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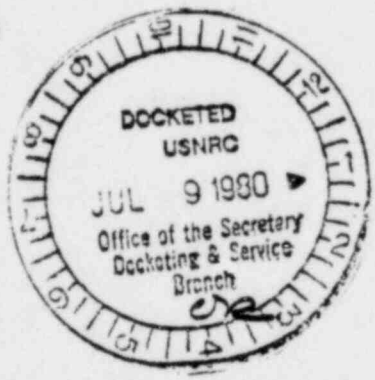
UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

In the Matter of	)	
	)	
PROPOSED RULEMAKING ON THE STORAGE AND DISPOSAL OF NUCLEAR WASTE	)	PR-50, 51 (44 FR 61372)
	)	
(Waste Confidence Rulemaking)	)	

STATEMENT OF POSITION OF THE
UNITED STATES GEOLOGICAL SURVEY

July 7, 1980



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I. Background and Scope of the Proceeding

The scope of this rulemaking as defined by the Nuclear Regulatory Commission (the Commission or NRC) is as follows:

> The purpose of this proceeding is solely to assess generically the degree of assurance now available that radioactive waste can be safely disposed of, to determine when such disposal or off-site storage will be available, and to determine whether radioactive wastes can be safely stored on-site past the expiration of existing facility licenses until off-site disposal or storage is available. (Federal Register, v. 44, p. 61372)

The Commission, on October 25, 1979, issued a Notice of Proposed Rulemaking which commenced this proceeding. Pursuant to that Notice, the United States Geological Survey (USGS), on December 20, 1979, notified the Commission that it wished to be a Full Participant. On January 29, 1980, a prehearing conference was held by the Presiding Officer appointed by the Commission to monitor the early stages of the proceeding and to assist the Commission in conducting the later portions. On March 12, 1980, by means of a letter from the Chairman of the Commission to the Secretary of Interior, the Commission requested the views of the USGS in this matter, in preliminary form if necessary, to make those views available to Participants for preparation of their statements. Accordingly, the USGS filed a Preliminary Statement on April 17, 1980. At about the same time, the Department of Energy (DOE) filed its Statement of Position.

Pursuant to the First Prehearing Conference Order issued by the Presiding Officer on February 1, 1980, and the Order Extending Time to File Statements and Cross-Statements of Position dated May 29, 1980, the USGS is filing this Statement of Position, an expanded and more detailed treatment of the matters covered in its Preliminary Statement.

The Presiding Officer also has ordered that this proceeding is concerned solely with spent fuel, and that issues of low-level waste, uranium mill tailings and the safety of transportation of waste materials are not within its scope.

II. United States Geological Survey Role and Experience

The USGS is the principal earth-science agency in the Federal Government. Its involvement in this rulemaking is appropriate because complex geologic and hydrologic questions must be resolved to achieve permanent isolation of high-level radioactive wastes. The USGS is addressing these questions through research programs that are designed to provide concepts, methods, data and analytical results that can be used by other agencies in the solution of the radioactive waste disposal problem.

The USGS program assists in the development of national policy on radioactive waste management by:

1) contributing to defining national program needs through consultation and cooperation with the lead agency (DOE) and the regulatory agencies and all other affected agencies and interagency groups.
2) participating in periodic comprehensive and critical assessments of the status of earth-science technology for managing high-level and transuranic wastes, low-level wastes, mill tailings, and other waste forms.

Within the past two years, the USGS has provided technical advice to the Department of the Interior (DOI) for its use as a member of the Interagency Review Group (IRG, 1979), contributed to an assessment of the status of scientific and technical knowledge needed for high-level waste isolation for the IRG (IRG, 1978, App. A) and cooperated with DOE in preparing an earth science technical plan to resolve technical questions involved in waste disposal in mined repositories (DOE/DOI, 1980). The USGS is currently working with DOE and all other concerned parties in the development of a detailed National Plan for Nuclear Waste Management as called for by the President in a Message to Congress on February 12, 1980 (Weekly Compilation of Presidential Documents, v. 16, no. 7).

An official statement outlining the scope of Geological Survey Participation in the National Radioactive Waste Disposal Program is attached as Appendix A.

The President's message of February 12, 1980, outlined an interim planning strategy, as recommended by the IRG, focussed on the use of mined repositories capable of accepting both waste from reprocessing and unreprocessed commercial spent fuel pending full environmental review under the National Environmental Policy Act. The 1981 Fiscal Year program DOE proposed to the Congress for the management of high level radioactive wastes incorporates elements of the President's policy. The USGS is qualified to comment on the President's interim planning strategy because it has expertise in the earth science aspects of exploration for sites for mined repositories, characterization of potential sites, and evaluation of the long-term performance of repositories. The USGS does not have expertise in the operational aspects of waste handling, storage, and transportation nor within the general area of biological pathways to man of radionuclides within the accessible environment.

III. Position of the United States Geological Survey

With regard to the first question raised in this proceeding, the USGS is confident that solid, high-level radioactive waste produced by nuclear facilities can be disposed of by burial in mined repositories with very low risk to the environment. However, USGS is unable to estimate when such disposal will be available and is not qualified to comment on the performance aspects of the short-term storage of wastes produced by nuclear facilities.

The USGS bases its confidence that burial of solid radioactive waste in mined repositories will result in low risks on extensive knowledge of geologic environments and the processes operating within them. These environments and processes can contribute to isolation by providing remoteness from the accessible environment in a stable setting and by preventing or retarding the migration of radionuclides if any escape.

The natural environment of a repository and its engineered aspects combine to form a complex system. Confidence that such a system will eventually be employed to isolate wastes depends on favorable outcomes to all of the following research and exploration efforts:

1. Design, construction and acceptance of a waste package that will meet performance criteria under repository conditions.

2. Identification of a suitably sized body of rock of low permeability that can be expected to retain its basic critical performance properties under the design loads of heat and radiation.

3. Identification of a geologic setting for which the time of transit of groundwater from the repository to natural discharge points is acceptably long and within which migration of key radionuclides is retarded.

4. Identification of a geologic environment in which the likelihood and consequences of human intrusion are minimized.

5. Identification of a geologic environment in which the likelihood of disruption by natural processes is low.

Attempts to accomplish the efforts described above are proceeding now in the Department of Energy's program for the managment of high level radioactive waste; several efforts have only recently been expanded in scope so that significant earth-science issues connected with the implementation of waste disposal in mined repositories are now being addressed. Implicit in the idea of a favorable outcome for these research and exploration efforts is the expectation that formal criteria will be available so that the attributes and processes specific to a given system can be judged to have been achieved or not. Such formal criteria do not yet exist, but are under development.

Numerous factors make it impossible to estimate now when disposal in mined repositories will be available. An important consideration is that the Congress has not yet adopted, and may not adopt, the President's program as the basis for the management and disposal of spent fuel. The level at which programmatic efforts are funded will affect the timing of when apparently qualified sites will be offered for licensing. The roles of the States and Indian nations in siting repositories is also not fully resolved. There are many social and institutional questions that must be resolved in order to begin to identify potential sites, to gain access for their characterization, and to carry out the licensing process. From a technical standpoint, such disposal requires new and hitherto untried technology. Implementation of new technology typically has been time-consuming, involving initial failure of some components to perform as originally conceived, discovery of new problems to be resolved, and re-consideration of design concepts. How much time should be allowed for such contingencies is not clear.

Any assessment on a generic basis that radioactive waste can be disposed of in mined repositories at acceptable levels of risk can achieve only limited

credibility. A complete set of general site acceptability criteria may not be possible (Nuclear Regulatory Commission, Federal Register, v. 45, p. 31387); and lacking these, successful site specific studies are required to determine site acceptability on a case-by-case basis. Notwithstanding the basic inadequacy of proceeding generically, increased emphasis on the problem of radioactive waste disposal in recent years has led to a widespread consensus among the technical and engineering communities on basic approaches and acceptance of a philosophy to proceed conservatively with all stages of repository siting, development, licensing, and operation. This statement discusses some recent regulatory, philosophical and technical developments as they relate to the earth sciences, indicates ways in which they increase confidence in safe radioactive waste disposal, and discusses a number of problems that are unresolved at this time.

These USGS comments are restricted to technical discussions related to fulfilling proposed formal earth science criteria (ONWI, 1980a; Federal Register, v. 45, p. 31393) which describe desirable conditions in the natural setting of the repository and in the man-made portions of the repository (including the waste package), and which specify performance standards for the components of the repository system. Detailed in situ tests will be necessary to generate the data needed to perform risk assessment for the actual sites; until this has been done, no site can be judged qualifed or suitable for waste disposal.

The President's February 12 message speaks to this point.

> "... because the suitability of a geologic disposal site can be verified only through detailed and time-consuming site specific evaluations, actual sites and their geologic environments must be carefully examined."

Confidence in safe waste disposal will be greatly increased after the first and subsequent actual sites have been characterized and found qualified for consideration for licensing. The environmental impact statement

and the licensing process among these qualified sites will increase confidence that the first site to be developed will perform successfully, and additional confidence will be obtained during initial start-up operations prior to full-scale repository operations.

IV. Generic Considerations Related to Approaches and Philosophy

1. Proposed regulations

A portion of proposed NRC regulations dealing with procedures for licensing of repositories has been published for comment (Federal Register, v. 44, p. 70408, December 6, 1979). The proposed procedures have been formulated to take account of the fact that disposal of radioactive waste in mined repositories requires new technology that must be developed in a stepwise, conservative manner. Each major step in the licensing provides opportunities for reevaluation of previous analyses and judgments; state and local officials and the general public will be involved in these reevaluations.

The proposed rule also calls for geologic exploration and *in situ* testing near proposed repository depths at several potential sites in different geologic media before licensing of the best qualified site from among this group for the first repository. Critical information on the properties of the geologic environment and the short- and long-term behavior of wastes within it can only be obtained by such testing. A valid comparison of geologic systems probably will require that *in situ* testing be carried out at all or virtually all sites considered in a comparison of alternatives. This procedure will greatly increase confidence that the site eventually chosen will successfully isolate the wastes. As noted by the IRG (1979, p. 43) and by a committee of the National Academy of Sciences (NAS, 1979), it is inherently impossible to verify that a repository will function properly over the time period involved. Reasonable assurance that the repository will comply with pre-established standards can be obtained, however, by conservative procedures and design, laboratory and *in situ* testing of critical components of the waste isolation system, and a thorough understanding of the processes taking place within the repository system after waste is emplaced. The proposed regulations provide for such procedures.

That portion of the licensing rule dealing with technical criteria for mined repositories was published in preliminary form for comment on May 13, 1980 (Federal Register, v. 45, p. 31393). The USGS has not yet commented upon the proposed criteria in detail but notes that they emphasize conservatism and multiple barriers within a systems context in accord with the recommendations of the Interagency Review Group and announced Presidential policy.

2. Presidential endorsement of the Interagency Review Group (IRG) recommendations as the basis for national waste management policy

The Interagency Review Group, consisting of representatives from 14 government organizations, conducted a far-reaching review of the high level radioactive waste problem. Its reports (IRG, 1978, 1979) were subject to extensive review by groups and individuals from industry, government, universities, and the general public.

From the point of view of confidence in the ultimate safe disposal of solid waste from nuclear facilities, the following technical conclusion of the IRG remains valid as an accurate statement of the status of research and exploration on this problem.

> "Present scientific and technological knowledge is adequate to identify potential repository sites for further investigation. No scientific or technical reason is known that would prevent identifying a site that is suitable for a repository provided that the systems view is utilized rigorously to evaluate the suitability of sites and designs, and in minimizing the influence of future human activities. A suitable site is one at which a repository would meet predetermined criteria and which would provide a high degree of assurance that radioactive waste can be successfully isolated from the biosphere for periods of thousands of years." (IRG, 1979. p. 42)

Emphasis in this and in several other conclusions of the IRG on a "systems" approach to siting and engineering repositories is appropriate. There are three basic components to any waste isolation system: waste package, host rock, and groundwater flow path. It is not necessary that each component

in a given system be optimal, but each should provide some measure of redundancy in providing for isolation of radionuclides.

The waste package component includes the actual radionuclides, the matrix or chemical compounds in which they are fixed, canisters, and specially designed overpacks. If the waste package can delay release of the radionuclides to circulating groundwater for a substantial periods of time and permit only a very slow release thereafter, confidence that radionuclides will not reach the biosphere in unacceptable concentrations will be greatly increased. Some of the technical details involved in fabricating such a waste package are discussed in section 3 of this filing.

A waste package that could maintain its integrity for 600 to 1000 years would eliminate any risk from the migration of short-lived fission products of principal concern, mainly ^{90}Sr and ^{137}Cs. The host rock and the groundwater flow path can also be very effective barriers to the movement of these nuclides because ground-water flow times to natural discharge areas of at least 1000 years are relatively common in hydrologic systems. However, the additional effort that would have to be applied to achieve isolation of the fission products for 1000 years is justified because such a package would provide protection against possible short-circuiting of the natural ground-water flow system by new or unknown fractures, improperly plugged shafts and boreholes, or in advertent human activities that might disturb the geologic system in the future. Isolation with respect to both groundwater transport and the effects of past and future human activities is required.

A waste package that can be expected to contain radionuclides for significantly longer periods (up to 1,000,000 years) is a reasonable possibility. The Swedish plan for disposing of spent fuel described by the Karnbränslesäkerhet group (KBS, 1978) envisaged use of a copper canister

with a postulated lifetime of hundreds of thousands of years, and the feasibility of such a canister in certain geologic environments was maintained by Swedish experts (KBS, 1978, p. 144), and a committee of the U.S. National Academy of Sciences (NAS, 1980, p. 35-42). The USGS has reservations that a thick copper container, such as proposed by the Swedish plan, might itself be an attraction for future human intrusion; but the principle of a long-lived canister has merit, and is within the capability of materials science technology to achieve in the same time frame as repository site identification, qualification and development.

The host rock component of the hydrologic system, if it functions properly, limits the access of ground water to the waste package and provides a strong resistance to migration of any radionuclides that may dissolve in liquids that penetrate the waste package. The properties of an appropriately selected host rock in a currently stable geohydrologic environment that has been stable for long periods of geologic time can be expected not to change so as to significantly affect the performance of the rock around the repository during the period for which isolation of radioactive wastes is required. Perturbations caused by the presence of the repository, discussed in sections 3 and 4, will, of course, have to be carefully evaluated in selecting a host rock and designing the repository.

Should the waste package fail to function as planned and should the properties of the host rock change, owing to natural forces, or forces resulting from the presence and operation of the repository or other human-induced forces, a third line of defense consists of the groundwater flow path from the repository to the biosphere. This part of the total system deserves attention and the application of a conservative siting strategy commensurate with the efforts placed on the other two major barriers. A groundwater residence time between the repository and the biosphere of 1000 years, in combination with the other barriers, would provide for isolation of the short-lived fission products with

virtual certainty. A groundwater system with a much longer residence time could effectively isolate many of the longer-lived radionuclides including most of the actinides and their daughters.

In summary, the USGS believes the systems approach greatly increases confidence in the safety of waste disposal by burial in mined repositories. Equal degrees of conservatism and care must be exercised in developing the major components of the system, both in the design of the engineered barriers and in the selection of environments with suitable natural properties. To the maximum extent possible, each of the major components should be independent.

3. Engineered barriers

As indicated in the First Prehearing Conference Order (Feb. 1, 1980, p. 9), spent nuclear fuel is the only waste form under consideration in this proceeding. Spent fuel is heterogeneous, is more complex chemically, and contains more transuranic elements than solidified high-level waste from reprocessing. These characteristics must be considered when assessing the suitability of a particular host rock or environment for disposal of spent fuel. Studies to characterize spent fuel and determine the mechanisms and rate of its alteration in a repository setting are beginning (DOE/DOI, 1980, Table 5, p. 26; ONWI, 1979), but results to date are fragmentary. DOE's program for developing the capability to successfully dispose of spent fuel will require several years of substantial effort and funding to assure confidence in the long-term performance of this waste form.

The goal of having a waste package capable of containing radionuclides for 600 to 1000 years, and perhaps longer, places great demands on current technology. The mechanically fragile and chemically complex spent fuel must be placed in a container and the container surrounded by materials chosen to prevent or resist the intrusion of groundwater and the outward migration of radionuclides (DOE,

1979, p. 3.1.59-3.1.62; ONWI, 1979, p. 16-22). Potential chemical reactions among all of these components - spent fuel, container, overpack and backfill materials, groundwater and host rock - will have to be explored and a determination made of the sum effect of these reactions on containment. For example, the possibility of galvanic cells that might lead to degradation of the canister or make certain radionuclides more mobile in repository fluids must be examined.

Spent fuel is heterogeneous; its chemical properties depend on its burnup, location within the reactor core, age and physical integrity. Studies of selected spent fuel pins indicate that some radionuclides are concentrated at the margins of the pins (Harwell and others, 1979, p. 10-11). Cesium and iodine are likely to be concentrated in a gap between the fuel oxide and the Zircaloy cladding and thus be available for release if the cladding were ruptured and the enclosing canister were breached (Deju and Fecht, 1979, p. 8, 18). Strontium is apparently not incorporated in the fuel oxide but is present in a second oxide phase that would be soluble in neutral or slightly acidic groundwater (Deju and Fecht, 1979, p. 8, 18). Untreated spent fuel contains fission product gases which could pose problems during the operational phase of the repository as well as the period immediately following closure. The possibility of separating these gases mechanically and the use of special methods of consolidating the solid spent fuel is under study (ONWI, 1979, p. 28).

A major engineering effort to design a system of engineered barriers for spent fuel within the context of specific hydrogeologic environments has begun (ONWI, 1979). The relatively non-reactive environment of crystalline rocks in Sweden appears from first analyses to be one where such a system can be provided (KBS, 1978). The brines included in some salt deposits are acidic and at the temperatures generated by spent fuel are relatively reactive (Stewart and Potter, 1979, p. 301). It will therefore be necessary to assure that such brines will not reach the spent fuel. Special materials with the potential to

provide a suitable canister in brines exist (ONWI, 1979, p. 20), but their cost, availability, and reliable fabrication must be carefully considered.

A combination of laboratory and in situ experiments will be needed to determine an effective combination of engineered barriers for spent fuel. These experiments will be difficult because of the intense radioactivity of spent fuel. As the experimental program proceeds, modifications to the proposed barriers will be made as indicated by the results (DOE/DOI, 1980, p. 44). The degree to which the subsystem of engineered barriers can perform to design specifications will be determined ultimately from monitoring the environment immediately around the waste during the initial stages of operation of a repository.

4. Thermal Effects

As has been noted often, many of the potential problems caused by the presence of the repository are greatly eased if temperatures, both in the immediate vicinity of the waste and throughout the repository volume, can be reduced, especially if they are kept below 100°C. Reactions between the waste and any liquids it contacts will proceed much more slowly, if at all, at lower temperatures than at higher. Effects on the groundwater system brought on by mechanical changes in the rock system are also reduced, especially at temperatures below that of the formation of steam (Bredehoeft and others, 1978, p. 6,7,12; Lawrence Berkeley Laboratory, 1979, p. 68).

The effects of even small amounts of heat must, of course, be evaluated. The interconnected effects on groundwater transport of thermal expansion, displacements, increased pore pressures, in situ stress, and changed viscosity must be determined at all anticipated temperatures in brittle rocks (Lawrence Berkeley Laboratory, 1979, p. 68). For repositories in salt, the mechanism, extent, and consequences of brine migration in a thermal gradient require additional understanding (Stewart and Potter, 1979). The effects of brine accumulation on retrievability also need to be assessed.

Confidence that the effects of heat have been satisfactorily evaluated and will not result in loss of isolation will come from *in situ* heater tests at a specific candidate site combined with improved understanding of the relevant physical and chemical processes. It is important that such tests begin early in repository development. The DOE is committed to conservative engineering strategies in developing repositories (DOE, 1978, p. 11). A conservative strategy including low thermal loading was recommended by the IRG (1979, p. 48). The Swedish plan for the disposal of spent fuel calls for temperatures in the repository to be kept below 80°C (KBS, 1978, p. 220). Under prevailing conditions in the granitic rock considered for a repository in Sweden, perturbations to the groundwater system from such a thermal loading are predicted to be small; these predictions will have to be tested underground at a specific site.

5. Risk assessment

The long-term performance of a repository and the risks associated with it can only be assessed by mathematical models (IRG, 1979, p. 43; NAS, 1979, p. 34). In the past, risk assessment activities concentrated on predicting the occurrence and consequences of natural events, but there has been recent emphasis on adding consideration of phenomena induced by the presence of the repository (DOE/DOI, 1980, p. 53-57; Burkholder, 1979).

Many mathematical models exist to describe both natural and induced phenomena. Still needed, however, are considerable data pertinent to the phenomena being modelled and a better understanding of the processes and events involved to assure that the models are an adequate representation of reality. Research efforts to obtain the necessary data and understanding are underway (DOE/DOI, 1980, App. D). However, much of the needed data and understanding can only come from site-specific investigations. It is particularly important to develop methods to determine the bulk retardation properties of large volumes of rock as this property is significant in all models of groundwater transport.

The uncertainty involved in predictive models increases as the time span of concern increases. Predictions involving human activities become highly uncertain after as little as a few hundred years (Rochlin, 1977). The situation is somewhat better with regard to natural events. Within some tectonic provinces, for example, the rate of occurrence of events such as faults or earthquakes appears to have remained relatively constant over time periods of at least several hundred thousand years (e.g., Wallace, 1978). The probability of a single event affecting a repository increases, of course, with increasing time. Efforts to model the consequences of single or rare events are needed (Wight, 1979).

Some measure of the uncertainties associated with the results of risk assessment models is needed, but it is not clear at present how this can be obtained. The probabilities calculated for rare geologic events do not lend themselves to estimates of formal error; upper bounds are much easier to determine and justify. In a complex integrated model of a total waste isolation system, calculation of formal uncertainty can be very lengthy and may be unrealistic if all variables do not have uncertainties that can be incorporated mathematically (for example, variables associated with human intrusion). Parametric and sensitivity studies coupled with conservative siting and engineering practices with regard to crucial components of the system may be the best way to provide confidence in repository performance.

V. Developments related to exploration

A screening process to select potential sites for detailed characterization should follow a rational plan that compares progressively smaller parcels of the Earth's crust against relevant criteria. From a purely earth science point of view, all parts of the country should be examined to determine their potential for providing the necessary multiple barriers to radionuclide migration. In practice, constraints of time and resources require that efforts be concentrated in limited regions fairly early so that detailed site specific characterization efforts can be undertaken in a timely way.

Present site exploration efforts by the Department of Energy (DOE) are focussed on 1) salt domes of the interior Gulf Coast, 2) bedded salt of the Permian basin, 3) salt anticlines of the Paradox Basin, 4) rocks at the Nevada Test Site, Nevada, and 5) basaltic rocks of the Hanford Reservation, Washington. Regional studies of salt formations in the Appalachian Basin were completed in previous years. Bedded salt in the Michigan Basin has also been studied briefly. These programs have concentrated on a single rock type (salt) or category of land use (nuclear reservations) from their beginning and, within this context, have proceeded in a scientifically sound fashion. They can lead to potential sites for detailed characterization provided, of course, that the sites eventually chosen meet the basic criteria established for all sites (ONWI, 1980a) and thus appear likely to meet NRC's pending licensing criteria.

The following sections include brief discussions of the geologic and hydrologic factors affecting the major natural barriers to radionuclide migration in these environments, and resource-related factors.

1. Gulf Coast interior salt dome basins

Seven salt domes within the Northeast Texas Basin, the North Louisiana Basin, and the Mississippi Basin are currently under study (DOE, 1980, p. 49). Depth to the top of these domes ranges from 35 to 500 meters; the cross-sectional areas of the domes at potential repository depths of 600 to 1000 meters range from 10 to 40 hectares (1000 to 4000 acres). Investigations have proceeded to different stages at the seven domes. Work is continuing to characterize the salt masses and to understand tne local and regional hydrology at each. Surface investigations and drill-hole data indicate that salt of the necessary depth and extent is present. Because salt is soluble, characterization of any salt formation must describe 1) the relative amount of fluid contained in or invading the evaporite mass and the nature of its solute content, and 2) the rates of dissolution, alteration and fluid movement around or through the evaporite section.

Some salt domes include shear zones along which masses of salt have moved differentially (Kupfer, 1968) and along which brine flow may occur (Harwell and others, 1979, p. 429). Location of any such shear zones and a determination of their effect on repository construction and operation will be required. A sheath of clay or clay gouge is apparently present to some extent around some domes (Johnson and Gonzales, 1978, p. 78, 90); where present it may constitute an important barrier to the incursion of groundwater and the escape of radionuclides.

The hydrology around Gulf Coast salt domes is complex both because of the lenticular and interfingering nature of the sedimentary section of sands and clays, and because of faults and fracture zones on the periphery of the domes where they have broken through overlying strata. Whether or not the domes are currently undergoing dissolution, and if so, at what rate, are basically unsolved

problems for all domes (Johnson and Gonzales, 1978, p. 69; Harwell and others, 1979, p. 4-14 - 4-17). It should be noted that there is no direct evidence that any of the seven domes under consideration are presently undergoing widespread or extensive dissolutioning. Regional hydrology is likewise complex. Considerably more measurements of transmissivity and hydraulic potential than are available are needed in order to model accurately the regional flow system adjacent to a salt-dome repository (Harwell and others, 1979, p. 7-4).

A preliminary evaluation of the effectiveness of the groundwater system in the Northeast Texas Basin in isolating radionuclides was made by Harwell and others (1979) by employing conservative values for transmissivities and hydraulic potentials. Flow times from the dome to natural discharge points in this analysis are on the order of 40,000 years. To further evaluate contaminant transport, Harwell and others (1979) modeled a massive breach of a salt dome repository caused by prolonged solution mining. They used retardation factors based on recent experiments with saline and bicarbonate waters expected in the subsurface as a result of the breach. Concentrations of all radionuclides were low (comparable with normal background) at the discharge point and would be lowered further depending on the flow of the receiving stream at the time of discharge. The groundwater flow system is calculated to be an effective barrier to radionuclide migration in this analysis, but more refined analyses and better data for the model are obviously needed and are being obtained.

The Interior Gulf Coast is a region of relative tectonic stability. Recent studies by Collins and others (1980) of the Elkhart graben on the southeast flank of the Northeast Texas Basin indicate evidence of Quaternary movement on three closely-spaced normal faults 20 km from two of the candidate domes. The rate of Quaternary movement is low and the faults may be aseismic. The potential effect of these faults on the hydrologic system will have to be

considered. The possibility of future salt dome growth with attendant fracturing and faulting must also be evaluated. Although questions of detail remain, there is a broad consensus that the growth of domes in the interior basins has declined since the Cretaceous and had effectively ceased by mid-Tertiary (Johnson and Gonzales, 1978, p. 67; Martinez and others, 1975). The conclusion is consistent with the theory that salt dome growth is promoted by differing rates of sedimentation on the dome and its flanks, and there is not now any significant sedimentation within the interior basins. A detailed study of Quaternary deposits surrounding certain domes, utilizing modern dating techniques may help resolve this question.

Of the seven domes now under consideration, one (Oakwood, TX) has supported significant oil and gas production on the dome (Johnson and Gonzales, 1978, p. 80). The domes may present a target for future drilling for hydrocarbons, sulfur or salt. They may also be attractive as the site of storage cavities for a variety of materials. Harwell and others (1979) analyzed the consequences of solution mining for salt in a dome for which it was assumed that records of earlier use for a radioactive waste repository were lost. The analysis made several worst case assumptions and did not assume engineered barriers surrounding the waste. Significant doses to humans from ingestion of contaminated table salt were calculated.

Fresh water at depths ranging up to 900 m in the Gulf Coastal Plain constitutes an extremely valuable natural resource that must be taken into account in locating and engineering a repository in this region.

2. Permian Basin

The Permian Basin is defined in the subsurface by extensive evaporites of Permian age in parts of Colorado, Kansas, Oklahoma, Texas, and New Mexico. Current exploration efforts in the basin are focussed in the Delaware basin at Los Medanos area, New Mexico, which was the site for a proposed Waste Isolation Pilot Plant (WIPP), and in the Palo Duro and Dalhart subbasins of the Texas panhandle.

a) Los Medanos area, Delaware Basin

The Los Medanos area has been the subject of an extensive Site Characterization Report (Powers and others, 1979) which shows that many of the attributes necessary for long-term isolation of radioactive waste are apparently present. The potential host rock is salt in the lower part of the Salado Formation at a depth of 900m. The Site Characterization Report is based solely on results of drilling and surface and downhole geophysical probes. The logical next step in the characterization of the site is the sinking of an exploratory shaft and limited drifts to assay subsurface conditions especially at the horizon within the salt where a repository would be constructed. Analyses of drill cores suggest that in the major portion of the Salado Formation the total fluid content is low (Powers and others, 1979, p. 7-31) although determination of fluid contents of salt cores where drilling mud has been used are well known to be difficult. Dissolution of the repository horizon by circulating waters appears unlikely during the period over which the wastes must be isolated (Bachman, 1974, 1976; Powers and others, 1979, p. 6-42 - 6-46). The potential host rock thus appears to be stable provided its performance is not degraded by the presence of a repository.

The groundwater flow system in the vicinity of the Los Medanos area has also been studied (Lambert and Mercer, 1977; Mercer and Orr, 1977; Mercer and Orr, 1979). The system has several favorable attributes. The evaporite section

is thick and serves to isolate underlying and overlying aquifer systems. The underlying aquifers contain brines and would not be apt to be utilized for human consumption. The overlying aquifers are of low transmissivity and, moreover, contain water of very poor quality that also would be unlikely to be utilized. The hydraulic potential decreases with depth in the overlying aquifers, so that under present conditions, there would be no flow from the repository to the surface (Mercer and Orr, 1979, p. 173). A less favorable condition is that hydraulic potentials in the underlying Bell Canyon formation are high enough to cause brine from these rocks to reach the upper aquifers if a hydraulic connection existed (Mercer and Orr, 1979, p. 170).

The effectiveness of the groundwater flow system as a resistance to radionuclide migration at the Los Medanos area has been assessed by means of a consequence analysis in a Draft Environmental Impact Statement for the WIPP project (DOE, 1979b, 9-98 - 9-128). The consequence analysis was performed for a repository containing weapons-related TRU waste and a limited number of spent fuel assemblies; the results are not applicable to a full-scale, spent-fuel repository. However, the consequence analysis indicated some of the key properties of the groundwater flow system. If a breach of the repository occurs, the flow path through the Salado and overlying or underlying evaporites may provide some, possibly significant, retardation of the radionuclides (Dosch and Lynch, 1978, p. 21). If radionuclides enter the overyling Rustler aquifer, a fractured dolomite, the flow path to the nearest point of discharge and the extent of retardation along that flow path become important. Under present conditions, the point of discharge for the Rustler aquifer is Malaga Bend 15 miles from the Los Medanos area. Travel times for this distance range from 5000 to 100,000 years for different values of hydraulic transmissivities used in the analysis (DOE, 1979b, p. 9-113). Laboratory data (Dosch and Lynch, 1978, p. 20) indicate

the possibility of significant retardation of the actinides along the rocks encountered in this flow path. However, the experiments made use of powdered rock samples; the retardation must eventually be determined with more realistic *in situ* tests.

Preliminary studies thus suggest that the hydrologic flow path in the vicinity of the Los Medanos area would be an effective resistance to the migration of radionuclides. Flow through the fractured dolomite of the Rustler Formation, however, is not well understood and may be heterogeneous. Confirmation of the flow path properties is needed by additional drilling and *in situ* tests where appropriate.

The Los Medanos area is in a region of relative tectonic stability. The Rio Grande Rift, a structure active in the late Quaternary, occurs 125 kms to the southwest (Howard and others, 1978). Similiar rifts are known to have migrated in the geologic past (Cerling and Powers, 1977) but the known rates of migration are such that there is little chance the Los Medanos area would be engulfed in a rift. Nevertheless, consequences of changes in the properties of the hydrologic flow path - as a result of tectonic and/or climatic changes - need to be ascertained for the Los Medanos area.

Significant potash resources occur above the proposed repository horizon in the Los Medanos area. There is also a potential for oil and gas occurrence in untested strata below the repository horizon although there is no obviously favorable structure present (DOE, 1979b, p. 9-15). As indicated above, preliminary studies indicate that the natural barriers of the Los Medanos sites would prevent hazardous radionuclide migration even if upward flow of water were to be established through the repository from the underlying to overlying aquifers as a result of human activities. Whether mining the potash at Los Medanos would result in consequences more serious than a hydraulic connection between the aquifers has not been established.

b) Palo Duro and Dalhart Basins

Exploration in these basins is in the early stages. Thick sections of Permian evaporites, similar in kind but less extensive and thinner bedded than those in the Delaware basin of the Permian basin occur at suitable depths in Palo Duro in the Palo Duro and Dalhart basins (Gustavson and others, 1979) and subsurface conditions may be expected from data in hand to be generally similar. The relative thinness of the evaporite beds may make choice of a repository horizon difficult. Subsurface waters at depth are mostly brines (Johnson and Gonzales, 1978, p. 128).

The basins are in regions of tectonic stability in an area of low seismic risk (Algermissen and Perkins, 1976).

The Palo Duro and Dalhart Basins are notably free of oil and gas fields, and there are no known potash deposits (Johnson and Gonzales, 1978, p. 129-131).

3. Paradox Basin

This basin in the east-central part of the Colorado Plateaus is defined by the extent in the subsurface of the Pennsylvanian Paradox member of the Hermosa Formation. Bedded salt of the Paradox member is the target of exploration for locating potential repository sites. The salt is interbedded with black shale, anhydrite and dolomite.

Exploration in the Paradox Basin was begun relatively recently and much geological, geophysical and hydrologic study remains to be done to locate potential sites. The rocks are shallow enough for consideration only in a series of domes and anticlines. Within these structures, the beds have been deformed to varying degrees of complexity. Four study areas are currently under investigation (DOE, 1980, p. 47). High-pressure, low-volume methane occurs throughout the Paradox section, mainly in the black shale and dolomite. Some liquid petroleum also occurs in the section, though rarely in commercial amounts (Hite and

Lohman, 1973, p. 23-44). The structural complexity and hydrocarbon content of the Paradox member will have to be carefully evaluated before and during any site characterization activities.

Little is known about the complex hydrology of the Paradox Basin at the depths contemplated for a repository.

The Colorado Plateau is a stable tectonic unit and the rate of occurrence of earthquakes is low (Algermissen and Perkins, 1976). The potential for renewed movement of the salt structures does not appear to be great, but must be evaluated.

The potential for resource development of the salt domes and salt anticlines appears to be relatively low. These structures have historically been explored for oil and gas and this activity will probably continue. Although there has been some production from these structures, not all the deep zones have been thoroughly evaluated. Potash occurs irregularly in parts of the basin (Johnson and Gonzales, 1978, p. 136).

4. Nevada Test Site

The Nevada Test Site is located in the southern part of the Great Basin about 160 km northwest of Las Vegas. It contains a variety of rock masses that might be suitable as the host rock for a repository. Currently, attention is being focussed on welded tuff at a location on Yucca Mountain in the southwest quarter of the reservation. Much of the rest of the reservation is not now being considered because of conflicts with Department of Defense activities.

Exploration of the tuff at Yucca Mountain was begun relatively recently. A program of drilling and geophysical studies is underway to assess the feasibility of constructing a repository in the tuff (DOE, 1980, p. 43).

A favorable hydrologic condition at the NTS is the relatively long flow paths from potential sites within the reservation to discharge points to the

southwest (Winograd and Thordarson, 1975). Many of these paths traverse rocks thought to be especially high in sorptive capacity (Winograd, 1974). In the Yucca Mountain area the hydrologic flow system is not well known in detail, and considerable additional characterization will be necessary if interest in the Yucca Mountain site continues.

The NTS lies within the Basin and Range Province which has been a broad zone of tectonism and volcanism probably resulting from the interaction of the North American and adjacent plates. The loci and rates of occurrence of faulting and volcanic activity have varied over time within the province. At present, the NTS lies inboard from the fault zones in California along which most of the strain built up by the interaction of the North American and Pacific plates is released. Historic earthquakes connected with faulting have occurred within the vicinity of NTS, but the rate of volcanic activity and the rate of strain expressed as faulting are currently relatively low compared to rates along the more active plate margin (Crowe and Carr, 1980; Atwater, 1970; Lawrence, 1976; Anderson, 1979; Wallace, 1978).

Like most of the Basin and Range Province, the NTS contains scattered mineral deposits; some of these were worked before the land was withdrawn for weapons testing. Because of this withdrawal, the reservation has not been the site of intense exploration and drilling; and the locations of all deep holes are well documented. Deep groundwater at the NTS and its vicinity is a potential resource; the possible effects of a repository on this resource and the possible effects of future utilization must be evaluated for specific sites.

5. Hanford Reservation

The Hanford Reservation is located on the Columbia Plateau in central Washington. It is underlain by basalt of the Columbia River Group which is under investigation as a repository host rock. The Umtanum flow, at a depth of approximately 1000 meters, is receiving the greatest attention at present although shallower basaltic flows above the water table may have potential (NAS,

1978, p. 108). Some drilling has been done to define the Umtanum flows at depth and determine the degree of hydrologic isolation they can provide (NAS, 1978). Variations in the thickness and properties of the flows and in the characteristics of the groundwater flow system are considerable (Apps and others, 1979, p. 223).

Although parts of the basalt section have very low hydraulic conductivity, there are numerous water-bearing interflow units and fractured zones of higher conductivity (Apps and others, 1979, p. 223; NAS, 1978, p. 106). A reasonably complete picture of the hydraulic characteristics at the depths of the proposed repository is lacking at present and will require considerable additional drilling and careful testing (Apps and others, 1979, p. 224; NAS, 1978, p. 160) prior to sinking of a shaft. Hydraulic heads show considerable lateral variation and determination of the direction of movement of the groundwaters may prove difficult. Where much of the flow is through fractures, it may be difficult to model.

Evidence garnered to date suggests that over parts of the reservation, water moves to a sink below the Umtanum flows and thence to the Columbia River (Apps and others, 1979, p. 222). Flow times of at least 1000 years are indicated. The hydrologic flow path may provide additional barriers to radionuclide movement in the form of significant amounts of smectite clays and zeolites along fractures or rubble zones (Benson and others, 1979; Deju and Fecht, 1979; NAS, 1978, p. 108). These may retard migration of radionuclides such that the groundwater system can be regarded as an acceptable barrier though there may be unavoidable uncertainty about the details of water movement. Appropriate tests to determine the extent of retardation along fractures, rubble zones, and interbeds will have to be carried out. The deep waters in the basalt section appear to be at least 10,000 years old (LaSala and Doty, 1971) indicating that flow times to the surface may be appropriately long but further measurements are needed (Apps and others,

1979, p. 25). Careful attention must also be given to the problems of repository construction and safety in a brittle, highly fractured, and water-bearing sequence of rocks.

The Hanford Area, like the NTS, lies inboard from the active plate margin and the rate of faulting and folding are relatively low. Estimates by Wight (1979) suggest that the strain rate on the Columbia Plateau may be comparable to that in the Basin and Range. The stress fields in the two provinces are very different: the Columbia Plateau is under north-south compression, the Basin and Range Province is under northwest-southeast extension.

Land of the Hanford Reservation has been withdrawn for defense-related activities for more than 30 years, and there are relatively few deep exploratory holes. The Columbia Plateau does not have an extensive record of resource extraction. Because of extensive shallow aquifers, deep groundwater does not constitute a resource of interest at present.

6. Michigan and Appalachian Basins

This region is defined by the subsurface extent of the Silurian Salina Group in Michigan, Ohio, Pennsylvania, and New York. The Salina Group includes interbedded salt, shales and carbonates. Salt of the required depth, thickness and extent is present over large areas. Most of the deep waters in the Salina Basin are saline (Johnson and Gonzales, 1978), but little is known of their flow characteristics.

The Michigan and Appalachian Basins are in areas of tectonic stability.

Many wells have been drilled for hydrocarbons throughout the basin, and there is some potential for oil and gas exploration and development in horizons beneath the salt.

Studies in this region are at an early stage. Several broad areas in Ohio and New York have been identified for additional study (DOE, 1980, p. 45) but no work is underway at this time.

VI. Summary

The USGS is confident that solid high-level radioactive waste can be disposed of by burial in mined repositories with very low risk to the environment after completion of a program of research and exploration that is substantially broadened over that which was in place in 1978 when the IRG review took place. Substantially increased knowledge is needed for the disposal of spent fuel as the waste form. Prediction of the time when mined geologic disposal facilities will be available will be imprecise and premature until many of the key issues identified in this Statement have been addressed.

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APPENDIX A

GEOLOGICAL SURVEY PARTICIPATION IN THE NATIONAL RADIOACTIVE WASTE DISPOSAL PROGRAM

I. Introduction

The United States Geological Survey has an obligation and responsibility by virtue of its extensive expertise as the principal earth-science agency in the Federal Government to participate in the National Radioactive Waste Management Program. It is especially important that Survey work in this program be consistent with its long-standing policies aimed at insuring scientific objectivity and impartiality.

II. Earth-science support to the Department of the Interior, other Federal agencies, and the States

A. The Geological Survey will provide geologic, hydrologic, mineral resource, and any other data and judgements within its scientific capability to the Department of the Interior as necessary for Secretarial decisions.

B. The Geological Survey, subject to mutual Memorandum of Understanding developed within the policy guidelines given below, will assist any other Federal agency or State within the constraints of available funds and personnel.

C. In addition to its traditional role of performing directly supported research on critical technical topics and informing both scientific and decisionmaking groups of the implications of research results, the Geological Survey will contribute to the development of national policy on radioactive waste management by:

1) contributing to defining national program needs through increased consultation to and cooperation with the lead agency (DOE) and the regulatory agencies and all other affected agencies and interagency groups.

2) participating in periodic comprehensive and critical assessments of the status of earth-science technology for managing high-level and transuranic wastes, low-level wastes, mill tailings, and other waste forms.

III. Identification of hydrogeologic environments[1/] for repositories

Given appropriate formal earth-science criteria (or working from broad guidelines as in V), the Geological Survey will identify or help to identify hydrogeologic environments that meet such criteria and suggest potential regions within those environments for further study by DOE. It may identify favorable and unfavorable aspects of these potential regions for disposal of various types of radioactive wastes.

1/ A "hydrogeologic environment" could comprise on the order 10^4 square miles, a "region" on the order of 103 square miles, and a "site" a few tens of square miles.

IV. Policy with regard to specific sites

A. The Geological Survey will assist in site evaluation by providing specific expertise, by assessing the adequacy of earth-science information and the appropriateness of conclusions concerning specific scientific and technical questions within its areas of earth-science expertise that relate to the future performance of a repository site to contain radionuclides.

B. The Geological Survey will provide data needed for the site selection process but should not be engaged directly in the selection of a repository site nor be engaged in site evaluation in ways that would imply endorsement or "proving-up" of a site.

C. If called upon to assist with independent judgments, as, for example, at the stage of evaluating a license application, the Survey will design and conduct specific investigations for the purpose of assessing the quality of existing information and studies of others and of providing impartial assistance to the regulatory process.

D. The Geological Survey should participate in the design of any investigative program in which the USGS is to have a major investigative role.

V. Criteria for site selection

The Geological Survey will provide its earth-science advice, if requested, to other agencies or institutions on the suitability or practicality of site selection criteria developed by them. For purposes of identifying hydrologic and geologic environments suitable for repositories as discussed under III, the Geological Survey will follow interim guidelines, developed internally or provided by others, but these shall be clearly identified as such and made broad enough to encompass any likely future formal criteria that may be developed.