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TRIP REPORT

REVIEW OF DOE NATIONAL LABORATORIES' GEOCHEMICAL RESEARCH PROGRAMS IN HIGH-LEVEL WASTE MANAGEMENT AUGUST/SEPTEMBER 1981

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1.0 Summary and Conclusion

As a follow-up to an NRC staff review of DOE/National Laboratory geochemical programs conducted in June 1980 (trip report - Robbins and others, September 1980), the NRC staff reviewed DOE's geochemical efforts during August/September 1981. This review consisted of one-day visits to nine laboratories where geochemical research is conducted for the DOE high-level radioactive waste disposal program.

We observed that DOE and its laboratories have made progress in dealing with some of the points raised in the 1980 review. Specifically, we feel that now there is agreement on the general geochemical issues. Little progress has been made, however, in directing effort toward getting agreement on what constitutes an adequate program, to include: (1) what are the geochemical issues dealing with the licensing of a particular site, (2) what is the level of effort necessary to adequately characterize the geochemistry of a site and effective timing of this effort, and (3) what is an adequate system for comparison of results, test methods, procedures and strategies among laboratories.

The dialogue and peer review that was encouraged by the annual WRIT program review has been eliminated. However, we observed that the effort

of individual researchers responding to specific technical concerns about tests and test methods being employed and their applicability to field conditions, such as those raised in 1980 by NRC, has resulted in a greater consistency in the way investigations are being conducted among laboratories. Nevertheless, there is no formal program directed toward documenting standardized procedures (when they become well developed) and/or testing-strategies which are to be followed throughout the program, and establishing their relevance to actual field conditions.

Without general agreement on these points, ongoing and future research may not produce results which are useful or reliable. More importantly, little credit may be given to the geochemical retardation of a site for purposes of licensing without a consensus among authorities on the issues described above. In addition, the process of establishing agreement and of building consensus on what constitutes an acceptable HLW geochemistry program is important because it will inevitably involve establishing what are the specific areas requiring research and involve establishing their priority in light of program needs, and the limited resources and time available.

The following observations were also made:

1. Increased emphasis must be given to collecting data on the solubility of radionuclide species anticipated at each site.

Work to develop information on radionuclide transport and retardation is ineffective without the benefit of basic radionuclide solubility data. To date, little systematic attention has been given to solubility research or the collection of solubility data. Emphasis should be given to the collection of actinide solubility data because little is known about aqueous speciation of actinides under conditions expected in typical or site specific groundwaters.

2. Communication among researchers and performance assessment modelers concerning the establishment of what is necessary, sufficient and practical to do to incorporate geochemistry into numerical performance assessment models, needs to be increased. For example, geochemists no longer give credit to Kd values although modelers continue to use these data. It is clear from the geochemical research performed thus far, that indiscriminant use of an empirical "Kd" (without taking into account a solubility and/or speciation function along with the several important and site specific parameters which control the extent to which these functions vary, viz: pH, Eh and temperature, etc.) will lead to unrealistic and unsupportable assessments. In addition, it is important for geochemists and modelers to determine through preliminary performance assessment the levels of precision and

accuracy that can be tolerated in individual geochemical parameters. The development of this consensus will help focus the geochemistry research program. Finally, performance assessment models should better reflect the significance of the uncertainties inherent in the determination of geochemical retardation. Coordination between these groups is essential to prioritize and to fully utilize the data.

3. The range of oxidation potential (Eh) representative of the ambient and estimated repository environment needs to be factored into sorption and solubility experiments. This important variable has not been routinely considered. The fundamental problem is that techniques for the measurement and/or control of Eh are still unreliable. Therefore, increased efforts need to be made to improve Eh measurement and control techniques.

4. The complexity and variability of the conditions which affect geochemical processes must be bounded, otherwise the amount of geochemical research needed in support of the HLW program will be enormous. Therefore, for site characterization, emphasis should be given to research and investigations that involve site-specific media (waste package/backfill/rock/groundwaters) under the

range of conditions found at specific sites, especially, ground-water pH, Eh, composition, ionic strength and rate of flow. However, basic research must also be done to provide generic information such as the thermodynamic constants for actinide speciation. If an adequate understanding of the fundamental chemistry is developed, the need for empirical data will be reduced.

5. Increased emphasis should be given to performing experiments over a range of temperatures that bound those which will occur over the long-term in a repository. To date, insufficient attention has been given to the effects of temperature on geochemical processes. Most testing has been done under ambient conditions. The geochemical behavior of a waste-package, backfill, groundwater and surrounding host rock may alter significantly as temperature rises in the repository.

6. Emphasis should be given to forming a connection between the natural occurances of radionuclide migration being studied (natural analogues), site specific repository conditions and laboratory experiments. This connection is necessary in order to establish a basis for extrapolating with confidence the results of laboratory analyses and short-term field

experiments to the assessment of the performance of a repository over long time periods. Further, such connection would ensure that mathematical modelling is more than a paper exercise.

Many of the above points were raised in the 1980 review. And, while the staff observed that increased attention has been given to them and that, generally speaking, progress is being made in the understanding and measurement of radionuclide migration and retardation processes, we consider that further attention to these points is needed.

2.0 Introduction and Background

2.1 The 1980 Geochemistry Trip

Dûring June 1980, NRC staff visited the United States Geological Survey (USGS), Argonne National Laboratory (ANL), Oak Ridge National Laboratory (ORNL), Los Alamos National Laboratory (LANL), Lawrence Berkeley National Laboratory (LBNL), and Pacific Northwest Laboratory (PNL). The purposes of this trip were to: (1) review DOE HLW geochemical research and obtain technical input helpful to the NRC for regulatory guidance on characterizing properties of geochemical retardation; (2) assess the state-of-the-art of HLW geochemical retardation research; (3) observe both the facilities and experimental procedures being used at the various laboratories; and (4) obtain insights into geochemical retardation research that would help to formulate NRC confirmatory research and technical support (Robbins and others, 1980).

At the conclusion of the 1980 review NRC encouraged DOE to achieve general agreement among the scientific community on: (1) what constitutes a sufficient program to characterize the retardation properties of a site; (2) proper experimental procedures for geochemical HLW research; (3) the use of laboratory data in support of field

estimates of retardation and vice versa; and (4) the levels of accuracy and confidence required in order for the geochemistry to be of use in site specific assessment of radionuclide migration. Also it was an NRC position that without general agreement on at least these issues, ongoing and future research may not produce results which would be useful. And, more importantly, little credit might be given to the geochemical retardation properties of a site during licensing without such a consensus (Robbins and others, 1980).

2.2 The 1981 Geochemistry Trip

In 1981 the NRC staff repeated and expanded its review of DOE's geochemical effort. During the week of 24 August 1981, NRC representatives made one-day visits to (1) the Oak Ridge National Laboratory (ORNL), (2) the Argonne National Laboratory (ANL) and (3) the Office of Nuclear Waste Isolation (ONWI). During the period from the 14th to the 19th of September, NRC representatives made one-day visits to the (4) Sandia National Laboratory (SNL), (5) Los Alamos National Laboratory (LANL), (6) the University of New Mexico (UNM), (7) Lawrence Livermore National Laboratory (LLNL), (8) Lawrence Berkeley National Laboratory (LBNL), and (9) the Pacific Northwest Laboratory (PNL).

The primary purposes of the 1981 review were to (1) follow-up on the 1980 review and assess progress made in addressing concerns such as those made in the 1980 trip report, (2) obtain technical input for regulatory guidance, (3) obtain insights that would help formulate NRC research and technical support, (4) maintain an overview of the DOE geochemical efforts being coordinated by ONWI for HLW repository siting, so that we can identify problem areas early that could disrupt the licensing process, (5) discuss with researchers geochemical research dealing with, and/or transferable to the problem of HLW repository siting, and (6) discuss the parts of 10 CFR 60 that relate to geochemistry.

In preparation for the 1981 trip, general areas of geochemical research important to HLW isolation were organized for discussion at each laboratory. The following general categories were identified as critical areas of geochemical research: (1) defining the expected working ranges (or the bounds) that can be placed on the geochemical variables required for performance assessment of a geologic repository; (2) radionuclide transport/retardation; (3) geochemical engineering of the waste form, backfills, plugs, and seals and the interaction of these components between each other and the rock environment; (4) performance assessment modeling; and (5) quality assurance. A package of discussion material was organized and distributed at each meeting (Appendicies A, B, and C). This material was used to focus discussion on important aspects of the geochemistry issues of high-level waste disposal.

3.0 Observations of the DOE Geochemistry Program (1981)

3.1 General

It appears that DOE is continuing to work toward a multibarrier high-level radioactive-waste deep-mined geologic repository consisting of (1) a waste package, (2) the repository structure, and (3) the site. The DOE geochemical research program for siting a high level waste repository is currently involved with studies that consider the geochemistry of each of the components of the multibarrier system, the geochemical interaction among these components, and the geochemistry of the system as a whole. The general areas of research involve (1) defining the expected working ranges (or the bounds) that can be placed on the geochemical variables required for performance assessment, (2) geochemical retardation, (3) chemical engineering of waste package, backfill and seals, and (4) modeling. A discussion of specific observations made at each laboratory visited is contained in Appendix D.

In the area of waste package research most of the experimental laboratory and field studies have been done on glass. Currently, while glass waste-form research dominates, crystalline materials are also under study. Backfill studies are concentrating on bentonite and bentonite - quartz mixtures.

Research concerning the migration of radionuclides has been and is still concentrating on the process of sorption as a function of rock or mineral type. Work on determining whether solution species are simple or complex ions, and on measuring the solubility of radionuclide species and precipitation of insoluble species are just beginning to receive attention. Further, while it appears that the analytical sensitivity of present techniques is (in most instances) sufficient to determine the chemistry of solid phases, these techniques are not always adequate for identifying the types of species of some of the radioisotopes that have a very low solubility in groundwater. Therefore, much of the solution chemistry work that is going on is involved with developing the measurement techniques as well as the required data.

Finally, performance assessment modelers are beginning to consider solubility and/or speciation and move away from the use of the unreliable empirical sorption (Kd) factors in their geochemical performance assessment codes.

Overall, much of this current work is responsive to some of the concerns and comments expressed in the 1980 trip report. For example radionuclide migration/retardation is now being viewed as a function of dissolution, precipitation and sorption/desorption. In addition, efforts are being made to bound the important parameters. This includes selecting nuclides which require investigation, detailing the chemistry and

interactions of important species of those radionuclides under site-specific conditions.

However, these investigations ought to be part of a systematically documented program plan for geochemistry. Unified plans need to be established for comparison of laboratory procedures and a rigorous interlaboratory comparison of research methods and results needs to be implemented. ONWI (Hubbard and Moody) presented preliminary plans which addressed many of the needs that we identified and could serve as the basis for a formal documented program plan.

3.2 Specific

(1) There is a need to greatly increase the collection effort of radionuclide solubility data (especially within the actinide series) on site-specific species. These solubility data are crucial to establishing reproducible sorption data. Further, it is possible that the low solubility of some radionuclide species may significantly limit radionuclide mobility and potential dose to man. For example, if the solubility limit of a radionuclide species is such that transport of the species would be below the EPA radionuclide release limit, then no additional retardation mechanism would need to be present and, alternatively, the presence of "sorption" would be a conservatism.

(2) Geochemists and performance assessment modelers must work out a strategy that benefits their mutual needs for characterizing radionuclide retardation. The geochemical retardation portion of transport models should be based on chemical speciation, reproducible solubility data, sorption isotherm data and the retardation contribution of irreversible reactions because these data are much more reproducible than empirical Kds and credit can be given to these retardation components. For example the Rockwell-Hanford Operation is modeling radionuclide transport by integrating solute concentration, an apparent diffusion coefficient, an average pore water velocity, distance, time, bulk density, effective porosity, amount of solute sorbed and a radioactive decay constant into a radionuclide transport algorithm. Since each component of this alogrithm involves uncertainty in both precision and accuracy an algorithm (or subroutine) should routinely accumulate and indicate the total uncertainty involved in geochemical retardation.

(3) More work has to be done to characterize the site-specific Eh environment and to run experiments under site-specific Eh conditions. Current Eh field measurement techniques are inadequate for repository investigations because the sensing electrode may respond preferably to certain aqueous species and electrode may not provide a representative measurement. Therefore, in addition to electrode measurement of Eh, ion couples should be used to define the range of Eh in site specific natural systems, for example CH_4-CO_2, NH_4^+-NO_3^-, Fe^{2+}-Fe^{3+} and Mn^{2+}-Mn^{4+}.

(4) The amount of geochemical research that could be done in support of high-level radioactive waste isolation is enormous. However, the geochemical research that needs to be done can become more tractable if future research and experiments such as those on sorption and solubility were conducted within expected site-specific ranges of physicochemical conditions. For example, sorption studies should be conducted under reducing conditions on well characterized representative site-specific substrates, and under anticipated repository temperature and pressure ranges.

(5) Further, there appears to be some concern about the stability of glass waste forms at temperatures above 100°C. In addition, the significance of instability of glass waste forms in the presence of gamma radiation needs to be assessed. Some recent research shows that radiation damage to glass waste forms, such as that caused by the Dran Effect, may lead to premature breakdown of glass in a brine. For example, in waste/glass/water systems, glass leaching is more complex than represented in the literature in that dissolution of the glass waste-form is apparently enhanced in the presence of gamma radiation. The significance of these data for the design of the waste package and the considerations of thermal-loads should be evaluated.

(6) Increased emphasis should be put on understanding site-specific hydrothermal and metamorphic alterations of minerals and amorphous materials. This is important for evaluating changing repository properties that could affect radionuclide migration. However, it is considered that some of this information is available in the literature and much of it could be compiled by the Offices of Basic Energy Sciences (OBES) in the DOE Office of Energy Research (DOE activities at Los Alamos National Laboratory).

(7) Reporting sorption data in terms of "sorption per unit mass" ignores the availability of the sorption sites of a particle or surface. Therefore, sorption measurements should be routinely presented in terms of both "unit mass" and "surface area". Without an understanding of both the mechanisms of sorption and their relationship to surfaces of minerals and mineral aggregates, sorption cannot be defined in terms of measurable host rock properties. Therefore, there will be no clear relationship between laboratory sorption studies and field conditions.

(8) Greater emphasis should be placed on understanding the causes and effects of naturally occuring processes that are relevant to assessing long-term repository and waste package performance. There is little evidence that knowledge gained from studies of natural analogues of repository systems or components has been utilized by workers in the laboratories, in the field or in modeling. There are uncertainties involved in the transferability of information derived from the study of ancient or existing natural occurences to the assessment of future geochemical changes in a repository. The natural systems are more complex than can be duplicated and controlled in the laboratory, they have developed on a larger scale and over vastly longer time periods than can be sustained in a laboratory. Understanding

natural analogues may enable us to extrapolate in time and in space the data and concepts derived from short-term lab-scale simplified experiments and models with greater confidence than we could have otherwise.

(9) The acceptance of geochemical retardation arguments relies on demonstrated accuracy and reproducibility of geochemical data. As the chemistry of radionuclide retardation becomes better understood, the complexity of the experiments increases. Given the requirement for geochemical data of high quality, there is a growing need for interlaboratory comparisons of research results in order to demonstrate reproducibility of the geochemical results. In addition, research results should be widely circulated in order to increase peer review.

(10) Colloid and/or particulate transport might be a significant means of radionuclide migration in groundwater in some environments. However, it is generally considered by many of the researchers visited that particulates are not present in significant amounts in the deep groundwaters being considered and that both particulates and colloids may be filtered out as they proceed through the near-field rock environment. Still, there is a lack of data to verify this, and eventually site-specific tests will be required.

APPENDICES

A

APPENDIX A

HANDOUT

Proposed Technical Criteria, 10 CFR Part 60,
Geochemical Parts Highlighted

Subpart E—Technical Criteria

§ 60.101 Purpose and nature of findings.

(a)(1) Subpart B of this part prescribes the standards for issuance of a license to receive and possess source, special nuclear, or byproduct material at a geologic repository operations area. In particular, § 60.41(c) requires a finding that the issuance of a license will not constitute an unreasonable risk to the health and safety of the public. The purpose of this subpart is to set out performance objectives and site and design criteria which, if satisfied, will support such a finding of no unreasonable risk.

(2) While these performance objectives and criteria are generally stated in unqualified terms, it is not expected that complete assurance that they will be met can be presented. A reasonable assurance, on the basis of the record before the Commission, that the objectives and criteria will be met is the general standard that is required. For § 60.111, and other portions of this subpart that impose objectives and criteria for repository performance over long times into the future, there will inevitably be greater uncertainties. Proof of the future performance of engineered systems and geologic media over time periods of a thousand or many thousands of years is not to be had in the ordinary sense of the word. For such long-term objectives and criteria, what is required is reasonable assurance, making allowance for the time period and hazards involved, that the outcome will be in conformance with those objectives and criteria.

(b) Subpart B of this part also lists findings that must be made in support of an authorization to construct a geologic repository operations area. In particular, § 60.31(a) requires a finding that there is reasonable assurance that the types and amounts of radioactive materials described in the application can be received, possessed, and disposed of in a repository of the design proposed without unreasonable risk to the health and safety of the public. As stated in that paragraph, in arriving at this determination, the Commission will consider whether the site and design comply with the criteria contained in this subpart. Once again, while the criteria may be written in unqualified terms, the demonstration of compliance may take uncertainties and gaps in knowledge into account, provided that the Commission can make the specified finding of reasonable assurance as specified in paragraph (a) of this section.

§ 60.102 Concepts.

(a) *The HLW facility.* NRC exercises licensing and related regulatory authority over those facilities described in section 203 (3) and (4) of the Energy Reorganization Act of 1974. Any of these facilities is designated an *HLW facility.*

(b) *The geologic repository operations area.*

(1) This part deals with the exercise of authority with respect to a particular class of HLW facility—namely a *geologic repository operations area.*

(2) A *geologic repository operations area* consists of those surface and subsurface areas that are part of a geologic repository where radioactive waste handling activities are conducted. The underground structure, including openings and backfill materials, but excluding shafts, boreholes, and their seals, is designated the *underground facility.*

(3) The exercise of Commission authority requires that the geologic repository operations area be used for *storage* (which includes *disposal*) of *high-level radioactive wastes (HLW).*

(4) HLW includes irradiated reactor fuel as well as reprocessing wastes. However, if DOE proposes to use the geologic repository operations area for storage of *radioactive waste* other than HLW, the storage of this radioactive waste is subject to the requirements of this part. Thus, the storage of *transuranic-contaminated waste (TRU),* though not itself a form of HLW, must conform to the requirements of this part if it is stored in a geologic repository operations area.

(c) *Areas adjacent to the geologic repository operations area.* Although the activities subject to regulation under this part are those to be carried out at the geologic repository operations area, the licensing process also considers characteristics of adjacent areas. First, there is to be an area within which DOE is to exercise specified controls to prevent adverse human actions. Second, there is a larger area, designated the *geologic setting* or *site* which includes the spatially distributed geologic, hydrologic, and geochemical systems that provide isolation of the radioactive waste from the accessible environment. The geologic repository operations area plus the geologic setting make up the *geologic repository.* Within the geologic setting, particular attention must be given to the characteristics of the host rock as well as any rock units surrounding the host rock.

(d) *Stages in the licensing process.* There are several stages in the licensing process. The *site characterization* stage, though begun before submission of a license application, may result in consequences requiring evaluation in the license review. The *construction stage* would follow, after issuance of a construction authorization. A *period of operations* follows the issuance of a license by the Commission. The period of operations includes the time during which *emplacement* of wastes occurs; and any subsequent period before permanent closure during which the emplaced wastes are *retrievable;* and *permanent closure,* which includes final backfilling of subsurface facilities, sealing of shafts, decontaminating and dismantling of surface facilities. Permanent closure represents the end of active human activities with the geologic repository operations area and engineered systems.

(e) *Containment.* Early during the repository life, when radiation and thermal levels are high and the consequences of events are especially difficult to predict rigorously, special emphasis is placed upon the ability to contain the wastes by waste packages within an engineered system. This is known as the *containment period.* The *engineered system* includes the waste packages as well as the underground facility. A *waste package* includes:

(1) The *waste form* which consists of the radioactive waste materials and any associated encapsulating or stabilizing materials.

(2) The *container* which is the first major sealed enclosure that holds the waste form.

(3) *Overpacks* which consist of any buffer material, receptable, wrapper, box or other structure, that is both within and an integral part of a waste package. It encloses and protects the waste form so as to meet the performance objectives.

(f) *Isolation.* Following the containment period special emphasis is placed upon the ability to achieve isolation of the wastes by virtue of the characteristics of the geologic repository. *Isolation* means the act of inhibiting the transport of radioactive material to the accessible environment in amounts and concentrations within limits. The *accessible environment* means those portions of the environment directly in contact with or readily available for use by human beings.

Performance Objectives

§ 60.111 Performance objectives.

(a) *Performance of the geologic repository operations area through permanent closure.*—(1) *Protection against radiation exposures and releases of radioactive material.* The geologic repository operations area shall be designed so that until permanent closure has been completed, radiation exposures and radiation levels, and releases of radioactive materials to unrestricted areas, will at all times be maintained within the limits specified in Part 20 of this chapter and any generally applicable environmental standards established by the Environmental Protection Agency.

(2) *Retrievability of waste.* The geologic repository operations area shall be designed so that the entire inventory of waste could be retrieved on a reasonable schedule, starting at any time up to 50 years after waste emplacement operations are complete. A reasonable schedule for retrieval is one that requires no longer than about the same overall period of time than was devoted to the construction of the geologic repository operations area and the emplacement of wastes.

(b) *Performance of the geologic repository after permanent closure.*—(1) *Overall system performance.* The geologic setting shall be selected and the subsurface facility designed so as to assure that releases of radioactive materials from the geologic repository following permanent closure conform to such generally applicable environmental radiation protection standards as may have been established by the Environmental Protection Agency.

(2) *Performance of the engineered system.*—(i) *Containment of wastes.*[2] The engineered system shall be designed so that even if full or partial saturation of the underground facility were to occur, and assuming anticipated processes and events, the waste packages will contain all radionuclides for at least the first 1,000 years after permanent closure. This requirement does not apply to TRU waste unless TRU waste is emplaced close enough to HLW that the TRU release rate can be significantly affected by the heat generated by the HLW.

(ii) *Control of releases.*[3]

(A) For HLW, the engineered system shall be designed so that, after the first 1,000 years following permanent closure, the annual release rate of any radionuclide from the engineered system into the geologic setting, assuming anticipated processes and events, is at most one part in 100,000 of the maximum amount of that radionuclide calculated to be present in the underground facility (assuming no release from the underground facility) at any time after 1,000 years following permanent closure. This requirement does not apply to radionuclides whose contribution is less than 0.1% of the total annual curie release as prescribed by this paragraph.

(B) For TRU waste, the engineered system shall be designed so that following permanent closure the annual release rate of any radionuclide from the underground facility into the geologic setting, assuming anticipated processes and events, is at most one part in 100,000 of the maximum amount calculated to be present in the underground facility (assuming no release from the underground facility) at any time following permanent closure. This requirement does not apply to radionuclides whose contribution is less than 0.1% of the annual curie release as prescribed by this paragraph.

(3) *Performance of the geologic setting.*—(i) *Containment period.* During the containment period, the geologic setting shall mitigate the impacts of premature failure of the engineered system. The ability of the geologic setting to isolate wastes during the isolation period, in accordance with paragraph (b)(3)(ii) of this section, shall be deemed to satisfy this requirement.

(ii) *Isolation period.* Following the containment period, the geologic setting, in conjunction with the engineered system as long as that system is expected to function, and alone thereafter, shall be capable of isolating radioactive waste so that transport of radionuclides to the accessible environment shall be in amounts and concentrations that conform to such generally applicable environmental standards as may have been established by the Environmental Protection Agency. For the purpose of this paragraph, the evaluation of the site shall be based upon the assumption that those processes operating on the site are those which have been operating on it during the Quaternary Period, with perturbations caused by the presence of emplaced radioactive wastes superimposed thereon.

§ 60.112 Required characteristics of the geologic setting.

(a) The geologic setting shall have exhibited structural and tectonic stability since the start of the Quaternary Period.

(b) The geologic setting shall have exhibited hydrogeologic, geo-chemical, and geomorphic stability since the start of the Quaternary Period.

(c) The geologic repository shall be located so that pre-waste emplacement groundwater travel times through the far field to the accessible environment are at least 1,000 years.

Ownership and Control of the Geolocghic Repository Operations Area

§ 60.121 Requirements for ownership and control of the geologic repository operations area.

(a) *Ownership of the geologic repository operations area.* The geologic repository operations area shall be located in and on lands that are either acquired lands under the jurisdiction and control of DOE, or lands permanently withdrawn and reserved for its use. These lands shall be held free and clear of all encumbrances, if

[2] The Commission specifically seeks comment on whether an ALARA principle should be applied to the performance requirements dealing with containment and control of releases. In particular, the Commission has considered whether the technical criteria should explicitly require containment to be for "as long as is reasonably achievable" and the release rate to be "as low as is reasonably achievable." Comments should address the merits of such a requirement, how to best frame it, and the practicality of its implementation.

significant, such as: (1) rights arising under the general mining laws; (2) easements for right-of-way; and (3) all other rights arising under lease, rights of entry, deed, patent, mortgage, appropriation, prescription, or otherwise.

(b) *Establishment of controls.* Appropriate controls shall be established outside of the geologic repository operations area. DOE shall exercise any jurisdiction and control over surface and subsurface estates necessary to prevent adverse human actions that could significantly reduce the site or engineered system's ability to achieve isolation. The rights of DOE may take the form of appropriate possessory interests, servitudes, or withdrawals from location or patent under the general mining laws.

Additional Requirements for the Geologic Setting

§ 60.122 Favorable conditions.

Each of the following conditions may contribute to the ability of the geologic setting to meet the performance objectives relating to isolation of the waste. In addition to meeting the mandatory requirements of § 60.112, a geologic setting shall exhibit an appropriate combination of these conditions so that, together with the engieered system, the favorable conditions present are sufficient to provide reasonable assurance that such performance objectives will be met.

(a) The nature and rates of tectonic processes that have occurred since the start of the Quaternary Period are such that, when projected, they would not affect or would favorably affect the ability of the geologic repository to isolate the waste.

(b) The nature and rates of structural processes that have occurred since the start of the Quaternary Period are such that, when projected, they would not affect or would favorably affect the ability of the geologic repository to isolate the waste.

(c) The nature and rates of hydrogeological processes that have occurred since the start of the Quaternary Period are such that, when projected, they would not affect or would favorably affect the ability of the geologic repository to isolate the waste.

(d) The nature and rates of geochemical processes that have occurred since the start of the Quaternary Period are such that when projected, they would not affect or would favorably affect the ability of the geologic repository to isolate the waste.

(e) The nature and rates of geomorphic processes that have occurred since the start of the Quaternary period are such that, when projected they would not affect or would favorably affect the ability of the geologic repository to isolate the waste.

(f) A host rock that provides the following groundwater characteristics—(1) low groundwater content; (2) inhibition of groundwater circulation in the host rock; (3) inhibition of groundwater flow between hydrogeologic units or along shafts, drifts, and boreholes; and (4) groundwater travel times, under pre-waste emplacement conditions, between the underground facility and the accessible environment that substantially exceed 1,000 years.

(g) Geochemical conditions that (1) promote precipitation or sorption or radionuclides; (2) inhibit the formation of particulates, colloids, and inorganic and organic complexes that increase the mobility of radionuclides; and (3) inhibit the transport of radionuclides by particulates, colloids, and complexes.

(h) Mineral assemblages that, when subjected to anticipated thermal loading, will remain unaltered or alter to mineral assemblages having increased capacity to inhibit radionuclide migration.

(i) Conditions that permit the emplacement of waste at a minimum depth of 300 meters from the ground surface. (The ground surface shall be deemed to be the elevation of the lowest point on the surface above the disturbed zone.)

(j) Any local condition of the disturbed zone that contributes to isolation.

§ 60.123 Potentially adverse conditions.

The following are potentially adverse conditions. The presence of any such conditions may compromise site suitability and will require careful analysis and such measures as are necessary to compensate for them adequately pursuant to § 60.124.

(a) *Adverse conditions in the geologic setting.*

(1) Potential for failure of existing or planned man-made surface water impoundments that could cause flooding of the geologic repository operations area.

(2) Potential, based on existing geologic and hydrologic conditions, that planned cnstruction of large-scale surface water impoundments may significantly affect the geologic repository through changes in the regional groundwater flow system.

(3) Potential for human activity to affect significantly the geologic repository through changes in the hydrogeology. This activity includes, but is not limited to planned groundwater withdrawal, extensive irrigation, subsurface injection of fluids, underground pumped storage facilities, or underground military activity.

(4) Earthquakes which have occurred historically that if they were to be repeated could affect the geologic repository significantly.

(5) A fault in the geologic setting that has been active since the start of the Quaternary Period and which is within a distance of the disturbed zone that is less than the smallest dimension of the fault rupture surface.

(6) Potential for adverse impacts on the geologic repositroy resulting from the occupancy and modification of floodplains.

(7) Potential for natural phenomena such as landslides, subsidence, or volcanic activity of such a magnitude that large-scale surface water impoundments could be created that could affect the performance of the geologic repository through changes in the regional groundwater flow.

(8) Expected climatic changes that would have an adverse effect on the geologic, geochemical, or hydrologic characteristics.

(b) *Adverse conditions in the disturbed zone.* For the purpose of determining the presence of the following conditions within the distrubed zone, investigations should extend to the greater of either its calculated extent or a horizontal distance of 2 km from the limits of the underground facility, and from the surface to a depth of 500 meters below the limits of the repository excavation.

(1) Evidence of subsurface mining for resources.

(2) Evidence of drilling for any purpose.

(3) Resources that have either greater gross value, net value, or commercial potential than the average for other representative areas of similar size that are representative of and located in the geologic setting.

(4) Evidence of extreme erosion during the Quaternary Period.

(5) Evidence of dissolutioning of soluble rocks.

(6) The existence of a fault that has been active during the Quaternary Period.

(7) Potential for creating new pathways for radionuclide migration due to presence of a fault or fracture zone irrespective of the age of last movement.

(8) Structural deformation such as uplift, subsidence, folding, and fracturing during the Quaternary Period.

(9) More frequent occurrence of earthquakes or earthquakes of higher

magnitude than is typical of the area in which the geologic setting is located.

(10) Indications, based on correlations of earthquakes with tectonic processes and features, that either the frequency of occurrence or magnitude of earthquakes may increase.

(11) Evidence of igneous activity since the start of the Quaternary Period.

(12) Potential for changes in hydrologic conditions that would significantly affect the migration of radionuclides to the accessible environment including but not limited to changes in hydraulic gradient, average interstitial velocity, storage coefficient, hydraulic conductivity, natural recharge, potentiometric levels, and discharge points.

(13) Conditions in the host rock that are not reducing conditions.

(14) Groundwater conditions in the host rock, including but not limited to high ionic strength or ranges of Eh-pH, that could affect the solubility and chemical reactivity of the engineered systems.

(15) Processes that would reduce sorption, result in degradation of the rock strength, or adversely affect the performance of the engineered system.

(16) Rock or groundwater conditions that would require complex engineering measures in the design and construction of the underground facility or in the sealing of boreholes and shafts.

(17) Geomechanical properties that do not permit deisign of stable underground openings during construction, waste emplacement, or retrieval operations.

§ 60.124 Assessment of potentially adverse conditions.

In order to show that a potentially adverse condition or combination of conditions cited in § 60.123 does not impair significantly the ability of the geologic repository to isolate the radioactive waste, the following must be demonstrated:

(a) The potentially adverse human activity or natural condition has been adequately characterized, including the extent to which the condition may be present and still be undetected taking into account the degree of resolution achieved by the investigations; and

(b) The effect of the potentially adverse human activity or natural condition on the geologic setting has been adequately evaluated using conservative analyses and assumptions, and the evaluation used is sensitive to the adverse human activity or natural condition; and

(c)(1) The potentially adverse human activity or natural condition is shown by analysis in paragraph (b) of this section not to affect significantly the ability of the geologic setting to isolate waste, or

(2) The effect of the potentially adverse human activity or natural condition is compensated by the presence of a combination of the favorable characteristics cited in § 60.122, or

(3) The potentially adverse human activity or natural condition can be remedied.

Design and Construction Requirements

§ 60.130 General design requirements for the geologic repository operations area.

(a) Sections 60.130 through 60.134 specify minimum requirements for the design of, and construction specifications for, the geologic repository operations area. Requirements for design contained in §§ 60.131 through 60.133 must be considered in conjunction with the requirements for construction in § 60.134. Sections 60.130 through 60.134 are not intended to contain an exhaustive list of design and construction requirements. Omissions in §§ 60.130 through 60.134 do not relieve DOE from providing safety features in a specific facility needed to achieve the performance objectives contained in § 60.111. All design and construction criteria must be consistent with the results of site characterization activities.

(b) Systems, structures, and components of the geologic repository operations area shall satisfy the following:

(1) *Radiological protection.* The structures, systems, and components located within restricted areas shall be designed to maintain radiation doses, levels, and concentrations of radioactive material in air in those restricted areas within the limits specified in Part 20 of this chapter. These structures, systems, and components shall be designed to include—

(i) Means to limit concentrations of radioactive material in air;

(ii) Means to limit the time required to perform work in the vicinity of radioactive materials, including, as appropriate, designing equipment for ease of repair and replacement and providing adequate space for ease of operation;

(iii) Suitable shielding;

(iv) Means to monitor and control the dispersal of radioactive contamination;

(v) Means to control access to high radiation areas or airborne radioactivity areas; and

(vi) A radiation alarm system to warn of increases in radiation levels, concentrations of radioactive material in air, and of increased radioactivity released in effluents. The alarm system shall be designed with redundancy and in situ testing capability.

(2) *Protection against natural phenomena and environmental conditions.*

(i) The structures, systems, and components important to safety shall be designed to be compatible with anticipated site characteristics and to accommodate the effects of environmental conditions, so as to prevent interference with normal operation, maintainence and testing during the entire period of construction and operations.

(ii) The structures, systems, and components important to safety shall be designed so that natural phenomena and environmental conditions anticipated at the site will not result, in any relevant time period, in failure to achieve the performance objectives.

(3) *Protection against dynamic effects of equipment failure and similar events.* The structures, systems and components important to safety shall be designed to withstand dynamic effects that could result from equipment failure, such as missle impacts, and similar events and conditions that could lead to loss of their safety functions.

(4) *Protection against fires and explosions.*

(i) The structures, systems, and components important to safety shall be designed to perform their safety functions during and after fires or explosions in the geologic repository operations area.

(ii) To the extent practicable, the geologic repository operations area shall be designed to incorporate the use of noncombustible and heat resistant materials.

(iii) The geologic repository operations area shall be designed to include explosion and fire detection alarm systems and appropriate suppression systems with sufficient capacity and capability to reduce the adverse effects of fires and explosions on structures, systems, and components important to safety.

(iv) The geologic repository operations area shall be designed to include means to protect systems, structures, and components important to safety against the adverse effects of either the operation or failure of the fire suppression systems.

(5) *Emergency capability.*

(i) The structures, systems, and components important to safety shall be designed to maintain control of radioactive waste, and permit prompt termination of operations and

evacuation of personnel during an emergency.

(ii) The geologic repository operations area shall be designed to include onsite facilities and services that ensure a safe and timely response to emergency conditions and that facilitate the use of available offsite services (such as fire, police, medical and ambulance service) that may aid in recovery from emergencies.

(6) *Utility services.*

(i) Each utility service system shall be designed so that essential safety functions can be performed under both normal and emergency conditions.

(ii) The utility services important to safety shall include redundant systems to the extent necessary to maintain, with adequate capacity, the ability to perform their safety functions.

(iii) The emergency utility services shall be designed to permit testing of their functional operability and capacity. This will include the full operational sequence of each system when transferring between normal and emergency supply sources, as well as the operation of associated safety systems.

(iv) Provisions shall be made so that, if there is a loss of the primary electric power source or circuit, reliable and continued emergency power is provided to instruments, utility service systems, and operating systems, including alarm systems. This emergency power shall be sufficient to allow safe conditions to be maintained. All systems important to safety shall be designed to permit them to be maintained at all times in a functional mode.

(7) *Inspection, testing, and maintenance.* The structures, systems, and components important to safety shall be designed to permit periodic inspection, testing, and maintenance, as necessary, to ensure their continued functioning and readiness.

(8) *Criticality control.* All systems for processing, transporting, handling, storage, retrieval, emplacement, and isolation of radioactive waste shall be designed to ensure that a nuclear criticality accident is not possible unless at least two unlikely, independent, and concurrent or sequential changes have occurred in the conditions essential to nuclear criticality safety. Each system shall be designed for criticality safety under normal and accident conditions. The calculated effective multiplication factor (k_{eff}) must be sufficiently below unity to show at least a 5% margin, after allowance for the bias in the method of calculation and the uncertainty in the experiments used to validate the method of calculation.

(9) *Instrumentation and control systems.* Instrumentation and control systems shall be designed to monitor and control the behavior of engineered systems important to safety over anticipated ranges for normal operation and for accident conditions. The systems shall be designed with sufficient redundancy to ensure that adequate margins of safety are maintained.

(10) *Compliance with mining regulations.* 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 geologic repository operations area 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. Any deviation from relevant design requirements in 30 CFR, Chapter I, Subchapters D, E, and N will give rise to a rebuttable presumption that this requirement has not been met.

§ 60.131 Additional design requirements for surface facilities in the geologic repository operations area.

(a) *Facilities for receipt and retrieval of waste.* Surface facilities in the geologic repository operations area shall be designed to allow safe handling and storage of wastes at the site, whether these wastes are on the surface before emplacement or as a result of retrieval from the underground facility. The surface facilities shall be designed so as to permit inspection, repair, and decontamination of such wastes and their containers. Surface storage capacity is not required for all emplaced waste.

(b) *Surface facility ventilation.* Surface facility ventilation systems supporting waste transfer, inspection, decontamination, processing, or packaging shall be designed to provide protection against radiation exposures and offsite releases as provided in § 60.111.

(c) *Radiation control and monitoring.*—(1) *Effluent control.* The surface facilities shall be designed to control the release of radioactive materials in effluents during normal and emergency operations. The facilities shall be designed to provide protection against radiation exposures and offsite releases as provided in § 60.111.

(2) *Effluent monitoring.* The effluent monitoring systems shall be designed to measure the amount and concentration of radionuclides in any effluent with sufficient precision to determine whether releases conform to the design requirement for effluent control. The monitoring systems shall be designed to include alarms that can be periodically tested.

(d) *Waste treatment.* Radioactive waste treatment facilities shall be designed to process any radioactive wastes generated at the geologic repository operations area into a form suitable to permit safe disposal at the geologic repository operations area or to permit safe transportation and conversion to a form suitable for disposal at an alternative site in accordance with any regulations that are applicable.

(e) *Consideration of decommissioning.* The surface facility shall be designed to facilitate decommissioning.

§ 60.132 Additional design requirements for the underground facility.

(a) General criteria for the underground facility.

(1) The underground facility shall be designed so as to perform its safety functions assuming interactions among the geologic setting, the underground facility, and the waste package.

(2) The underground facility shall be designed to provide for structural stability, control of groundwater movement and control of radionuclide releases, as necessary to comply with the performance objectives of § 60.111.

(3) The orientation, geometry, layout, and depth of the underground facility, and the design of any engineered barriers that are part of the underground facility shall enhance containment and isolation of radionuclides to the extent practicable at the site.

(4) The underground facility shall be designed so that the effects of disruptive events such as intrusions of gas, or water, or explosions, will not spread through the facility.

(b) *Flexibility of design.* The underground facility shall be designed with sufficient flexibility to allow adjustments, where necessary to accommodate specific site conditions identified through in situ monitoring, testing, or excavation.

(c) *Separation of excavation and waste emplacement (modular concept).* If concurrent excavation and emplacement of wastes are planned, then:

(1) The design shall provide for such separation of activities into discrete areas (modules) as may be necessary to assure that excavation does not impair waste emplacement or retrieval operations.

(2) Each module shall be designed to permit insulation from other modules if an accident occurs.

(d) *Design for retrieval of waste.* The underground facility shall be designed to—

(1) Permit retrieval of waste in accordance with the performance objectives (§ 60.111);

(2) Ensure sufficient structural stability of openings and control of groundwater to permit the safe conduct of waste retrieval operations; and

(3) Allow removal of any waste packages that may be damaged or require inspection without compromising the ability of the geologic repository to meet the performance objectives (§ 60.111).

(e) *Design of subsurface openings.*

(1) Subsurface openings shall be designed to maintain stability throughout the construction and operation periods. If structural support is required for stability, it shall be designed to be compatible with long-term deformation, hydrologic, geochemical, and thermomechanical characteristics of the rock and to allow subsequent placement of backfill.

(2) Structures required for temporary support of zones of weak or highly fractured rock shall be designed so as not to impair the placement of permanent structures or the capability to seal excavated areas used for the containment of wastes.

(3) Subsurface openings shall be designed to reduce the potential for deleterious rock movement or fracturing of overlying or surrounding rock over the long term. The size, shape, orientation, and spacing of openings and the design of engineered support systems shall take the following conditions into considerations—

(i) natural stress conditions;

(ii) deformation characteristics of the host rock under normal conditions and thermal loading;

(iii) The kinds of weaknesses or structural discontinuities found at various locations in the geologic repository;

(iv) Equipment requirements; and

(v) The ability to construct the underground facility as designed so that stability of the rock is enhanced.

(f) *Rock excavation.* The design of the underground facility shall incorporate excavation methods that will limit damage to and fracturing of rock.

(g) *Control of water and gas.*

(1) Water and gas control systems shall be designed to be of sufficient capability and capacity to reduce the potentially adverse effects of groundwater intrusion, service water intrusion, or gas inflow into the underground facility.

(2) Water and gas control systems shall be designed to control the quantity of water or gas flowing into or from the underground facility, monitor the composition of gases, and permit sampling of liquids.

(3) Systems shall be designed to provide control of water and gas in both waste emplacement areas and excavation areas.

(4) Water control systems shall be designed to include storage capability and modular layouts that ensure that unexpected inrush or flooding can be controlled and contained.

(5) If the intersection of aquifers or water-bearing geologic structures is anticipated during construction, the design of the underground facility shall include plans for cutoff or control of water in advance of the excavation.

(6) If linings are required, the contact between the lining and the rock surrounding subsurface excavations shall be designed so as to avoid the creation of any preferential pathway for groundwater or radionuclide migration.

(h) *Subsurface ventilation.* The ventilation system shall be designed to—

(1) Control the transport of radioactive particulates and gases within and releases from the subsurface facility in accordance with the performance objectives (§ 60.111);

(2) Permit continuous occupancy of all excavated areas during normal operations through the time of permanent closure;

(3) Accommodate changes in operating conditions such as variations in temperature and humidity in the underground facility;

(4) Include redundant equipment and fail safe control systems as may be needed to assure continued function under normal and emergency conditions; and

(5) Separate the ventilation of excavation and waste emplacement areas.

(i) *Engineered barriers.*

(1) Barriers shall be located where shafts could allow access for groundwater to enter or leave the underground facility.

(2) Barriers shall create a waste package environment which favorably controls chemical reactions affecting the performance of the waste package.

(3) Backfill placed in the underground facility shall be designed as a barrier.

(i) Backfill placed in the underground facility shall perform its functions assuming anticipated changes in the geologic setting.

(ii) Backfill placed in the underground facility shall serve the following functions:

(A) It shall provide a barrier to groundwater movement into and from the underground facility.

(B) It shall reduce creep deformation of the host rock that may adversely affect (*1*) waste package performance or (*2*) the local hydrological system.

(C) It shall reduce and control groundwater movement within the underground facility.

(D) It shall retard radionuclide migration.

(iii) Backfill placed in the underground facility shall be selected to allow for adequate placement and compaction in underground openings.

(j) *Waste handling and emplacement.*

(1) The systems used for handling, transporting, and emplacing radioactive wastes shall be designed to have positive, fail-safe designs to protect workers and to prevent damage to waste packages.

(2) The handling systems for emplacement and retrieval operations shall be designed to minimize the potential for operator error.

(k) *Design for thermal loads.*

(1) The underground facility shall be designed so that the predicted thermal and thermomechanical response of the rock will not degrade significantly the performance of the repository or the ability of the natural or engineered barriers to retard radionuclide migration.

(2) The design of waste loading and waste spacings shall take into consideration—

(i) Effects of the design of the underground facility on the thermal and thermomechanical response of the host rock and the groundwater system;

(ii) Features of the host rock and geologic setting that affect the thermomechanical response of the underground facility and barriers, including but not limited to, behavior and deformational characteristics of the host rock, the presence of insulating layers, aquifers, faults, orientation of bedding planes, and the presence of discontinuities in the host rock; and

(iii) The extent to which fracturing of the host rock is influenced by cycles of temperature increase and decrease.

§ 60.133 Design of shafts and seals for shafts and boreholes.

(a) *Shaft design.* Shafts shall be designed so as not to create a preferential pathway for migration of groundwater and so as not to increase the potential for migration through existing pathways.

(b) *Shaft and borehole seals.* Shaft and borehole seals shall be designed so that:

(1) Shafts and boreholes will be sealed as soon as possible after they have served their operational purpose.

(2) At the time of permanent closure sealed shafts and boreholes will inhibit transport of radionclides to at least the same degree as the undisturbed units of rock through which the shafts or boreholes pass. In the case of soluble rocks, the borehole and shaft seals shall also be designed to prevent groundwater circulation that would result in dissolution.

(3) Contact between shaft and borehole seals and the adjacent rock does not become a preferential pathway for water.

(4) Shaft and borehole seals can accommodate potential variations of stress, temperature, and moisture.

(5) The materials used to construct the seals are appropriate in view of the geochemistry of the rock and groundwater system, anticipated deformations of the rock, and other in situ conditions.

(c) *Shaft conveyances used in radioactive waste handling.*

(1) Shaft conveyances used to transport radioactive materials shall be designed to satisfy the requirements as set forth in § 60.130 for systems, structures, and components important to safety.

(2) Hoists important to safety shall be designed to preclude cage free fall.

(3) Hoists important to safety shall be designed with a reliable cage location system.

(4) Hoist loading and unloading systems shall be designed with a reliable system of interlocks that will fail safely upon malfunction.

(5) Hoists important to safety shall be designed to include two independent indicators to indicate when waste packages are in place, grappled, and ready for transfer.

§ 60.134 Construction specifications for surface and subsurface facilities.

(a) *General requirement.* Specifications for construction shall conform to the objectives and technical requirements of §§ 60.130 through 60.133.

(b) *Construction management program.* The construction specifications shall facilitate the conduct of a construction management program that will ensure that construction activities do not adversely affect the suitability of the site to isolate the waste or jeopardize the isolation capabilities of the underground facility, boreholes, shaft, and seals, and that the underground facility is constructed as designed.

(c) *Construction records.* The construction specifications shall include requirements for the development of a complete documented history of repository construction. This documented history shall include at least the following—

(1) Surveys of underground excavations and shafts located via readily identifiable surface features or monuments;

(2) Materials encountered;

(3) Geologic maps and geologic cross sections;

(4) Locations and amount of seepage;

(5) Details of equipment, methods, progress, and sequence of work;

(6) Construction problems;

(7) Anomalous conditions encountered;

(8) Instrument locations, readings, and analysis;

(9) Location and description of structural support systems;

(10) Location and description of dewatering systems; and

(11) Details, methods of emplacement, and location of seals used.

(d) *Rock excavation.* The methods used for excavation shall be selected to reduce to the extent practicable the potential to create a preferential pathway for groundwater or radioactive waste migration or increase migration through existing pathways.

(e) *Control of explosives.* If explosives are used, the provisions of 30 CFR 57.6 (Explosives) issued by the Mine Safety and Health Administration, Department of Labor, shall be met, as minimum safety requirements for storage, use and transport at the geologic repository operations area.

(f) *Water control.* The construction specifications shall provide that water encountered in excavations shall be removed to the surface and controlled in accordance with design requirements for radiation control and monitoring (§ 60.131(c)).

(g) *Waste handling and emplacement.* The construction specifications shall provide for demonstration of the effectiveness of handling equipment and systems for emplacement and retrieval operations, under operating conditions.

Waste Package Requirements

§ 60.135 Requirements for the waste package and its components.

(a) *General requirements of design.* The design of the waste package shall include the following elements:

(1) *Effect of the site on the waste package.* The waste package shall be designed so that the in situ chemical, physical, and nuclear properties of the waste package and its interactions with the emplacement environment do not compromise the function of the waste packages. The design shall include but not be limited to consideration of the following factors: solubility, oxidation/reduction reactions, corrosion, hydriding, gas generation, thermal effects, mechanical strength, mechanical stress, radiolysis, radiation damage, radionuclide retardation, leaching, fire and explosion hazards, thermal loads, and synergistic interactions.

(2) *Effect of the waste package on the underground facility and the natural barriers of the geologic setting.* The waste package shall be designed so that the in situ chemical, physical, and nuclear properties of the waste package and its interactions with the emplacement environment do not compromise the performance of the underground facility or the geologic setting. The design shall include but not be limited to consideration of the following factors: solubility, oxidation/reduction reactions, corrosion, hydriding, gas generation, thermal effects, mechanical strength, mechanical stress, radiolysis, radiation damage, radionuclide retardation, leaching, fire and explosion hazards, thermal loads, and synergistic interactions.

(b) *Waste form requirements.* Radioactive waste that is emplaced in the underground facility shall meet the following requirements:

(1) *Solidification.* All such radioactive wastes shall be in solid form and placed in sealed containers.

(2) *Consolidation.* Particulate waste forms shall have been consolidated (for example, by incorporation into an encapsulating matrix) to limit the availability and generation of particulates.

(3) *Combustibles.* All combustible radioactive wastes must have been reduced to a noncombustible form unless it can be demonstrated that a fire involving a single package will neither compromise the integrity of other packages, nor adversely affect any safety-related structures, systems, or components.

(c) *Waste package requirements.* The waste package design shall meet the following requirements:

(1) *Explosive, pyrophoric, and chemically reactive materials.* The waste package shall not contain explosive or pyrophoric materials or chemically reactive materials that could interfere with operations in the underground facility or compromise the ability of the geologic repository to satisfy the performance objectives.

(2) *Free liquids.* The waste package shall not contain free liquids in an amount that could impair the structural integrity of waste package components (because of chemical interactions or formation of pressurized vapor) or result in spillage and spread of contamination in the event of package perforation.

(3) *Handling.* Waste packages shall be designed to maintain waste containment during transportation, emplacement, and retrieval.

(4) *Unique identification.* A label or other means of identification shall be provided for each package. The identification shall not impair the integrity of the package and shall be applied in such a way that the information shall be legible at least to the end of the retrievable storage period. Each package identification shall be consistent with the package's permanent written records.

Performance Confirmation Requirements

§ 60.137 General requirements for performance confirmation.

The geologic repository operations area shall be designed so as to permit implementation of a performance confirmation program that meets the requirements of Subpart F of this part.

Subpart F—Performance Confirmation

§ 60.140 General requirements.

(a) The performance confirmation program shall ascertain whether—

(1) Actual subsurface conditions encountered and changes in those conditions during construction and waste emplacement operations are within the limits assumed in the licensing review; and

(2) Natural and engineered systems and components required for repository operation, or which are designed or assumed to operate as barriers after permanent closure are functioning as intended and anticipated.

(b) The program shall have been started during site characterization and it will continue until permanent closure.

(c) The program will include in situ monitoring, laboratory and field testing, and in situ experiments, as may be appropriate to accomplish the objective as stated above.

(d) The confirmation program shall be implemented so that:

(1) It does not adversely affect the natural and engineered elements of the geologic repository.

(2) It provides baseline information and analysis of that information on those parameters and natural processes pertaining to the geologic setting that may be changed by site characterization, construction, and operational activities.

(3) It monitors and analyzes changes from the baseline condition of parameters that could affect the performance of a geologic repository.

(4) It provides an established plan for feedback and analysis of data, and implementation of appropriate action.

§ 60.141 Confirmation of geotechnical and design parameters.

(a) During repository construction and operation, a continuing program of surveillance, measurement, testing, and geologic mapping shall be conducted to ensure that geotechnical and design parameters are confirmed and to ensure that appropriate action is taken to inform the Commission of changes needed in design to accommodate actual field conditions encountered.

(b) Subsurface conditions shall be monitored and evaluated against design assumptions.

(c) As a minimum, measurements shall be made of rock deformations and displacement, changes in rock stress and strain, rate and location of water inflow into subsurface areas, changes in groundwater conditions, rock pore water pressures including those along fractures and joints, and the thermal and thermomechanical response of the rock mass as a result of development and operations of the geologic repository.

(d) These measurements and observations shall be compared with the original design bases and assumptions. If significant differences exist between the measurements and observations and the original design bases and assumptions, the need for modifications to the design or in construction methods shall be determined and these differences and the recommended changes reported to the Commission.

(e) In situ monitoring of the thermomechanical response of the underground facility shall be conducted until permanent closure to ensure that the performance of the natural and engineering features are within design limits.

§ 60.142 Design testing.

(a) During the early or developmental stages of construction, a program for in situ testing of such features as borehole and shaft seals, backfill, and the thermal interaction effects of the waste packages, backfill, rock, and groundwater shall be conducted.

(b) The testing shall be initiated as early as is practicable.

(c) A backfill test section shall be constructed to test the effectiveness of backfill placement and compaction procedures against design requirements before permanent backfill placement is begun.

(d) Test sections shall be established to test the effectiveness of borehole and shaft seals before full-scale operation proceeds to seal boreholes and shafts.

§ 60.143 Monitoring and testing waste packages.

(a) A program shall be established at the repository for monitoring the condition of the waste packages. Packages chosen for the program shall be representative of those to be emplaced in the repository.

(b) Consistent with safe operation of the repository, the environment of the waste packages selected for the waste package monitoring program shall be representative of the emplaced wastes.

(c) The waste package monitoring program shall include laboratory experiments which focus on the internal condition of the waste packages. To the extent practical, the environment experienced by the emplaced waste packages within the repository during the waste package monitoring program shall be duplicated in the laboratory experiments.

(d) The waste package monitoring program shall continue as long as practical up to the time of permanent closure.

Subpart G—Quality Assurance

§ 60.150 Scope.

(a) As used in this part, "quality assurance" comprises all those planned and systematic actions necessary to provide adequate confidence that the repository and its subsystems or components will perform satisfactorily in service.

(b) Quality assurance is a multidisciplinary system of management controls which address safety, reliability, maintainability, performance, and other technical disciplines.

§ 60.151 Applicability.

The quality assurance program applies to all systems, structures and components important to safety and to activities which would prevent or mitigate events that could cause an undue risk to the health and safety of the public. These activities include: exploring, site selecting, designing, fabricating, purchasing, handling, shipping, storing, cleaning, erecting, installing, emplacing, inspecting, testing,

APPENDIX B

HANDOUT

Table A - General Topics of Geochemical Research For HLW Isolation

This table is a characterization of geochemical research topics applicable to high-level waste repository siting issues. This table is not intended to be a guide for proposing research strategies or to be considered a prioritization of geochemical issues. The table was used solely as a basis for discussion of geochemistry activity among the labs visited as described in this trip report.

The categories in table A were synthesized from: (1) NRC 1980 Trip Report - review of DOE/National Laboratory Geochemical Retardation Programs September 1980; (2) NRC trip report: "Waste/Rock Interaction Technology Meeting, November 1980; (3) the NRC Standard Format and Content Guide - Draft; (4) NRC contractor work being conducted under: FIN No. B-3109 (LBL) Geochemistry Research Planning, and B-3040 (LBL) Geochemical Interaction; FIN NO. B-0462 (ORNL) - Valence Effects on Absorption; and FIN NO. A-2230 (ANL) Lab Model of Radwaste Leaching and Sorption.

Table A. General Topics of Geochemical Research For HLW Isolation[1]

Theoretical Considerations and Working Ranges of Variables for Waste/Water/Rock Interactions	Radionuclide Transport		Chemical Engineering	Numerical Analysis, and Quality Assurance
	Lab Research	Field Research		
1. Theoretical Considerations o Thermodynamic o Mass transport/transfer o Kinetic o Mineralogy o Hydrochemistry	1. Solubility Research o Stability fields for site specific radionuclide species o Solubility limits of site specific radionuclide species o Influence of solid solutions in waste form solubilities	1. Mineralogical and Chemical Characterization on a Site Specific Basis Including Recharge Areas o Fluid pathways o Lithologic units o Groundwaters o Fluid inclusions o Hydrostratigraphic units o Gases o Physicochemical conditions	1. Chemical Characterization of Waste Package o Leach resistance o Radiation effects o Thermomechanical stability o Thermochemical stability	1. Performance Assessment o Radionuclide transport o Geochemical interactions o Engineered systems
2. Site Specific Ranges of Physicochemical Conditions o Thermochemical o Reduction-oxidation o pH o Thermomechanical o Fluid-rock heat transfer o Radiation field	2. Sorption Research For Site Specific Ranges in Physicochemical Conditions and Site Specific Ranges of Compositional Variables	2. Host Rock Stability Experiments o Thermochemical o Thermomechanical	2. Chemical Characterization of Backfills, Plugs, Seals, and Liners. o Sorptive capacity o Buffering capacity o Thermomechanical properties o Thermal conductance	2. Quality Assurance o Documentation
3. Site Specific Ranges of Compositional Variables o Radionuclide species o Groundwater o Rock o Mineral phases o Engineered systems o Gas phases o Organics	3. Colloidal and Particulate Transport	3. Migration Experients o Fracture migration o Tracer o Gas permeability o Brine migration	3. Ranking of Component Stability on a Thermochemical-Thermomechanical Basis	3. Quality Control o Standardization of sampling and experimental procedures o Contamination o Methodology o Peer reviews of procedures o Reproducibility, precision and accuracy. o Interlaboratory comparisons o Chemical processing of engineered components o Record-keeping procedures o Documentation
	4. Site Specific Hydrothermal and Metamorphic Alterations o Dissolution and cementation o Dehydration o Stability of minerals along fractures and porous zones	4. Demonstration Experiments o Component testing o Scaling o Prototype testing	4. Interactions Among Engineered Components o Thermochemical o Termomechanical o Corrosion	
	5. Laboratory Analogues	5. Monitoring	5. Interactions Between Components and Geologic Environment	
		6. Natural Analogue Studies	6. Accelerated Testing of Engineered Components	

(cont.)

Table A (Continued)

Theoretical Considerations and Working Ranges of Variables for Waste/Water/Rock Interactions	Radionuclide Transport		Chemical Engineering	Numerical Analysis, and Quality Assurance
	Lab Research	Field Research		
	6. Electrochemistry o Eh determinations o Electrical potential			
	7. Radiolysis			
	8. Development of Age dating Techniques			
	9. Concentration and Dispersion of Actinides			
	10. Site Specific Hydraulic Diffusivities o Storage coefficients			

[1]This table provides key categories of geochemical information that will be required for reviewing a license submittal. Although the table provides specific categories of information it also allows coverage of information which result from combinations of information categories. For example, a review of information related to "Interactions Among Engineered Components" (Chemical Engineering, item 4) will require information being generated under "Demonstration Experiments" (Field Research, item 4) "Solubility Research," "Laboration Analogues," "Electrochemistry" and "Radiolysis (Lab Research items 1, 5, 6, and 7 respectively), all items under "Theoretical Considerations and Working Ranges of Variables," and "Quality Control" considerations (Numerical Analysis, and Quality Assurance, item 3).

APPENDIX C

HANDOUT

Table B - Coverage of General Topics of
Geochemical Research for HLW Isolation
By 10 CFR 60 and Standard Format and Content Guide

This table is a characterization of geochemical research topics applicable to high-level waste repository siting issues. This table is not intended to be guide for proposing research strategies or to be considered a prioritization of a geochemical issues. The table was used solely as a basis for discussion of geochemistry activity among the labs visited as described in this trip report.

Table B. Coverage of General Topics of Geochemical Research for HLW Isolation by 10 CFR 60[A] and the SF & CG[B]

Theoretical Considerations and Working Ranges of Variables for Waste/Water/Rock Interactions	Radionuclide Transport Lab Research	 Field Research	Chemical Engineering	Numerical Analysis, and Quality Assurance
1. Theoretical Considerations A) 60.135(a)(2) B) 6.1 6.2	1. Solubility Research A) 60.123(b)(14) 60.122(G)(1,2,3) 60.123(b)(5) B) 6.3	1. Mineralogical and Chemical Characterization on a Site Specific Basis Including Recharge Areas A) 60.10 60.21(1)(ii)(A) 60.122(H) B) 6.2 6.3	1. Chemical Characterization A) 60.135 60.143 B. 11.1 6.3	1. Performance Assessment A) 60.21(1)(ii)(C,D,E) B) 6.8 12.1
2. Sites pecific Ranges of Physicochemical conditions A) 60.21(1)(i)(C,E,F) B) 6.1	2. Sorption Research For Site Specific Ranges of Physico-chemical Conditions and Site Specific Ranges of Compositional Variables A) 60.123(b)(15) 60.122(G)(1)	2. Host Rock Stability Experiments A) 60.21(1)(i)(F) B) 6.7	2. Chemical Characterization of Backfills, Plugs, Seals, and Liners A) 60.133 B) 6.3	2. Quality Assurance A) Subpart G B) 12
3. Site Specific Ranges of Compositional Variables A) 60.21(1)(i)(E) B) 6.1 6.2 6.3 11.1	3. Colloidal and Particulate Transport A) 60.122(G)(1&2) B) 6.1 6.3	3. Migration Experiments A) 60.21(1)(ii)(E) B) 6.4	3. Ranking of Component Stability on a Thermo-chemical-Thermomechanical Basis A) 60.21(1)(ii)(3) B) 6.3 6.7 11.2 11.4	3. Quality Control A) Subpart G 60.153 60.21(1)(ii)(F) B) 12.2 12.42 12.43
		4. Demonstration Experiments A) 60.142 60.21(1)(ii)(E) B) 6.6 6.3	4. Interactions Among Components A) 60.135(a)(1,2) B) 6.7	
		5. Monitoring A) 60.141 60.21(1)(ii)(E) B) 6.6	5. Interactions Between Engineered Components and Geologic Environment A) 60.123(b)(14) B) 6.3 11.1	
		6. Natural Analogue Studies A) 60.21(1)(ii)(E) B) 6.5 6.6	6. Aging of Engineered Components A) 60.122(h) B) 6.3	

(cont.)

Table B. (Continued)

Theoretical Considerations and Working Ranges of Variables for Waste/Water/Rock Interactions	Radionuclide Transport			
	Lab Research	Field Research	Chemical Engineering	Numerical Analysis, and Quality Assurance
	4. Site Specific Hydrothermal and Metamorphic Alterations A) 60.122(h) B) 6.1 6.2			
	5. Laboratory Analogues A) 60.21(i)(ii)(E) B) 6.5			
	6. Electrochemistry A) 60.123(b)(13,14) B) 6.7			
	7. Radiolysis A) 60.155(a)(2) B) 6.7			
	8. Development of Age Dating Techniques A) 60.112(b) B) 6.2			
	9. Concentration and Dispersion of Actinides A) 60.130(b)(8) B) 6.7			
	10. Site Specific Hydraulic Diffusivities A) 60.21(1)(D) 60.122(f) B) 6.4 6.6 6.7			

APPENDIX D

Summary of Observation of Each Laboratory Visited

OAK RIDGE NATIONAL LABORATORY (ORNL)

Dates: August 24-25, 1981

Organizations Visited: Chemical Technology Division, Risk Assessment Group, Chemistry Division, Energy Division, Environmental Sciences Division, and Health and Safety Research Division.

Participants: Appendix E

I. Overall Objectives

In general, the ORNL staff was making contributions to all of the information requirements of Table A (Appendix B) except in the areas of "field research" and "quality assurance." For example, ORNL workers are assessing radionuclide biochemistry and environmental chemistry through studies of contamination through radioactive-waste-migration-associated biological - uptake and assessing the speciation of transuranics from shallow land burial sites for low level radioactive wastes. Also, they have recently initiated a study to assess valence effects on sorption (NRC FIN NO. B-0462).

Major efforts at ORNL entail the writing of a topical report on "Brine Migration," in support of ONWI programs. The objective of this work is to establish expected environmental parameters in salt repositories. These parameters include temperature, fluid (brine and vapor) pressure, and brine chemistry. The results of this work are expected to be useful to scientists and engineers involved in material performance testing, repository design site characterization and license application information, waste form and packaging as well as to identify areas

requiring further investigation. Other work includes waste form research, reference-repository environment studies in salt, waste form/canister/backfill interactions, valence effects on adsorption of natural materials through the use of column tests, the development of a finite-element model of waste transport through saturated/unsaturated porous media, and the development of radioactive dose-to-man models.

II. Major Points:

The work done to date suggests that there is a need for:

(1) a critical review of the chemistry of the principal nuclides,
(2) determination of solubilities and solution chemistry of principal nuclides,
(3) the development of adsorption isotherms and models for host rocks and minerals, and
(4) studies of geochemical interactions with actual host material.

The aim of the foregoing research should be to help determine to what extent nuclide behavior in a HLW repository is predictable or understood.

ARGONNE NATIONAL LABORATORY (ANL)

Dates: August 26-27, 1981

Organizations Visited: Office of Waste Management Programs, Chemical Engineering Division, Chemistry Division, Material Science Division.

Participants: Appendix E

I. Overall Objectives

At ANL efforts are aimed at understanding and establishing the retardation properties of the far-field. In addition, the NRC is initiating work with ANL directed at evaluating radionuclide migration in a laboratory simulated repository environment (FIN No. A-2230). In general, the ANL staff is making contributions in the area of laboratory research and chemical engineering in Appendix B.

Major efforts at ANL involve the management of the National Sodium Waste Technology Program, leach/sorption studies of radionuclides in geologic media, development and characterization of high-level waste forms, ways of controlling the migration of tritium and carbon-14, determination of diffusion coefficients, research in support of the subseabed disposal program, solution speciation/redox behavior/complexing and absorption of actinides, critical evaluation of sorption experiments and measurements, laboratory analogue experiments, and the development of tracers for field experiments.

II. Major Points:

1. Waste form research: The objectives of this work are to determine leach rates of waste materials through the use of radioactive

tracers, and to establish testing techniques and detection limits in order to evaluate various other methods. Experiments to date have been made on glasses and defense waste forms. Future plans call for experiments using "synroc."

2. The glass waste-form studies show that adherent surface layers form on the waste glass during leaching that may retard further leaching. The behavior of such layers seems to vary with glass type. This layer formation is also observed to occur when glasses are subjected to weathering in nonaqueous environments.

3. Other work at Argonne shows that short duration bombardment may greatly increase the etching or leaching of silicate glasses when in the presence of a hot saline solution (the Dran Effect). The purpose of this work is to evaluate the effect first reported by Dran and others, and to determine its cause.

4. ANL is sensitive to the difficulties in measuring and interpreting distribution coefficients (Kds). The problem of determining accurate Kd values has involved: uncontrolled pH and Eh; mistaken knowledge of the valence state of the nuclide present; and undetected precipitation accompanying sorption. ANL is pursuing a laboratory analogue approach that uses the rock column technique to determine Kd rather than batch Kd experiments.

OFFICE OF NUCLEAR WASTE ISOLATION (ONWI)

Date: August 28, 1981

Participants: Appendix E

I. Overall Objectives

The Office of Nuclear Waste Isolation coordinates the National Waste Terminal Storage Program's (geochemical) technology development and (geochemical) site characterization of non-DOE lands.

The purpose of the ONWI meeting was to get an overall perspective of the DOE geochemical program. Our objective was to determine if the ONWI program would fulfill the geochemical information needs expressed in Appendix B. The discussion was divided into two sessions: 1) geochemical program description and, 2) model-interface activities.

II. Major Points:

1. The session on geochemical program description provided an overview of current and planned "near-field" and "far-field" research activities. In total, the planned research covered aspects of all of the categories of geochemical information requirements listed in Appendix B. However, the ONWI program now emphasizes the need to provide (critical) thermodynamic and solubility data for waste/water/rock systems currently being investigated.

2. "Kd/Rd" work is being de-emphasized as the sole definition of geochemical retardation. Work that is going to be emphasized will include (1) the solubility of key compounds like NpO_2 and TcO_2 as a function of Eh and pH, (2) absorption isotherms for important

radionuclides will be determined as a function of pH, total radionuclide concentration, ionic strength, and Eh, and (3) determination of stability fields of major actinide oxides as a function of oxidation state.

3. The session on model-interface activities pointed out to the modelers that it is inappropriate to integrate geochemistry into performance models through the use of what is presently referred to as a "Kd". Further, ONWI geochemists and modelers are evaluating existing and new approaches to adequately model retardation geochemistry. However, there are no clear plans concerning the incorporation of these codes into the performance assessment modeling effort. Important questions that must be answered concerning the use of these characterizations are (1) what level of complexity would be required of the geochemical portions of the performance assessment model to satisfy performance assessment requirements and (2) what approaches could be used to deal with changes in geochemistry as a function of time and changing environments.

SANDIA NATIONAL LABORATORY (SNL)

Dates: September 14, 1981

Organizations Visited: Geophysics Research, Subseabed research, NTS Tuff research, Overpack, backfill and waste package design, WIPP Sites Waste Geochemistry.

Participants: Appendix E

I. Overall Objectives:

Sandia is focusing their work on the development of instrumentation for in situ testing, geochemical studies of nuclide migration, hole plugging, and waste package design. In general, the Sandia staff are conducting laboratory research on radionuclide transport. This research is being done on subseabed clays. Although much of this effort has been done using batch sorption testing techniques, they are in the process of switching over to column sorption techniques. At present they are not controlling Eh and they are assuming oxidizing conditions (since the experiments are open to air). To date this work has been done with illite and smectite in the presence of Rb, Cs, Sr, Ag, Cd, Ce, Pm, Eu, Gd, Tc, U, Pu, Am and Cm. It is expected that these data will be of use in backfill studies.

II. Major Points:

1. A theoretical and experimental basis is being developed for analysis of radionuclide transport in jointed rock. The object of the program is to identify the important sorption mechanisms and important chemical reactions, and obtain sufficient

data so that the phenomenon can be described quantitatively using appropriate mathematical expressions. To date, batch equilibration and rate experiments involving samples of argillite and tuff in contact with solutions containing Cs, Sr or Pm indicates that most radionuclide sorption was associated with the surfaces of very small intergranular regions and that the rate of sorption is controlled by diffusion of the nuclides into such regions.

2. Field research involves the characterization of fluid flow along fractures at NTS. Radioactive tracer techniques to track the fluid flow through the fractures are being supplied through interaction with workers at Argonne.

   In doing this work, Sandia has developed a rapid technique for characterizing the mineralogy of very fine-grained rocks. The approach uses standard microprobe analyses along with standard computer plotting and statistical analysis techniques. This approach can be used with rocks such as tuff or basalt.

3. In the area of chemical engineering, Sandia is doing thermomechanical studies of bentonite/quartz mixtures for backfill material, and borehole plugging in a salt environment. To date, work suggests good thermomechanical stability of various mixes of bentonite/quartz for backfills. The smectite swelling clay (bentonite) has shown: 1) good sorptive capacity for actinides and rare earths, 2) retention of sorption properties in mixtures with sand (quartz), 3) capability to buffer brine pH in a near-neutral range, 4) low liquid permeability, 5) favorable swelling properties, 6) and adequate thermal conductivity and high-temperature performance.

4. The work dealing with borehole plugging in salt suggests that an evaporite seal with composition identical to the host rock material is possible.

LOS ALAMOS NATIONAL LABORATORY (LANL)

Dates: September 13, 1981

Programs Reviewed: Office of Nuclear Waste Isolation Geochemistry Program; Geochemistry Program of Basic Energy Sciences Program.

Participants: Appendix E

I. Overall Objectives:

Los Alamos efforts are directed at scaling laboratory tests to large scale fractured and solid rock block/column laboratory tests in order to provide a bridge between current (small scale) laboratory tests and field tests. Also, LANL is studying chemical changes in rocks which are being subjected to hydrothermal conditions through geothermal loop experiments in order to assess changes in bulk chemistry under repository conditions. Researchers are currently working in all areas of Table A (Appendix B). And, they are focusing on the Nevada Test Site studies concerning solution chemistry, the chemical retardation properties of tuff, radionuclide transport by aqueous flow in tuff, hydrothermal conditions, nuclide migration field tests, natural repository analogue study of Oklo, mineralogy/petrology of Yucca Mountain, and NTS quality assurance.

The current and planned objectives of LANL NTS work is to characterize the mineralogy/petrology of the samples from the NTS drilling program, to correlate sorption with mineralogy, to determine oxidation states of sorbates on mineral phases, and to understand reactions of radionuclides with mineral phases in groundwater. To date, workers have determined

that sorptive properties vary with tuff lithology in a reasonably predictable manner if semi-quantitative knowledge of mineralogy and groundwater is known. Further, nuclide speciation and solubility data are critical variables for understanding retardation.

II. Major Points:

1. LANL data show that reducing conditions are necesary for sorption of some elements. For example, the migration of technetium and uranium is only minimally retarded and the sorption of neptunium is poor under oxidizing conditions. In general, anion sorption is low in tuff.

2. Matrix diffusion appears to be a major factor that enhances retardation in Yucca Mountain tuff. Further, radionuclide transport in a fracture appears to depend on fracture aperture, matrix porosity, diffusion coefficients, fluid velocity, sorption, kinetics, and flow path.

3. The DOE Office of Basic Energy Science, and the Division of Geothermal Research are doing work that includes research on element migration, and rock-water interactions. Some of this work could be of benefit to the Waste Management Program.

UNIVERSITY OF NEW MEXICO

Date: September 16, 1981

Participants: Appendix E

I. Overall Objectives:

The University of New Mexico work involves lab studies of waste forms. In general, they are focusing on mineralogical alteration caused by alpha recoil from uranium and thorium atoms, and natural analogue studies of radionuclide migration.

II. Major Points:

1. Doug Brookins is working with LBL (NRC #3040) to identify geologically suitable sites for natural analogue work. Together, they are searching for igneous intrusions into candidate-repository rock types accompanied by a circulating hydrothermal system; alkalic intrusions that contain high abundances of radionuclides and fission-product analog elements; and suites of samples from evaporite rocks cut by dikes.

   They have identified a potential location for the investigation of element distributions associated with intrusions into tuffaceous terrain in the Alamosa River Stock region (in Colorado). In general, this is an area of tuffaceous rocks cut by a monzonite intrusion. It is expected that examination of the distribution of radio-elements and trace elements associated with these occurrences give indications of the migration and transport of such elements in a convective setting in contrast to the conductive conditions observed in the Eldora-Idaho Springs traverses.

2. Early Paleozoic alkalic and carbonatitic dikes and stocks in the Wet Mountains area of Colorado which intrude Precambrian crystalline terrain are being considered as potential analogs for the observations of radionuclides and trace element migration and transport within and from discrete sites that contain concentrations of these elements. The distribution of elements within the intrusives may indicate migration pathways between glassy and crystalline zones, analogous to prospective waste forms. Possible migration of elements from the intrusions into the Precambrian crystalline rocks and into the overlying Tertiary volcanic rocks will be studied. The studies will attempt to determine the degree of migration into the Precambrian rocks accompanying intrusion of the dikes and stocks as well as the following intrusion, and the transport of elements into the Tertiary volcanic rocks by more recent fracture-controlled hydrologic systems.

3. R. C. Ewing has been working on mineral analogues of crystalline waste forms. He has made systematic comparisons of glass and crystalline waste forms through leach tests, thermal stability tests, mechanical stability tests. His preliminary work suggests crystalline waste forms ("Synroc") are not obviously superior to glass forms. Further, the structural breakdown of glass due to alpha radiation (the Dran Effect which has been described by workers at ANL to lead to the early breakdown of glass), may not be as serious as some workers believe.

LAWRENCE LIVERMORE NATIONAL LABORATORY (LLNL)

Date: September 17, 1981

Organization Visited: Nuclear Chemistry Division

Participants: Appendix E

I. Overall Objectives

Studies at Lawrence Livermore Laboratory stress field fracture migration and sorption research. In addition, LLNL is involved in geochemical modeling, in modeling transport scenarios, in compiling thermodynamic data and in conducting basic geochemical research.

II. Major Points:

1. The field studies are designed to understand radionuclide migration in fractured granite, to compare retardation factors measured in the field with laboratory measured values, and to develop reliable in situ retardation tests that can be used at any repository site in fractured rock. In doing this they are using existing hydrologic models for pretest predictions and data interpretation.

2. LLNL is involved in waste-form leaching studies. This work involves the investigation of the potential for migration of radionuclides in groundwater from the sites of underground nuclear explosions. This analogue approach was used because the techniques required to study radionuclide migration from underground nuclear tests are very similar to those required for studying the geologic disposal of high-level vitrified nuclear reactor wastes.

3. Field radionuclide retardation observations were compared to reported laboratory Kd data on radionuclide migration. For example, LLNL has been studying Ru migration at the Cambric Test Site at NTS. As they expected there was no correlation between the field- observed retardation and the laboratory values. It was explained that this result was not surprising since the customary batch Kd laboratory work inherently fails to model retardation if more than one radionuclide species is present in solution.

4. For the above experiments LLNL found that batch tests which showed a high sorption Kd for Ru integrate sorption values for several species. Therefore, the low sorption Kd observed in the field was for a fast moving species while the dominant species in the batch tests had a high Kd.

5. In order to quantify the reasons for the field-observed fast migration of Ru, LLNL is trying to establish individual Kd values for the individual species. Chromatographic approaches are being employed to identify the individual species. Finally, it was concluded that total geochemical retardation of the species has to be characterized by properly integrating solubility limits, sorption and irreversible reactions under appropriate field conditions.

LAWRENCE BERKELEY NATIONAL LABORATORY (LBNL)

Dates: September 18, 1981

Participants: Appendix E

I. Overall Objectives:

LBNL researchers are working on a number of projects for DOE related to understanding sorption processes and developing a capability to predict and model near-field retardation in addition to their work for NRC (FIN B-3109, B-3110, B-3040).

Since 1980, LBNL Rockwell Hanford basalt investigations and WRIT program sorption studies have been discontinued. However, the LBNL staff is working in all of the general areas outlined in Table A (Appendix B). Finally, general comments concerning Table A led to the conclusion that the cumulative effects of uncertainties have generally been disregarded and must be taken into account. This would be most important in performance assessment modeling and should be a "bulleted" item in our chart.

II. Major Points:

1. While sorption research is continuing, emphasis is now on the collection of radionuclide solubility data. During the week of 7 September LBNL sponsored a symposium on actinide geochemistry. The participants saw the need for basic data on solid and liquid phase speciation in order to understand radionuclide retardation. In 1980 efforts entailed obtaining equipment and formulating analytical methods. In 1981 the emphasis was on data collection.

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2. LBNL is continuing to conduct disequilibrium studies as a means of dating groundwater, assessing aquifer pathway processes, and assessing whether fracture systems are connected.

3. LBNL staff identified a need for basic carbonate-radionuclide equilibrium data since carbonate species are prevalent in most groundwaters. In addition, they see a specific need to identify the rates and extent of hydrolysis reactions in repository environments.

4. LBNL emphasized the need to characterize fracture-filling materials in order to establish the rock history. In order to do this they suggested the use of disequilibrium studies using both uranium and strontium isotopes. This work is suggested as a means of evaluating the infiltration of mixing of atmospheric and deuteric waters.

5. There is a need for field research for evaluating the effect of mineralogic changes on permeability of the rock flow system.

6. With regard to tests designed to evaluate the migration of fluids along fractures they recommend that networks of fractures should be studied as well as a simple single fracture. They suggested a joint laboratory/field program that could be used in support of performance assessment modeling.

7. In the area of chemical engineering, LBNL has a strong program in backfill evaluation. However, to model quantitatively the transport of ions through the engineered barrier, the orientation of grains of clay backfill such as montmorillonite, which might

influence transport rates, must be understood. This understanding may involve the application of maze or random-walk theory modeling rather than the modeling of straight line transport of ions through the engineered barrier as is presently done.

8. With respect to modeling, LBNL has identified solubility, sorption/desorption, and irreversible reactions as key input for characterizing geochemical retardation. However, they stress that careful consideration must be given to the coupling of various geochemically models into the performance assessment programming effort. The problem they foresee is a needlessly complicated and unwieldly performance assessment model.

9. LBNL stresses the need for characterizing the cumulative effects of data uncertainty when coupling models of use to the overall performance assessment program.

PACIFIC NORTHWEST LABORATORY (PNL)

Dates: 21 September 1981

Participants: Appendix E

I. Overall Objectives

PNL research stresses the study of sorption mechanisms, the dependence of sorption measurements on laboratory techniques, and actinide chemistry. PNL researchers are working in all five general categories of Table A (Appendix B). Major activity is focused on determining the solubility of radionuclides, geochemical modeling, radionuclide transport studies, the use of natural analogs to study long-lived radionuclides in nuclear wastes, and interactions among waste package/backfill/basalt/groundwater.

The WRIT program has been reorganized. Waste package work is now a separate program, and waste/rock geochemistry is now organized under GMIS (Geochemical Modeling Waste/Rock Media Interaction Studies). The work being pursued appears to be well targeted and falls into three areas: (1) geochemical model development; (2) studies of solubilities of key compounds, development of adsorption isotherms and the stability field of major actinide oxides; and (3) interaction activities such as geochemical modeling with hydrologic modeling, data integration for the geochemical codes and the development of rock/waste-package interface codes.

II. Major Points:

1. PNL is developing models to assist in the prediction of potential concentrations of various species of radionuclides in

(transporting) groundwaters from HLW repositories. The specific focus of PNL work is three-fold. First, PNL is developing and testing thermodynamic geochemical models for phenomena such as nuclide speciation, sorption, retardation kinetics at variable temperatures. Second, they are experimentally evaluating and determining solubilities of waste-form compounds, stability fields of solution species and isotherms for predictive models. Finally, PNL is supporting the NWTS waste package design, site characterization/selection and performance assessment efforts through the linkage of geochemical models with hydrology models.

2. PNL retardation studies have stressed radionuclide solubility measurements rather than Kd measurements. They have defined the most soluble americium species to be Am $(OH)^{+}_{2}$ and estimated the range of solubilities of Pu compounds under natural conditions.

3. PNL is using an element analog approach for studying the transuranic elements. To date they have compared natural ions with the transuranics and found good comparsion between ionic sizes in solution and in the solid state. They have also found good comparison between the Kd's of the pairs and have noted a striking similarity in their uptake in plants. In addition, they have developed a non-coincidence NAA technique for resolving small activities associated with trace elements. This technique involves the use of two detectors collecting emissions from a single source. The geometric relationship between the source and the collectors allows the detection of small amounts of a trace element that would normally be lost in the background noise of a single detection system.

4. Solution chemistry work at PNL on Am is producing interesting results. For example, Am solubility appears to be controlled by an Am solid phase that has fast precipitation kinetics. Also, Am concentration in solution decreases by a factor of 10 with an increase of one pH unit (However, Am concentration decreases to nondetectable levels near pH7). Further, reported high Am Kd values appear due to Am precipitation.

Appendix E
List of Participants

USNRC/OAK RIDGE NATIONAL LABORATORY (ORNL) MEETING

24-25 August, 1981

Participants:

Don Alexander, USNRC

David Brooks, USNRC

George Birchard, USNRC

R.E. Blanco	ORNL/Chemical	Technology	Division
L.R. Dole	"		"
E.J. Frederick	"	"	"
H.W. Godbee	"		"
G.H. Jenks	"	"	"
J.G. Moore	"	"	"
K.J. Notz	"	"	"
C.D. Scott	"	"	"
P. Angelini	ORNL/Metals	and Ceramics	Division
F.J. Homan	"		"
H. McCoy	"	"	"
E.Bondietti	ORNL/Environmental	Sciences	Division
N. Cotshall	"		"
S. Stow	"		"
T. Tamura			
J. Trabalka	"		"
D. Reichle	"	"	"
R. Chester	ORNL/Heath and	Safety Research	Division
D. Kocher	"	"	"
C. Little	"		"
P. Rowher	"		"

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USNRC/ARGONNE NATIONAL LABORATORY (ANL) MEETING
August 26-27, 1981

D. Alexander, USNRC
G. Birchard, USNRC
D. Brooks, USNRC

John Bates	ANL-Chemical Engineering Division
Howard Kittel	ANL-Office of Waste Management Program
Martin Seitz	ANL-Chemical Engineering Division
Vijay Sethi	ANL-Materials Science Division
Nick Susak	ANL-Chemistry Division
Rex Couture	ANL-Chemistry Engineering Division
Herbert Diamond	ANL-Chemistry Division
Sherman Fried	ANL-Chemistry Division
Lesslie J. Jardine	ANL-Chemical Engineering Division
Daniel J. Lam	ANL-Materials Science Division
Douglas Karim	ANL-Materials Science Division
R. Poeppel	Ceramic Waste Form Laboratory
W. Primak	SSS Radiation and Interferometry Laboratory
F. Schreimer	SEABED Research
James C. Sullivan	ANL-Chemistry Division
John Unik	ANL-Chemistry Division

USNRC/OFFICE OF NUCLEAR WASTE ISOLATION (ONWI) MEETING

August 28, 1981

D. Alexander, USNRC

G. Birchard, USNRC

D. Brooks, USNRC

R. Wright, USNRC

E. Quinn, USNRC

S. Goldsmith, ONWI

N. Hubbard, ONWI

J. Moody, ONWI

J. Perry, ONWI

G. Raines, ONWI

USNRC/SANDIA NATIONAL LABORATORY (SNL) MEETING

September 14, 1981

D. Alexander, USNRC

G. Birchard, USNRC

D. Brooks, USNRC

K. Erickson	SNL/Subseabed/NTS Tuff
S. Lambert	SNL/WIPP Site Water Geochemistry
B. Luth	SNL/Geophysics Research Division
M. Molecke	SNL/WIPP Site Water Geochemistry

USNRC/LOS ALAMOS LABORATORY (LANL) MEETING
September 13, 1981

D. Alexander, USNRC
G. Birchard, USNRC
D. Brooks, USNRC

D. Bish	LANL
J. Blacic	LANL
P. Bussolini	LANL
F. Caporuscio	LANL
B. Crowe	LANL
D. Curtis	LANL
W. Daniels	LANL
C. Duffy	LANL
B. Erdal	LANL
J. Kerrisk	LANL
T. Newton	LANL
A. Ogard	LANL
E. Treher	LANL
R. Vidale	LANL
D. Viniman	LANL
G. Walter	LANL
K. Wolfsberg	LANL

USNRC/UNIVERSITY OF NEW MEXICO (UNM) MEETING

September 16, 1981

D. Alexander, USNRC

G. Birchard, USNRC

D. Brooks, USNRC

D. Brookins, UNM

C. Ewing UNM

USNRC/LAWRENCE LIVERMORE NATIONAL LABORATORY (LLNL) MEETING

September 17, 1981

Participants

D. Alexander, USNRC

G. Birchard, USNRC

D. Brooks, USNRC

D. Isherwood, LLNL

L. Ramspot, LLNL

USNRC/LAWRENCE BERKELEY NATIONAL LABORATORY (LBNL) MEETING

September 18, 1981

participants:

D. Alexander, USNRC
G. Birchard, USNRC
D. Brooks, USNRC

J. Apps, LBNL
C. Carnahan, LBNL
F. Jahnke, UC/Berkeley
M. Michel, LBNL
C. Miller, LBNL
C. Radke, LBNL
C. Tsang, LBNL
O. Weres, LBNL
C. Wilson, LBNL
H. Wollenburg, LBNL

USNRC/PACIFIC NORTHWEST LABORATORY (PNL) MEETING

21 September 1981

D. Alexander, USNRC
G. Birchard, USNRC
D. Brooks, USNRC

D. Coles, PNL
M. Foley, PNL
J. Fruchter, PNL
D. Girvin, PNL
F. Hodges, PNL
J. Laul, PNL
D. Rai, PNL
J. Relyea, PNL
D. Westerman, PNL