radionuclides but these minerals and glass are altered along fractures to clay minerals (dominantly smectite and nontronite), and zeolites, all of which have high sorption capacities. Also, most radionuclides have low solubilities in dilute, strongly reduced alkaline waters (see next section and National Research Council 1983, Chapter 7). Escape of most radionuclides should be strongly impeded by these multiple natural barriers. The principal exceptions probably are iodine-129, selenium-79, krypton-85, and neptunium-237, perhaps in that order.

Adequacy of Data

Specific data on the sorption properties of BWIP alteration minerals are not yet available, so the specific behavior of these basalts under repository conditions is not yet known. However, the abundant unstable glass has persisted through its initial cooling and exposure to mildly thermal groundwater for approximately 15 million years. This glass has probably hydrated somewhat (better data are needed), but most is evidently not devitrified, probably because of access of only a little water in cracks. Alteration along crack margins has probably produced self-sealing clay minerals and zeolites, as observed in old natural silicic glass (Keith et al. 1978). Devitrification at modest temperatures seems to require both liquid water and open spaces that permit solution and redeposition of hydrous minerals with greater specific volumes than the initial glass. Most alteration minerals can accept some minor constituents in their crystal lattices but cannot accept others, which must either crystallize as separate minerals or dissolve and be removed in flowing water.

Most Critical Rock-Chemical Problems

Will clays, zeolites, and other alteration and primary minerals provide sufficient sorption capacity to inhibit the escape of many soluble or slightly soluble constituents? Data on specific radionuclides are critically needed. Will the reducing capacity of abundant ferrous iron stabilize most radionuclides in low-solubility forms? Measured and calculated Eh's (M. J. Smith, Rockwell Hanford Operations, personal communication to D. E. White, 1981) suggest that conditions will be strongly reducing, perhaps $\sim$ -0.50 mv.

Favorable Rock-Chemical Characteristics

The abundant ferrous iron insures that long-associated waters are reducing (low in Eh) and favorable for maintaining low solubilities of most radionculides (National Research Council 1983, Chapter 7); primary minerals and abundant undevitrified glass close to fractures are altered to clays and zeolites that are effective in sorbing most radionculides, and also provide "self-sealing" (increased volume to fill initial open spaces), thereby decreasing permeabilities with time (Keith et al. 1978).

GEOCHEMICAL CHARACTERISTICS OF NATURAL WATERS

Chemical Compositions

Some aspects of natural pore waters were previously discussed, along with hydrologic characteristics. Unconfined water in the shallow sediments above the basalt flows of RRL has been contaminated by radionuclides from Hanford activities of the past (for example, see Cloninger and Cole 1981). Confined waters in the Saddle Mountains formation, including flows and abundant interbeds to $\sim$ 330 m in depth, are dilute and sodium bicarbonate in type (Table 1), with about 360 ppm total dissolved solids, low chlorine, and 1 to 2 ppm fluorine. Underlying basalts and interbeds of the Wanapum basalt (approximately 330 m to 630 m in depth) generally contain sodium bicarbonate waters that increase in salinity eastward from RRL (Figure 5 and Table 1), especially in sodium, chlorine, fluorine (4 to 12 ppm, which is too high for domestic and many agricultural purposes), and increase modestly in total dissolved solids (approximately 400 ppm). Waters of the Grande Ronde basalts, including the Umtanum flow, are dominated by sodium chloride, generally with significant sulfates, minor bicarbonates, $\sim$ 20 ppm fluorine, and are also relatively high in pH, (Table 1). Total solids are close to 800 ppm and fluorine is much too high for most domestic and agricultural uses. However, even the deeper waters are relatively low in constituents that might form soluble complexes with radionuclides, although fluorine and sulfates may be marginally significant.

The overall downward increase in salinity and apparent age of the waters since recharge (Figure 4) are consistent with slower travel times and lower proportions of reacting water to rock. The data are also consistent with greater vertical permeability than conceded by Rockwell, with some probable upflow of saline water from the Grande Ronde into the overlying basalts, as previously discussed. Deuterium/hydrogen (D/H) isotope ratios, stated as δD, per mil (^{o}/oo), indicate increasing deuterium content downward (less negative δD contents in Figure 4) with depth, related to increasing age and isotopic composition of precipitation at times of recharge. Apparent ages of confined waters (from carbon-14, assuming no exchange, precipitation in carbonate minerals, or access of "dead" carbon from depth) increase with depth (20,000 to 30,000 years old in Saddle Mountains basalt, 25,000 to $>$ 32,000 years in Wanapum, and too old to measure in the Grande Ronde). No chemical data were provided for waters from the underlying basalt flows.

The general character of the subsurface waters is evident in Figure 4. Representative detailed analyses are shown in Table 1; pH's tend to increase downward from $\sim$ 8.2 to $\sim$ 9.7 (moderately alkaline). Eh measurements have been made but are highly unreliable, being most strongly influenced by kinetic effects from rapid reactions between ferrous iron and oxygen in the water, rather than from equilibrium of all water/rock reactions. However, abundant Fe^{+2} in minerals and basaltic glass (see previous section) insures moderately reducing conditions after an initial period strongly influenced by local O_2 introduced during repository construction. Some introduced O_2 may persist for a few years or possible even decades. Most radionuclides will have low to very low solubilities in the dilute reduced waters that will eventually resaturate the repository (National Research Concil 1983, Chapter 7). In contrast, radionuclides that are soluble in reducing environments include iodine-129, cesium-137, and krypton-85. Technetium-99, generally a radionuclide of major concern, is relatively immobile in the strongly reduced BWIP environment. Contents of chlorine, fluorine, sulphates, and the carbonates are probably too low to form ion-pairs or complexes that might increase solubilities of radionuclides.

Apparent Ages and Travel Times

The apparent ages of groundwater since recharge, and projected travel times from the repository to points of discharge, were discussed in a previous section, and may be ~10,000 yrs for Grande Ronde waters. Supporting qualitative data for considerable age of Grande Ronde waters, even though not precise, are provided by deuterium analyses (δ D) of the waters, which show 15 to 23 per mil (°/oo) increase (less negative) below the Wanapum-Grande Ronde contact (Figure 4).

Adequacy of Hydrochemical Data

The data are modestly adequate (National Research Council 1983, Chapter 7), but more study is needed on solubilities and retardation coefficients of the most critical radionuclides. Data are almost totally lacking for any enhanced solubility due to ion pairs or complexes. These are unlikely to be highly important for the dilute BWIP waters, but may have major impact in salt and some other repository rock types. Real ages of water mixtures since recharge probably differ considerably from the "apparent" carbon-14 ages of Figure 4, but Grande Ronde waters probably are satisfyingly old, supported in part by contrasts in deuterium and sulphate contents.

Most Critical Hydrochemical Problems and Outstanding Favorable Characteristics

Actual solubilities and retardation coefficients of the most hazardous radionuclides in the BWIP environment are not yet well known. Are the data in Table 7-1 of the Waste Isolation Systems Panel report (National Research Council 1983) sufficiently reliable for present needs? Are the strongly reducing conditions established by the abundant Fe^{+2} relative to Fe^{+3} of the rocks actually effective in providing sufficiently low solubilities for most radionuclides? And will the common alteration clay and zeolite minerals adsorb most of the radionuclides that do have appreciable solubility? Do the contrasting salinity, sulfate, and deuterium contents of Grande Ronde waters, as compared to shallower waters above the Grande Ronde-Wanapum contact, indicate isolation, low pore velocities, and relatively low vertical permeabilities across the contact? If the answers to these questions are all positive, as we suspect, the hydrogeochemical properties of BWIP provide strong positive barriers to radioactive-waste migration, and constitute the site's most favorable characteristics relative to other candidate rock types.

CHANGES AND PROBLEMS RELATED TO REPOSITORY CONSTRUCTION

Physical Problems in Constructing the Repository

Physical problems in constructing the repository, in the order in which the problems would be encountered, include:

- Shaft sinking that will encounter moderately high temperatures, high permeabilities, and very high water flows in some aquifers of the Saddle Mountains and Wanapum Basalts. Freeze-driving of the shafts has been suggested, but probably at high cost.
- Core discing, probably related to strong horizontal north-south compression, suggests that moderate rock-bursting (inward, sudden collapse of excavation margins) may first be encountered near 300 m in depth and is likely to increase downward, perhaps to an intense degree in the more massive basalts at depths below 800 m.
- Irregularities in the upper and lower contacts of the Umtanum central zone because of primary flow characteristics, topographic irregularities overrun by the flow, and secondary folding and faulting. These will cause serious problems in constructing horizontal tunnels and rooms. The Umtanum's irregular contacts will be higly permeable, at least locally, and must be avoided. Some margins will rise and fall in altitude as construction advances. A slight rise away from central drainage sumps can be tolerated, but decreasing altitudes of contacts will require special drainage and local pumping.
- Rock temperatures at RRL are likely to be at least 57°C and may be considerably higher. Precise data are not yet available. A full-sized repository with a network of tunnels and rooms distributed over an area of several square kilometers, especially if remaining open for decades for possible waste recovery, will require refrigeration on a scale probably not yet attempted elsewhere in the world.

Temperature Changes

Temperature changes related to heating of the repository is discussed in Chapter 5 of the National Research Council (1983) report. In summary, near-field modeling by Rockwell (Basalt Waste Isolation Project Staff 1981b) predicts a maximum rock temperature of ~190°C within four years after closure, assuming water resaturation to a sufficient height (water pressure) above RRL. If rock temperatures are not permitted by design to exceed 100°C, a very limited "working range" of only ~ 43°C (100°C less 57°C) is available for maximum waste heating.

Other Physical Changes in Host Rocks and Engineered Barriers

If discing of drill core (National Research Council 1983) indicates an extreme tendency for "rock-bursting," the consequences could be most serious, not only in constructing the repository but also in maintaining its integrity and isolation from adjacent major aquifers for time durations of decades if continuing access is required. Massive rock bursts could progress rapidly upward to the permeable flow breccia top and be exceedingly difficult to control once started. Downward progression of rock bursting is less likely but could also intersect permeable rocks. Thermal expansion as the repository is heated will probably initially decrease vertical permeability because of closure of steep-dipping fractures by thermal expansion.

Evolution of Local Physical Hydrology As Related To Construction

Initial Dewatering

A mass of rock, formerly water-saturated, is dewatered by drainage and pumping. Principal inflows will be grouted and sealed where possible, but minor and some major inflows will probably continue to leak, with total flow increasing as the repository is enlarged. If repository temperature was initially between 57°C and 68°C (the maximum of quoted ranges), refrigeration on a scale not yet attempted in world mining operations may be required. Fluid pressures, formerly hydrostatic (~ 100 bars at 1 km depth), decrease to atmospheric pressure (~ 1 bar), but pressure gradients in the repository walls may continue at high levels, especially if near-wall grouting is successful. If holes, are drilled in storage-room floors for canisters (6.4 m deep), they cannot be drained adequately. Hazards from rockbursts will be greatest during this and the following stage.

Active Period of Waste Emplacement

Dewatering continues, with cooling by air circulation and refrigeration. Emplaced waste heats the local environment around each canister, but removal of drainage water insures atmospheric pressure in repository rooms. The total fluid pressure in undrained canister holes will not exceed ~ 1.6 bars, which provides an upper limit of 112°C for boiling to occur. If and when temperatures exceed 100°C to 112°C in the canister holes, adsorbed water of rocks, clays, and zeolites will locally be lost by boiling and vapor transfer. No structural water of the hydrous minerals is lost below ~ 250°C.

Temperatures adjacent to the canisters will not greatly exceed 100°C until absorbed water is lost, unless the backfill is very tightly packed and nearly impermeable. Temperatures may then exceed 100°C, with water vapor pressures >1 bar, with the excess depending on rate of heating and permeability of the backfill, and permeability could decrease significantly outward where advected vapor condenses and fills pore spaces. Hazards from steam flow and hydrothermal explosions are greatest at this time, especially if a canister storage hole is reentered through tightly packed backfill.

Resaturation

Resaturation starts when the water drainage system is shut off and the repository is sealed. Water levels rise slowly as the repository rooms resaturate, and then rise rapidly as the limited-volume shafts are filled. Increased fluid pressures will eventually prohibit any further steam advection around canisters. Even if local absorbed water is driven off, clays and zeolites will rehydrate with no structural change in the minerals as water reenters the dried material. Flow gradients are all <u>into</u> the repository until resaturation is completed. The repository volume then becomes integrated into the regional hydrologic flow regime, but with some changes in flow patterns resulting from changes in permeability and temperature. Vertical flow gradients to the nearest overlying aquifer change upward from negative to positive, with magnitude being the major uncertainty. The time required for resaturation probably ranges from a few years to decades, depending on seepage rates into the repository after sealing, and the repository's unsaturated pore volume. No reliable estimates can be made until late in the stage of waste emplacement when final pore volume of the repository and seepage rates become known at the time of closure.

Long-Lived Changes after Reintegration of the Repository Volume into the Regional Flow System

Permeability may increase initially because of near-field radiogenic thermal expansion, disruption of joint blocks, and dissolution of basaltic glass, but thermal expansion may cause joints and fractures to close, thereby reducing permeability. However, new minerals start to deposit in constrictions in flow channels (Keith et al. 1978), as discussed in the following section.

Corresponding Changes in Groundwater Chemistry

Dewatering and Repository Construction

Waters from all surrounding environments flow into the repository due to greatly increased pressure gradients. Downward-flowing waters are in general more oxidizing. Air circulation for ventilation and refrigeration introduces abundant oxygen, greatly increasing the local Eh and oxidizing some Fe^{+2} minerals (as in glass, nontronite, and pyrite). Much additional oxygen is probably adsorbed on mineral surfaces.

The same regime continues during waste emplacement and backfilling. After sealing, resaturation starts. Higher-level, oxidized waters are gradually reduced and then eventually excluded as slightly more saline reduced waters from within and below the Umtanum gradually dominate the repository pore volume. Chemical effects of engineered barriers (clays, zeolites, cement, metals and any other reducing agents) are initially prominent, perhaps for decades to thousand of years, depending on their buffering capacity and flow rates through the repository.

Water interaction with fresh rock, especially basaltic glass on fractures and brecciated rock, increases greatly as temperatures increase, thereby increasing the solubilities of most constituents. Unstable glass, the dominant constituent of the central zone of the Umtanum flow, dissolves, but most constituents will reprecipitate locally in flow channels as more stable clays and zeolites of higher water content and specific volume. These secondary minerals tend to concentrate in flow channels, especially near constrictions, thus tending to "self-seal" these channels (Keith et al. 1978). Amorphous silica, the most soluble form of SiO_2, dissolves from the glass, but then precipitates as amorphous SiO_2 (common opal) and other less soluble forms as temperatures decrease along flow channels. These processes tend to decrease permeability with time, but seldom, if ever, result in complete self-sealing. These processes are not yet well understood, and are exceedingly difficult if not impossible to reproduce in the laboratory in all essential aspects, but are clearly evident in natural geothermal systems (Keith et al. 1978).

Strong support for their existence is also evident in the basalts themselves. The central Umtanum zone (entablature) is intimately fractured from thermal contraction during initial cooling, and initially this zone must have been modestly to highly permeable. However, the cracks are now lined (filled) with low-density clays and zeolites of high-water content that crystallized and decreased permeability of the zone to present low values. Continued existence of abundant glass within joint blocks (Basalt Waste Isolation Project Staff 1981b) indicates probable hydration but not devitrification to high-water clays and zeolites. These relations provide evidence that continued access of water along primary joint fractures became greatly inhibited as the open joints were filled.

Another strong argument for "self-sealing" is the general decrease in permeability of the basalt sequence with time. Values for interflows (flow-breccia tops) are highest in the upper (younger) basalts and are about two orders of magnitude lower in the older Grande Ronde basalts (Basalt Waste Isolation Project Staff 1981b). Long-lived changes, as mentioned above, continue, but at decreasing rates as thermal gradients and vertical permeabilities decrease.

Adequacy of Data

Data are especially inadequate for assessing the significance of core discing, with its implications of extreme rock bursting that could encroach on adjacent aquifers. Data bearing on self-sealing of flow channels are inadequately understood and difficult to reproduce experimentally. The phenomena are indicated most strongly by the natural environments of the Pasco Basin basalts and by natural geothermal systems (Keith et al. 1978). No data are available for estimating times required for resaturation of the repository or for reattainment of geochemical steady state.

Most Threatening Effects of Repository Construction,

Effects from Rock Bursting

Special studies of the present stress environment by recognized experts are needed to establish the magnitude of the problems. Direct communication with permeable local aquifers may become established.

Changes in Altitude

Inhomogeneities in Umtanum's central zone, with changes in altitude of its contact (initial and superposed) as construction advances. The repository must remain nearly "centered" in this zone and must avoid permeable faults, fractures, and primary flow structures. Advancing construction can tolerate slightly increased contact altitudes, thereby maintaining water drainage to central sumps, but declining altitudes will result in costly and troublesome drainage problems.

High In-Situ Temperatures

Construction of the repository at very high in-situ temperatures, estimated by Rockwell to be 57°C but possibly considerably higher. Refrigeration on a scale seldom if ever attempted in world mining may be necessary. The costs in time, money, energy, and lives of men are likely to be very high.

Even if each of the above is individually tractable, all in combination may be intolerable. More satisfactory alternatives probably can be found elsewhere.

GEOGRAPHIC AND ENVIRONMENTAL ASPECTS NOT CONSIDERED ABOVE

Proximity to Present and Future Population Centers

The Hanford site is relatively favorable in many respects. No reason is yet evident to expect a high rate of future population growth beyond the country-wide average after repository construction is completed.

Environmental Concerns

The Umtanum flow seems especially favorable for slow or negligible release of most radionuclides to the biosphere because of the sorption capacities of clays and zeolites and the generally low solubilities of most nuclides in the strongly reducing high pH environments (National Research Council 1983, Chapter 7). The most hazardous nuclides are iodine, lead, and selenium. Technetium-99, of major concern for most repositories, is relatively insoluble in BWIP's environment. Present flow patterns in Pasco Basin basalts are very complex and low in velocities, tending to disperse the upflows that probably do occur. Radionuclides that may escape the natural barriers provided by low solubilities, high adsorptions, and great dispersion, would be greatly diluted by the Columbia River.

Attractiveness for Human Intrusion

In general, the area is unfavorable for mineral or energy resources. Undiscovered natural gas deposits may exist below the thick basalt flows. Because temperatures have been so high in the past during maximum volcanism, recoverable petroleum deposits seem less likely. The potential for nonelectrical geothermal resources is now small, but could become attractive, especially through use of the heat of the deeper saline waters, followed by mixing with shallow cold waters for irrigation.

CONCLUSIONS

o The area is not geologically favorable relative to some other potential sites. Active tectonic deformation is still occurring; shallow earthquakes are frequent but small. The best available part of the basalt sequence is in the "uniform" center of the Umtanum flow, 47 ± 5 m thick, near the axis of the Cold Creek Syncline. However, vertical and horizontal inhomogeneities are likely to occur (initial flow irregularities, later folding, and possibly numerous faults). Altitude changes in boundaries of the "uniform" flow center, rising and falling with inhomogeneities, will be very difficult to predict in advance of mining, thereby risking unpredicted encroachments on permeable flow margins and faulted offsets.

o Performance of the Umtanum during repository construction is especially critical. The region has been and probably still is undergoing extensive north-south horizontal stress, probably causing the unusual degree of intense spalling of hard drill core into "discs" or "poker chips" as thin as 0.5 cm (National Research Council 1983, Chapter 6) as the rock is penetrated by the core bit. This phenomenon has not been adequately recognized in previous BWIP studies and has not been recognized in other basalts, at least to this extreme degree. The discing is probably a forewarning that "rock bursting" (sudden collapse of rock margins during excavation) may be difficult or even impossible to control at reasonable costs.

o Waters of the Grande Ronde basalts (deepest and oldest of 3 BWIP basalt formations, including the Umtanum flow) are probably $>$10,000 years old, with indicated pore velocities probably ranging from 0.04 to 4 m/yr (from carbon-14 and D/H contents, relative to present day recharge water). Flow patterns are very complex in detail, involving significant but as yet unmeasured vertical permeability. Flow patterns cannot yet be modeled reliably; previous efforts involve only selected parts of the physical data and almost no chemical data. No convincing agreement yet exists on areas of discharge, travel times, or path lengths from the deep Umtanum to the environment.

o The rocks and waters of BWIP are favorable for retardation of most radionuclides (perhaps the most favorable of considered candidates). Ferrous iron is greatly dominant over ferric, thus insuring a reducing environment that removes atmospheric O_2 from recharging water. Major consequences are: (a) rates of corrosion of metal radioactive-waste containers will be very low, especially if imbedded in low-permeability clay mixed with reducing agents; (b) solubilities of most radionuclides, including the normally troublesome technetium-99, will be very low (National Research Council 1983, Chapter 7); and (c) clays and zeolites that coat and fill fractures are very effective sorbants that will retard most radionuclides escaping from the container and other engineered barriers. The principal hazard is iodine-129. Lead and selenium may not be completely controlled. Strontium, cesium, technetium, and neptunium, which are mobile in some environments, will probably be retarded at BWIP (National Research Council, Chapter 7).

o Effects from rock bursting (or exaggerated yielding), inhomogeneities in the Umtanum's central zone (changing in altitude with advancing construction), and constructing a repository at such high initial temperatures ($\sim$57°C or higher and only 40°C below planned canister surface temperature), may each be individually tractable; but all in combination may be intolerable in cost of money, time, energy, and loss of lives, especially if rock bursting is frequent and difficult to predict.

RECOMMENDATIONS

o Study intensively present stress relations in drillholes, by utilizing acknowledged experts and focusing on states of stress as related to depth and intensity of core discing, to proximity of folds and faults, and to depth of the Umtanum.

o Study intensively any relations of subsurface temperature, water composition, depth, and position within the flow sequence. Each of the three major basalt formations has characteristic differences in water chemistry, locally displaced upward or downward by cross-formational flow (indicated by comparison of hydrostratigraph relationships in individual deep wells). Reliable temperatures and water compositions, in combination, can greatly clarify complex flow patterns that include strong vertical components, but such data have not been utilized to date in hydrologic modeling of BWIP. The same combination of water compositions, and temperatures in shallow holes near the Columbia River should help immensely in resolving uncertainties on areas of discharge from the system.

o Obtain more drillhole data near and below the Umtanum for possible existence of deep aquifers. Inclined holes are more helpful than vertical holes in identifying steep-dipping faults and fractures, and assessing vertical permeability.

o Obtain detailed hydrostratigraphic data to the bottoms of all deep holes in and near RRL, especially the paired holes DC-1/DC-2, DC-4/DC-5, DC-7/DC-8, and hole DC-3. Five charts from holes more distant from RRL have been supplied, but similar data are not yet available from the other drillholes, at least in part because of differences in drilling methods. Several of these holes or new holes should be drilled at least 60 to 300 m below the Umtanum and hydrostratigraphically charted in detail.

o Delay in construction of high-cost shafts and the repository is recommended, at least until low-cost data obtainable from drilling are better utilized than at present. The geologic and some hydrologic aspects of BWIP (excluding geochemical relations) are unfavorable enough to raise serious questions about its eventual suitability as a repository. Most of these questions can either be resolved or intensified, perhaps fatally, prior to major construction commitments.

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