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1.0. PURPOSE AND SCOPE

Certain criteria are suggested herein for site characterization data that seek to assure retrievability of waste, in accordance with regulatory requirements. In particular, the criteria covered herein are concerned with the level of physical and numerical demonstrations needed to assure retrievability in an application for a license to construct a repository and to receive and possess waste for disposal in a repository.

The regulatory requirements for retrievability and retrieval that are covered in this paper are chiefly those of 10 CFR 60, which prescribes retrieval for reasons related to health and safety. Requirements for other aspects of retrievability appear in the NWPA and in the EPA Rule, 40 CFR 191.

The discussions in this paper are limited to the general design of retrieval concepts and waste emplacement systems applicable to the proposed repository site at Yucca Mountain, Nevada. Present emplacement and retrieval concepts are described in the SCP-CDR and various supporting background documents. The most relevant of these are listed in the Background Chapter herein.

The observations made in this paper are drawn from the rationale for retrieval articulated in 10 CFR 60 and in the Statements of Consideration supporting it, together with consideration of data needs, schedule requirements for licensing and waste emplacement, present level of retrieval system development as described by the DOE, and information and concepts accruing from NRC technical papers and the several workshops, meetings, and other NRC-DOE interactions that have involved subjects pertinent to retrieval. Throughout the pre-licensing process that has been the context for these interactions, it has been the NRC position that retrieval and retrievability are strongly impacted by site characteristics and that retrievability could be precluded by inadequate consideration of site characteristics.

Thus the site data will need to specifically address retrievability
issues. Retrievability cannot be adequately assured through equipment development alone, in the absence of detailed site data. Detailed design of retrieval systems needs to be accomplished prior to license application and the designs must be shown to cover the full range of site characteristics and repository-induced conditions. It is expected that this will involve some combination of site data collection, and analyses of physical demonstrations specific to retrieval.

The questions addressed in this paper are what levels of data and demonstrations are needed, and when in the design and licensing schedule is it necessary to fulfill these needs. This paper will discuss the data and criteria for computer simulations, demonstrations, and operational studies that are pertinent to adequate resolution of retrieval issues for licensing.
2.0. REGULATORY AND NON-REGULATORY TECHNICAL BACKGROUND

Retrieval required under the NRC's regulatory authority is covered in 10 CFR 60 as detailed below. Aspects of waste movement for any purpose also are covered under 10 CFR 20. Other regulations and documents of pertinence to retrieval and retrievability are mentioned separately.

2.1. Provisions of 10 CFR 60

Preclosure performance objectives of the geologic repository call for preservation of the option of waste retrieval (10 CFR 60.111(b)):

(b) Retrievability of Waste

(1) The geologic repository operations area shall be designed to preserve the option of waste retrieval throughout the period during which wastes are being emplaced and, thereafter, until the completion of a performance confirmation program and Commission review of the information obtained from such a program. To satisfy this objective, the geologic repository operations area shall be designed so that any of all of the emplaced waste could be retrieved on a reasonable schedule starting at any time up to 50 years after waste emplacement operations are initiated, unless a different time period is approved or specified by the Commission. This different time period may be established on a case-by-case basis consistent with the emplacement schedule and the planned performance confirmation program.

(2) This requirement shall not preclude decisions by the Commission to allow backfilling part or all of, or permanent closure of, the geologic repository operations area prior to the end of the period of design for retrievability.

(3) For purposes of this paragraph, a reasonable schedule for retrieval is one that would permit retrieval in about the same time as that devoted to construction of the geologic repository operations area and the emplacement of wastes.

The following items are critical aspects of repository design that affect
retrievability: (1) coupled thermal-mechanical-hydrological-chemical (T-M-H-C) response of the host rock as it may affect waste packages and the ability to access and remove waste packages, and (2) repository ventilation, as it may affect rock behavior, environmental conditions and isolation capabilities prevailing during retrieval. Both are covered explicitly in terms of retrieval, and implicitly in terms of broad design criteria, in 10 CFR 60.

Design criteria explicitly pertaining to rock mass response and retrieval are found in 10 CFR 60.133:

"The underground facility shall be designed to permit retrieval of waste in accordance with the performance objectives of 60.111", (10 CFR 60.133(c)); "openings in the underground facility shall be designed so that operations can be carried out safely and the retrievability option maintained", (10 CFR 60.133(e)(1)).

Implicit applicability to retrieval with respect to rock response is found in 10 CFR 60.133(e)(2):

"openings in the underground facility shall be designed to reduce the potential for deleterious rock movement or fracturing of overlying or surrounding rock."

In addition, the general and additional design criteria set forth in 10 CFR 60.130, 60.131, 60.132, and (for the waste package) in 60.135 apply to retrieval designs and systems as well as routine repository operations systems. In particular, 10 CFR 60.135(b)(3) explicitly requires that the waste package design be such that containment is maintained during transportation, emplacement, and retrieval.

Ventilation of the underground facility is covered in 10 CFR 60.133(g) requiring that the ventilation system be designed to:

"control the transport of radioactive particulates and gases within, and releases from, the underground facility in accordance with the performance objectives of 10 CFR 60.111(a), assure continued function during normal operations and under accident conditions; and, separate the ventilation of excavation and waste emplacement areas."

By including both normal and accident conditions, by referring to section 111(a) which covers performance at all times up through permanent closure, and by not restricting the applicability of any requirement to normal repository operations, these provisions apply as much to retrieval as to other aspects of repository operation. The design is also to provide for control of water or gas intrusions (10 CFR 60.133(d)), and assure that the effect of disruptive events such as flooding, fires, and explosions will not spread through the facility (10 CFR 60.133(a)(2)). Again, these requirements would apply during retrieval
operations as well.

It is noted that most of these provisions would govern waste "removal" as well as waste retrieval (see Section 3.6 for discussion of these terms). Retrieval operations must be carried out according to retrieval plans, which are required as part of the Safety Analysis Report (10 CFR 60.21(c)(12)) that is submitted with the license application. If "removal" of the waste is distinguished from "retrieval", as has been proposed by the DOE, then these plans may not necessarily be prepared for waste "removal" of activities. The NRC may wish to take a position on this topic. In any event, the NRC may enforce its other means for monitoring the movement of waste connected with such activities to be sure they are covered explicitly within the Safety Analysis Report. Regardless, 10 CFR 60 requires updates to be submitted, and these updates could occur out of retrievability considerations.

An NRC decision to order retrieval of the waste, or allow permanent closure of the underground facility, will most likely be based on the results of the performance confirmation program. This program is not designed to test waste retrieval, but its results may trigger a decision to retrieve, and will generate data that may be useful in predicting or evaluating the performance and/or safety risks, if any, of the retrieval act itself. Performance confirmation must be initiated by the DOE during site characterization and is likely to continue until permanent closure. Performance confirmation includes, among other things, "in situ monitoring, laboratory and field testing, and in situ experiments" (10 CFR 60.140(c)). Results from the performance confirmation program will ensure that geotechnical and other parameters used in the repository design are confirmed (see 10 CFR 60.141).

The performance of the overall system following permanent closure is covered in 10 CFR 60.112. The performance of particular barriers following permanent closure is covered in 10 CFR 60.113. We find no language in the Rule indicating an exemption from these requirements in the event of retrieval. Therefore, these performance objectives must be satisfied for the remaining waste should retrieval occur. Should the requirement for retrieval be limited to only part of the waste inventory, the remaining inventory must still meet the performance objectives, unless they are modified by the Commission. Similarly, if the requirement for retrieval is to remove all the waste inventory, the result of the retrieval should be such that all the performance objectives, as stated herein or as modified by the Commission, would be met. In other words, should some radioactive material be left behind after implementation of the retrieval plan, (doubtless an unanticipated event), the Commission would determine whether the overall system performance objective would nevertheless be met (10 CFR 60.113(b)). It is noted that the DOE position prescribes design provisions to retrieve all the waste, but the potential for incomplete success in achieving that objective should nonetheless be considered.

2.2. Statements of Consideration to 10 CFR 60

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The rationale for the retrievability provisions of 10 CFR 60 and some insight into the relative importances of retrievability and other design provisions may be found in the Statements of Consideration published by the Commission (NUREG-0804) in response to public comment on the original proposed 10 CFR 60. The full text of the Statements of Consideration pertaining to retrieval is reproduced as Appendix A to this report. The key points as we interpret them are as follows:

Role of retrievability in design - Although the design should provide for the option to retrieve the waste, the principal purpose of the repository is permanent disposal, not tentative disposal in what would amount to a geologic, interim, retrievable storage facility. The waste is to be emplaced with the intention that it will never again be disturbed. Hence, retrievability requirements should not unnecessarily complicate or dominate repository design. However, closure of the repository could only occur upon the Commission's satisfaction that the performance objectives would be met. Therefore there may be uncertainties in projected performance that could make it necessary for retrievability to dominate or complicate the design.

Statements indicating the Commission's intent about the level to which the design is to accommodate retrieval are as follows: "the ability to retrieve be incorporated into the design"; "the design shall keep open the option of retrieval"; "design should allow retrieval to be undertaken"; "retrievability design provisions", and "it should not be made impossible or impractical to retrieve the waste" (emphases added). The Commission seems to be saying that the need is to assure that the waste not be irretrievable, and in order to accomplish this, explicit provisions for retrieval need to be made in the design.

Duration of retrievability - The Commission expressly relieved itself from stipulating in advance the conditions under which it might require retrieval, and asserted that its discretion in calling for retrieval should not be limited at the time of issuance of 10 CFR 60. Indeed, stipulating detailed reasons for retrieval seems to mitigate the importance of a Commission review of the performance confirmation program prior to a decision to close the repository.

Characteristics of retrieval - In keeping with the view that the repository is intended and designed to be for permanent emplacement of waste, the Commission recognized that retrieval may be unusual, expensive, and involved. There is no requirement for continuous, ready or easy access to the waste. The additional costs that may be incurred in providing for retrieval were considered to be justifiable, based on the need for a meaningful closure decision.

2.3. Other Regulations
Various source documents besides 10 CFR 60 and the Statements of
Consideration were used in the preparation of this technical paper. These further amplify and frame the retrieval issue and/or establish additional regulatory obligations for the NRC with respect to retrievability.

2.3.1. 10 CFR 20

The radionuclide exposure standards for personnel in restricted and unrestricted areas are established in 10 CFR 20, which is referenced extensively in 10 CFR 60 including in the overall preclosure performance objective 10 CFR 60.111(a) which, as described above, applies to retrieval as well as other repository operation activities:

"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 such generally applicable environmental standards for radioactivity as may have been established by the Environmental Protection Agency."

Disposal of wastes, which for retrieval could include decontamination, repackaging, or disposal of other wastes generated by the retrieval process, is covered under 10 CFR 20.

Monitoring for purposes of radiation protection, notification requirements for incidents, precautionary procedures (including surveys, storage and control of licensed materials in unrestricted areas) and the control of radioactive effluents to unrestricted areas, are also covered under 10 CFR 20 and will need to be considered in retrieval plans.

2.3.2. NWPA

The Nuclear Waste Policy Act (NWPA) of 1982 and as amended in 1987 (NWPA Amendment, or NWPAA) prescribes environmental protection controls for waste disposal. It requires retrievability for the control of adverse impacts to the environment. This sense of retrieval is, for present purposes, the same as the health and safety rationale in 10 CFR 60.

2.3.3. 40 CFR 191

The regulations in 40 CFR 191 are those promulgated by the EPA which describe the performance requirements for the repository engineered barriers and the geologic setting. It refers to an ability to recover wastes after disposal. This provision would rule out certain disposal options, such as deep-well injection, considered undesirable by the Agency. The Agency specifically
asserted in its proposed rule that, in its view, any then-existing concept for a mined geologic repository would meet the requirement for waste recovery mentioned in the proposed rule. It considered for example that shaft closure and backfilling (decommissioning measures as proposed in current designs) would not preclude retrieval. The rationale was in part that the multiple engineered barrier system called for under 10 CFR 60 would be more than adequate in addressing concerns regarding the feasibility of such waste recovery.

In making these statements, the Agency seems to be tolerant of a higher level of cost and occupational risk in effecting retrieval than would be tolerated under 10 CFR 60. Such tolerance is obviously needed if the difficulty of the type of post-closure retrievability encompassed by the Agency position is to be accommodated. The Agency's position appears to be that future generations would have the option -- even if a desperate one by today's standards -- to remine the repository and recover the wastes if necessary. Regarding the design and site characterization data, the requirement for retrievability of waste under 10 CFR 60 would appear to be the more stringent.

These regulations (40 CFR 191) do specify reduction of exposure to the public to the extent reasonably achievable and specify preclosure and postclosure requirements. These are incorporated by reference in 10 CFR 60.111.

2.3.4. 10 CFR 960

Site characteristics that are qualifying, disqualifying, favorable, or unfavorable for a repository are listed in 10 CFR 960. These were the grounds upon which the DOE was to designate and rank sites for characterization. The preclosure guideline on rock characteristics does not mention retrieval specifically. It does mention repository operation, which would presumably encompass retrieval. Qualification/disqualification is related to the way in which the rock characteristics do or do not present significant risk to health and safety of personnel, taking into account mitigating measures based only on reasonably available technology. Favorable conditions are related to flexibility in horizon and layout selection and the ability of the openings to be stable with minimal or no support. Potentially adverse conditions are related to lack of flexibility in layout and positioning of the repository, need for engineering measures beyond reasonably available technology, need for extensive maintenance of openings, potential for deleterious rock mass reaction to repository-induced conditions, or occurrence of unfavorable rock features such as faults. It could be, and has been, debated whether retrieval systems are within the scope of "reasonably available technology". Obviously, successful demonstrations of the types dealt with in this paper would go a long way towards resolving these debates and, thereby, reduce the scope of potential challenges to the DOE's findings of site suitability. "Reasonably available technology" referred to in 10 CFR 960 is technology that would be available and delivered at the time it will be required.
2.4. Other Source Documents

In 1985, the DOE issued a Draft Position Paper on Retrievability. The NRC and others commented and a revised position was incorporated in 1986 into the GR (Generic Requirements) for a mined geologic repository, as Appendix D (OGR/B-2). Frequent reference will be made to this document in this paper. In addition, notes and observations from the July, 1985 NRC-DOE meeting regarding the DOE position paper were reviewed, as was the formal transmittal of NRC comments on the draft position (letter to Ralph Stein, DOE, dated 30 August 1985, from Hubert J. Miller, NRC). The GR and lower-tier design guidance proceeding from it, will govern the purpose and progress of the retrieval allowance developed for the design.

This technical paper is written at a time when a single site, that of Yucca Mountain in Nevada, is being proposed for site characterization. Therefore, although it is the aim of this paper to be as broadly applicable as practicable, it is important that the observations made herein be relevant to the potential retrieval plans and conditions at the Yucca Mountain site. Therefore, the retrieval plans in the Site Characterization Plan Conceptual Design Report (SAND 84-2641), particularly Appendices D, E, J, and L-2, were reviewed.

An NRC publication that deals specifically with retrieval that was considered in preparing this paper is NUREG-3489 (Assessment of Retrieval Alternatives for the Geologic Disposal of High-Level Wastes, by Engineers International, Inc., 1982). This report identifies the generic and site-specific problems in attaining waste retrieval in various media.

Finally, the NRC's Regulatory Guide 4.17, Standard Format and Content of Site Characterization Reports, gives guidance relevant to the parameters important to retrieval that should be addressed during site characterization.
3.0. CONCEPTS AND TERMINOLOGY

The questions of retrievability and advance assurance of retrieval pertinent to licensing introduce new concepts not normally encountered on engineering projects. For purposes of this technical paper, the concepts and terminology used herein are defined in the following discussion.

3.1. General Goals of Retrievability

The overall goal of 10 CFR 60 is to ensure the health and safety of the public with respect to nuclear waste disposal activities connected with a geologic repository. It also requires measures to assure the safety of workers involved in waste handling. These goals cannot be assured unless the waste is kept under control at all times. The essence of the regulatory process is to assure this control of the waste.

This can be appreciated through the Statements of Consideration to 10 CFR 60 and the language of 10 CFR 60 itself, covered in the previous chapter. Were the waste not retrievable, the decision to leave the waste in place would, in effect, be irrevocably made merely by the act of emplacement, regardless of whether such a decision would otherwise have been justifiable on health and safety grounds.

The desired waste control takes several forms. During the operational period, direct human control of the waste is possible, through containment. Containment is initially afforded by transportation casks, later by confinement within the waste handling building, and finally, during subsequent transportation, transfer, and emplacement operations, containment is afforded by the waste container itself. However, once the container is emplaced, direct control would be relinquished, unless the waste were fully retrievable.

Even following repository closure, the regulations provide for some control of the waste. During this period, even though direct, human control of the waste is relinquished to the geologic setting, indirect control remains, through the selection and preservation of the geologic setting as an isolating medium. This is permitted to occur only after it is acceptably assured that the geologic setting will provide effective isolation of the waste, and that the waste container will continue to reliably afford containment.

Before any measure of direct control of the waste is relinquished to the geologic setting or to the waste container, the satisfactory performance of the repository system must be assured. Therefore, if waste is to be emplaced, it must be retrievable. Furthermore, if waste is to be retrieved, the retrieval
action must present an opportunity for control that is at least equivalent to that of simply leaving the waste in place.

Retrievability is, therefore, a critical provision for control of the waste. In a very real sense, it is the ultimate safety provision in the licensing process and in the design. If the waste is not fully and safely retrievable, then it is out of full and direct control. This must not occur until a decision can be justified to accept the indirect sources of control afforded by the geologic setting and waste container.

3.2. "Retrieval" Versus "Retrievability"

In the past, confusion has arisen when the terms "retrieval" and "retrievability" have been used. Recent program guidance from both NRC and DOE have sought to resolve this situation. "Retrieval" refers to the act of physically removing emplaced waste. Retrieval is not mandated in 10 CFR 60 except as considered warranted by the Commission. "Retrievability" refers to the capability to retrieve the waste, and is a regulatory requirement.

3.3. Time Periods for Retrieval and Retrievability

The time required for retrieval and retrievability are set forth in 10 CFR 60.111(b)(1) which has been paraphrased by the DOE in Appendix D to the Generic Requirements document (GR) for a geologic repository (DOE document number OGR/B-2). The wording of 10 CFR 60.111(b)(2) has been included in Chapter 2 herein and is not repeated here. However, several salient points merit special mention.

- Retrievability must be preserved from the time emplacement is initiated until after a Commission review of performance confirmation information. The rule does not define "retrievability period". The 50-year retrievability period following the beginning of waste emplacement that is referred to in the Rule is a design guideline and the Commission could specify a different period for design purposes, whether or not it is requested by the DOE. Regardless, the retrievability period in practice must extend through the Commission's review of the performance confirmation program, or (obviously) until full retrieval is complete.

- Retrieval is to be accomplished on a "reasonable schedule", which is described for illustration purposes as approximately the time required to construct the repository and emplace the waste. There is nothing in 10 CFR 60 that precludes establishing a different retrieval schedule should conditions so warrant. At present, repository construction is projected
by the DOE to take 6 years and emplacement an additional 28 years, so that the retrieval schedule for present purposes would be, at most, 34 years after retrieval commences.

The two points above mean that the design basis, and the current regulatory guidance, are such that retrievability must be maintained for 50 years following the beginning of emplacement, and that retrieval would therefore be possible at any time during this interval. Retrieval of the entire waste inventory could theoretically be initiated just prior to the expiration of the 50th year and could require, under present design concepts, as much as an additional 34 years to complete, for a total of 84 years. Since waste not yet retrieved after the 51st year would nonetheless need to be retrieved on a reasonable schedule, "retrievability" must be maintained throughout the retrieval period also.

The design periods are, in essence, hypothetical. What is significant for licensing is that assurance of retrievability must prevail for a very long period (as compared to most engineering lifetimes) and must encompass retrieval conditions as well as the more-quiescent conditions expected for undisturbed, emplaced waste.

In its position on retrieval and retrievability, the DOE has mandated that retrieval would be carried out "as quickly as is safely practicable" (OGR/B-2 Revision 3, p. D-6), the requirement for safety being preeminent. However the DOE also notes that the period of preparation for retrieval may be lengthy and that retrieval itself may require more time per unit of waste than emplacement (ibid.). Also, the DOE has asserted that there would be no time limit on partial retrieval (retrieval of less than the full waste inventory) if emplacement operations are continuing (ibid.). This portion appears to assume that emplacement and retrieval operations could occur simultaneously.

3.4. Level of Assurance of Retrievability

Perhaps the most significant questions regarding consideration of retrievability in licensing have to do with how "retrievable" the waste has to be; in other words, What level of retrieval success must be assured before there is adequate justification for issuance of a license? Since projections of retrieval success will be subject to uncertainty, a related question is brought up: To what extent can uncertainties about achieving the projected level of retrieval success be tolerated within the requirements of the regulations? Does the Commission have to have 100 percent assurance that 100 percent of the waste will be "retrievable" in accordance with all the regulatory constraints 100 percent of the time? Or is some lesser degree of assurance acceptable?

The Rule, 10 CFR 60, does not specifically define the extent to which the
Commission must be assured of retrievability before a license to emplace waste could be granted. Elsewhere, however, the Rule introduces the concept of "reasonable assurance" with regard to other measures of performance (10 CFR 60.101(a)(2)). Unfortunately, the Rule does not define "reasonable assurance". Therefore, within the context of the discussions herein, "reasonable assurance" of retrievability will be held to be that level of assurance necessary to establish that the design, and retrieval provisions contained in any retrieval plans developed by the DOE, will result in full control of the waste, in accordance with the performance objectives and safety requirements of 10 CFR 60 until the time of repository decommissioning, and in accordance with the provisions of 10 CFR 60 regarding exposures in both restricted and unrestricted areas. (Here, we again stress that these performance objectives require retrievability, as well as containment and preservation of the isolation characteristics of the geologic setting, during the preclosure period.)

Retrieval can be viewed as the ultimate safety provision in the regulations governing a repository. However, it is also true that retrievability may never be needed; in fact, retrieval is referred to as a "contingency" or "option" in both NRC and DOE documents. Because of this, care must be taken not to acquire the attitude that retrievability need not attain the same level of design as other repository systems with safety or protection goals. Such an attitude could be used to justify deferral of retrieval system designs to some future date, when they would be "worked in" to the repository system as it had evolved at that time. The intent of the regulations seems to require a greater level of assurance than would be expected from add-ons to a pre-existing design. Rather, the process of making design choices and provisions should involve retrievability in concert with other aspects of the operating and safety systems.

Therefore, a design or plan for retrieval must provide a level of protection for workers, the general public, and the environment, equivalent to that which would be required of any other aspect of repository operations. Concepts, designs, demonstrations, and tests documenting retrievability and submitted in support of licensing should therefore be sufficiently comprehensive to establish that all the applicable regulatory requirements will be met.

Since retrieval must take place in accordance with the provisions of 10 CFR 60 regarding safety, containment, isolation, and maintenance of the retrieval option for the unretrieved waste, and other objectives such as the ability to retrieve within the required time, and since other regulations such as 10 CFR 20 also apply, the retrieval concept should not be considered viable if compliance with these requirements cannot be demonstrated to the satisfaction of the Commission. If such compliance cannot be demonstrated, "retrievability" cannot be said to exist.

3.5. Site-Specific Retrieval System Design Provisions

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Those aspects of retrieval and retrievability that are impacted by site conditions must be covered by data collected during site characterization. "Site Characterization" is defined in 10 CFR 60.2, as "the program of research, both in the laboratory and in the field, undertaken to establish the geologic conditions and the ranges of those parameters of a particular site relevant to the procedures under this part." The Rule does not restrict the period of site characterization in terms of the licensing schedule. Accordingly, "site characterization" could extend beyond the time of License Application (10 CFR 60.102(d)). However, it is our opinion that the period, during which demonstrations to establish retrievability would occur, should not extend beyond this point. In accordance with 10 CFR 60.24, the license issued by NRC may rest upon (or even be contingent on) information obtained during construction.

It is the intent of this paper to ascertain what level of demonstrations and related studies should be planned to occur during site characterization to adequately support a reasonably-complete license application. It is the view of this paper that further demonstrations and development may be needed to correct specific deficiencies, if any are found, in the technical support submitted for the application for the construction authorization. Such tests and demonstrations would therefore be contemporaneous with repository construction. To the extent that uncertainties in retrieval plans and designs could affect basic aspects of repository construction, and to the extent that some construction (such as completed excavation) may be irrevocable whether unfavorable to retrieval or not, the deficiencies should be corrected and questions about the retrieval system at the time of repository construction should be answered. At the least, all aspects of retrievability that could potentially be limited by site characteristics (as expressed either in the retrieval system or in repository construction) should be resolved within the scope of site characterization prior to construction authorization.

Therefore, for these site-specific aspects of retrievability, the applicable period of site characterization should end prior to the application for construction authorization. In support of this, 10 CFR 60.31(a)(3) states that a construction authorization may be issued if the Commission has reasonable assurance that "the site and design comply with the performance objectives and criteria contained in Subpart E of this part", with Subpart E containing the requirement for retrievability embodied in 10 CFR 60.111(b). It is noted that the Construction Authorization may be made conditional, per 10 CFR 60.32(a), and that other parts of 10 CFR 60 describe design update reporting requirements consistent with the data obtained through site characterization activities (10CFR60.18 (g)).

3.6. "Retrieval" Versus "Removal" of Emplaced Waste

The Rule provides for retrieval as a means to implement and make meaningful the NRC's decision to close the repository or not. The DOE presumed
that the "retrieval" referred to in the Rule is that which the NRC would require because of "evidence that the health and safety of the public would otherwise be adversely affected by the emplaced waste" (OGR/B-2, revision 3, p. D-3) and if the Commission "has cause to believe that the geologic repository isolation system as planned and implemented will not meet the performance standards and objectives" governing waste disposal. The DOE position also considers the effects on the environment to be the same as the effects on public health and safety (ibid.) so that the provision for "retrieval" called for in Section 122 of the NWPA is also addressed in the DOE position. "Retrieval" could also occur for resource recovery reasons at the discretion of the DOE, subject to applicable NRC regulations and the NWPA. All other waste removal is not considered "retrieval" for purposes of the DOE position.

Certain aspects of waste removal fall under NRC regulations regardless of the purpose and it is likely that many of the activities engaged therein would be identical to similar steps taken for the form of "retrieval" identified by the DOE. Movement of waste within the repository for any reason must conform to applicable regulations. Also, the ability of the repository to meet the performance objectives for the undisturbed waste must not be compromised by waste removal activities, regardless of the purpose for the removal of the waste. Since it is probably impractical and unnecessary to design two entirely different waste removal schemes, one for "retrieval" and one for non-"retrieval", when most of the regulatory standards would be the same for either case, it would appear that some "retrieval" systems and components would be fully operational and would be used occasionally in waste "removal" (performance confirmation purposes, transferring waste for operational reasons, or other purposes).

The reason for distinguishing waste "removal" and "retrieval" may actually have the most to do with differences in the expectation of off-normal or hostile conditions. Waste movement ("removal") not falling under the DOE's definition of "retrieval" would be expected to take place under normal conditions, with little or no likelihood that off-normal conditions would be encountered, whereas "retrieval", which by the DOE definition would necessarily be accompanied by some perceived threat to health and safety, would be more likely to encounter off-normal conditions. Nonetheless, in neither case could measures for environmental or personnel protection against off-normal conditions be ruled out. Equipment and procedures to support retrievability under 10 CFR 60 should therefore appreciate that off-normal conditions for waste retrieval are the principal, although not exclusive, concern.

With these observations made, this technical paper will use the term "retrieval" when removal of the waste is required by the NRC under its regulatory authority. This technical paper does not address the need for "retrieval" for resource recovery purposes, except insofar as NRC regulations apply. All other relocation of emplaced waste is referred to as "removal" in this paper rather than "retrieval", although, as pointed out previously, certain NRC regulations pertaining to waste movement will also apply regardless of
nomenclature.

To our knowledge, the NRC has neither accepted nor disputed the DOE's concept of "retrieval" as quoted above.
4.0. INFORMATION NEEDED FOR ADEQUATE ASSURANCE OF RETRIEVABILITY

4.1. Systems and Components Important to Retrievability

In Section 3.4., Level of Assurance of Retrievability, it was shown that various regulatory requirements, besides the ones requiring the ability to remove the waste, will be satisfied in a design that truly incorporates retrievability. To establish that the waste "is retrievable" it must therefore be shown that the proposed retrieval system will accomplish the following:

- Establish suitable environmental conditions for retrieval.
- Attain access to panel and emplacement drifts.
- Attain access to emplacement sites (waste package locations).
- Assure personnel and public radiological safety through appropriate monitoring, surveys, shielding and ventilation measures, before, during, and following actual retrieval operations.
- Contact, grasp, and withdraw waste packages and any radioactive material or debris that may have accrued from waste storage or retrieval, with an acceptable expectation of success.
- Safely transport to the surface the waste containers and any radioactive material or debris recovered, while maintaining containment.
- Provide adequate waste handling capabilities for retrieved waste both underground and on the surface such that safety, containment, and any continuing repository operations are not adversely affected.
- Assess the post-retrieval radiological condition of the former emplacement sites and take whatever preventive, as well as remedial, action is most effective for protection of public health and safety.
- Decontaminate retrieval equipment as appropriate, and control and properly dispose of all decontamination effluents.
- Assure continued containment, isolation, and retrievability of the remaining waste inventory.
- Accomplish retrieval in the time specified as necessary under the
circumstances requiring retrieval.

It must be shown that each of these objectives will be satisfied if claims of "retrievability" are to be credible. For example, it is not sufficient to merely indicate a high probability that remote access to waste packages will be possible, if adequate protection of public health and safety requires that all packages targeted for retrieval must positively be removed, and if overcoming a failure to gain remote access could compromise containment and retrievability of the waste. In such a case it must be shown that access and removal of all waste would not require measures that could compromise safety and containment, or preclude retrievability. A considerable level of modeling followed by realistic demonstrations would be needed to provide reasonable assurance of retrievability in this case.

In order to establish retrievability, it is necessary to consider the range of parameters, both site-specific and non-site-specific, that impact the assurances itemized above.

Some categories of systems, components and parameters that will be crucial to the retrievability of waste are as follows:

- Drift stability (ground support) needed to establish and maintain safe access to and from emplacement sites.
- Borehole and liner configuration, stability, and construction.
- Retrieval equipment involved in the physical location, contact, grasping, withdrawal, and transportation of the waste.
- Method and records of emplacement; emplacement configuration; characteristics of the waste and its container.
- Ventilation and ability to establish the necessary environment for retrieval, including contribution to control of rock mass behavior, as applicable.
- Anticipation of, and development of procedures for, normal and off-normal conditions together with consideration of post-retrieval consequences.
- Surveys, shielding, inspection, and monitoring of releases, drift and emplacement hole conditions, and other parameters before, during, and after retrieval operations and conditions.
- Handling, transportation, and interim storage of waste materials, including possible radioactive debris or materials accruing from the retrieval process, and all effluents from retrieval, including decontamination effluents and ventilation air.

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o Decontamination and maintenance procedures.

o Anticipated and unanticipated processes and events.

4.2. Assessment of Systems and Components

The systems, activities, and components above will be reviewed by the NRC to determine if the design truly presents retrievability. Due to the complex and unprecedented nature of some of the systems and activities required in retrieval, the analyses conducted by the DOE and the reviews performed by the NRC must be both thorough and conservative.

Test programs, construction experience, and ESF operational experience will constitute a data base from which development of retrieval concepts, and assessments of retrievability, may be begun. The retrieval concepts must encompass the full range of conditions and circumstances that will be involved, so that relevant and meaningful assessments of retrievability can be made. The following, in our opinion, are minimum requirements that have relevance to site conditions. Some are entirely site-specific and a few are indirectly site-specific in that they rely only partially on site data.

o Rock Mass Characteristics

- strength and deformability, under repository-induced conditions, and at various levels of confinement corresponding to pillar interiors, drift walls, and contact areas with borehole liners
- porosity and level of saturation, both initially and at the time of retrieval operations
- thermal properties -- ability to conduct and store heat, and transfer it to passing ventilation
- geochemical environment and variations
- hydrogeological environment and variations
- in situ and induced stresses, both mechanical and thermomechanical, including the effects of pore pressures, if any
- strength, deformability, occurrence, and hydrologic characteristics of discontinuities: joints, fractures, faults, bedding planes, lithophysae, anisotropy in rock fabric, and so on
- time-dependent properties, if any, under repository-induced conditions

- rock-structure interaction for borehole liners, equipment positioning systems, equipment reaction points, and rock support systems

- ambient rock temperature and gradient.

o Construction and Operational Data

- water control/infiltration measures and effectiveness, including control of effluents, such as from decontamination

- ventilation effectiveness, resistances, heat removal characteristics, filtering, variations in networks, bulkhead construction and relocation, need for additional shafts/drifts

- blasting damage and disturbed zone characteristics, which will produce irregularities in excavated surfaces relative to borehole closures, shielding closures, positioning of equipment, cutting of rock, etc., and which will affect ground control

- dust production and control

- vibration control and effect on rock, supports, liners, and waste packages

- ground support effectiveness and longevity under repository-induced conditions

- procedures for re-excavation, if applicable, and for blind location of waste packages

- incidence of unexpected ground conditions and provisions for same

- waste handling, transportation, and disposal methods, both for containerized and unpackaged waste materials; rate, efficiency, reliability

- operational analysis to determine responsiveness to off-normal conditions or unanticipated events given subsurface access, ventilation, and space limitations

- processes or events in between the time of emplacement and
retrieval
- inspection procedures for waste packages, bulkheaded drifts, and emplacement boreholes given likely ranges of conditions in the subsurface
- acquisition and storage of emplacement records
- monitoring of air and fluids prior to, during, and following retrieval
- utilization of equipment: maintenance, training, human factors suitability of equipment to retrieval environment, alignment at emplacement site
- redundancies in operating, support, instrumentation, monitoring, ventilation, and other systems
- removal and handling of overcoring cuttings, excavated muck, and so on.
- handling of individual waste packages that are at very high skin temperatures

- Unanticipated processes and events
- Waste package design in view of retrieval loadings and geochemical environment

Site characterization data must encompass the combinations of these parameters that would be experienced in retrieval. It is seen that there are information needs that combine and extend basic site characteristics in ways that are important in retrievability, such as performance of rock support under widespread elevated temperature conditions, efficiency in removing heat from extensive regions of repository workings through ventilation, impact of vibrations and pulling forces on waste package integrity, and many others. These combinations will govern the expectation of retrieval success, but may not be completely covered in the site characterization program. These considerations and their synergistic effects constitute a need for separate demonstrations and analyses, to which site characterization data collected for other reasons may contribute.

4.3. Required Demonstrations of Systems and Components

Retrieval systems and components will need to function within the range of conditions prevailing at the time of retrieval. While site characterization data will help define those conditions, the effectiveness of retrieval
operations cannot be assured unless the performance of the retrieval systems and components is assured. Therefore, the function of these systems and components must be studied through demonstrations that are relevant to actual retrieval conditions.

Since retrieval constitutes a contingency that may never be used, but that is critical nonetheless to the assurance of full control of the waste until decommissioning and closure, a conflict arises when approaching the problem of how to demonstrate retrievability. On the one hand, complete knowledge of the retrieval system and its performance under realistic conditions would seem to be required. However, this would require also that the technology of retrieval be fully-developed and proven, covering the full range of repository conditions and encompassing human factors, such as training and operator skill. On the other hand, it can be argued that such a level of design is an unnecessary and even detrimental burden on the designers, since the range of potential retrieval scenarios is large and, moreover, allocation of design resources to solving such a range of hypothetical problems could detract from the efforts to design repository systems that are expected to be necessary. Furthermore, such a level of assurance may not even be possible for a new technology such as retrieval. It will therefore be necessary to judge whether "reasonable assurance" of full retrievability has been attained in the design, but it would not be advisable to require full proof of retrievability in every conceivable case.

If components or operations whose failure could preclude retrievability have attributes that are not covered by the construction experience or site data that would be expected to grow out of the site characterization program, then the NRC would require a demonstration sufficient to evaluate the reliabilities of such components or operations, within the context of "reasonable assurance".

In particular, demonstrations of retrieval equipment would most likely be required for items that incorporate new technology or combinations of technology that have not been proven through field use for similar applications. Examples of equipment falling into this category would be the retrieval systems and components used to extract waste packages from boreholes.

Another category would incorporate items of equipment or processes where prior applications exist, but are changed significantly for the intended retrievability concept. An example of this type of equipment would be the systems and components for retrieval of waste when off-normal conditions exist.

4.3.1. Types of Demonstrations Proposed by the DOE

Three types of demonstrations are outlined in SAND 84-2242, entitled
"NNWSI Project Retrievability: Strategy for Compliance Demonstration". They are:

1) Proof-of-Concept Demonstrations
2) Prototype Demonstrations
3) In Situ Demonstrations

Proof-of-Concept Demonstrations

SAND 84-2242 indicates that Proof-of-Concept demonstrations will not be required for the vertical emplacement configuration because a demonstration was performed in granite at the Climax facility, NTS. These tests for the most part were used to determine the feasibility of excavation and vertical boring, and include coring up to 152 mm ("6") diameter holes, but do not include overcoring to retrieve a cask with a diameter of approximately one meter. Should this configuration be chosen, Proof-of-Concept demonstrations for overcoring may be required.

According to SAND 84-2242, Proof-of-Concept demonstrations for the horizontal emplacement configuration would include:

1) Borehole Drilling
2) Borehole Components
3) Turntable and Emplacement Mechanism
4) Retrieval Backup System

After these Proof-of-Concept demonstrations, a decision as to which is the preferred configuration (horizontal or vertical) would be made and then prototype demonstrations would be done for the selected configuration.

This could be a very costly and time-consuming approach. The choice between vertical and horizontal emplacement should be evaluated in detail and potential risks carefully compared so that there is justification for the expense and time involved with Proof-of-Concept demonstrations of horizontal emplacement if this approach is to be used.

It is our opinion that the Proof-of-Concept demonstrations for the horizontal configuration are necessary, but only if the benefits that would be derived from horizontal emplacement can justify the cost and performance risks involved. For vertical emplacement the most important Proof-of-Concept demonstration would probably be for the overcoring and container withdrawal procedures under off-normal conditions.

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A satisfactory scale for these types of demonstrations may be difficult to determine, especially in demonstrations associated with borehole equipment and fittings, due to the fact that the actual size of the boreholes is small in relation to drift size and operating or development equipment sizes. The scale of the models should be sufficient to allow a fairly detailed and realistic demonstration to be conducted, particularly with respect to waste container size, weight, and temperature.

It would be expected that site characterization data would be sufficient to meet most of the Proof-of-Concept requirements for remining, ground support performance, rock mass disturbance, and ventilation, so long as separate models and analyses dedicated to retrievability are performed. Site characterization results may not directly cover all geologic conditions, however.

Prototype Demonstrations

Whichever configuration is selected will require full-scale, fully-operational demonstrations. As stated in SAND 84-2242, the demonstrations would include:

1) Borehole drilling
2) Borehole preparation
3) Waste emplacement
4) Waste retrieval

It is our opinion that the waste retrieval demonstration should include simulated "off-normal" conditions and should be conducted in an underground environment under simulated repository conditions. With the number of boreholes to be placed in the repository, off-normal conditions should be anticipated. It will be necessary to show that a viable method of retrieval does exist for such conditions no matter how unlikely their occurrence may be. Site characterization data and operational analyses should be presented in support of the ranges of conditions covered by prototype demonstrations.

In Situ Demonstrations

The DOE proposes to establish a training area for retrieval and emplacement operations and recommends that representative boreholes within the repository be selected for performance confirmation purposes -- all boreholes so chosen would be fully instrumented. Because this implies that waste emplacement would previously have been allowed, this is a suitable intention, only so long as prototype demonstrations have previously accomplished in the
rock mass of interest, with repository-induced conditions, consideration of post-retrieval performance incorporated and results available to support licensing.

Instrumentation is not detailed in SAND 84-2242 and will be discussed below.

4.3.2. Demonstrations and Site Characterization

Data on rock properties and construction experience acquired during site characterization will have to be a prime consideration for Proof-of-Concept and prototype demonstrations. The demonstrations should reflect the latest data acquired during site characterization and thus the actual repository conditions as can best be determined or modeled at the time of the demonstration.

It is our opinion that Proof-of-Concept and prototype demonstrations should be a part of the site characterization activities for the following reasons:

1) Should a particular piece of equipment or system not perform well during the demonstrations, adjustments and/or other options can be developed prior to a final licensing decision, without major delays in the repository licensing process.

2) Licensing cannot proceed without positive assurance that retrieval is not precluded.

3) Time is a primary concern. Building equipment, gathering data, demonstrating equipment and assessing demonstrations will require a good deal of time.

4) Should unexpected site conditions be encountered during construction, adjustments to retrieval systems can be made accordingly.

5) Instrumentation programs, for performance confirmation programs in which retrieval would occur, can be developed during prototype demonstrations so that the in situ testing/instrumentation will be well developed during the site characterization phase and adjusted as needed for the performance confirmation demonstrations.

4.4. Instrumentation, Testing and Quality Control for Retrieval Demonstrations

Because retrieval equipment will be used in an extremely harsh
environment, it should be demonstrated and proven in an environment that resembles the actual or anticipated environment as closely as possible.

Major factors to be considered are:

1) High temperatures/thermal expansions
2) Squeezing and possible linear deformation or failure
3) Isolation and monitoring for radioactive contamination — solids, gas, and fluids
4) Ventilation and cooling efficiencies/time
5) Emplacement Drift stability and size limitations
6) Tolerances required for boreholes
7) Size and weight of waste packages to be handled.

These factors will require consideration for normal and off-normal conditions to assure the retrievability of waste packages.
5.0. LEVEL OF RETRIEVAL DEMONSTRATION NEEDED DURING SITE CHARACTERIZATION

Previous discussion in this paper has shown why retrieval should be afforded the same level of design and assurance as any other feature of the repository providing public or worker safety assurances. The aim of demonstrations should be to fulfill operational analyses and design studies that are not fully-supported by general site characterization data or ESF operating experience. While these assurances, and therefore the data and demonstrations they rest upon, are needed before license issuance and in many cases before, construction authorization, it is not necessary for retrieval designs and demonstrations to outpace the repository design. However, data and demonstrations sufficient to support retrievability should not lag behind the design of repository systems such that retrieval system provisions could become "appendages" to repository systems, such as ventilation, muck handling, waste handling, monitoring and so on.

Ultimately, physical demonstrations of integrated retrieval systems, under realistic ranges of conditions, will be needed to assure the waste will be under sufficient control to justify a license to receive and process waste.

Up to that point, the function of integrated systems could be simulated from demonstrations of their principal subsystem components, so long as these components are also studied under realistic conditions. The level of simulation involved should diminish as the pre-license process advances. These "proofs-of-principle" (or Proofs-of-Concept, in current DOE nomenclature) must reflect a rational identification of the subsystems to be proven and show, through careful experimental design and repository systems analysis, how the subsystem studies taken together are representative of the performance of the retrieval system under realistic, repository-induced conditions.

The preceding chapter identified categories of information needs that should be satisfied, at one time or another, before it can be shown that the proposed retrievability provisions will in fact acceptably assure control of the waste. These can be divided into categories reflecting the degree to which they are site-specific or site-independent, and further, as to the nature of their impacts on repository design, as follows.

- Aspects that are site-specific and depend on gross rock mass properties could affect the basic repository layout and other design features that would be difficult or impossible to modify at the time of retrieval. Demonstrations to support these aspects would need to be essentially complete, and the principles essentially proven, prior to issuance of construction authorization. Examples are ventilation effectiveness (need to leave space for additional shafts
and drifts), or performance of rock support in heated drifts (may determine excavation limits). Most of the basic thermomechanical rock mass behavior tests and design/operations studies, such as detailed ventilation sequencing, fall into this category.

- Aspects that are site-specific, but do not affect comprehensive features of the repository initial construction, need to be supported by site characterization data, but some of these data could accrue from, or be collected during, repository construction. Examples are a widening of the range of rock conditions studied in borehole liner-rock iteration analyses, tests of the thermomechanical response of rock adjacent to faults or fractured zones during positioning of equipment and overcoring operations, strengthening of the concepts of ranges in repository conditions throughout the repository block, and initial tests of prototype equipment and systems for inspections, and for locating and extracting waste containers.

- Non-site-specific studies and tests that must be performed to support proofs-of-principle and prototype development may be performed off-site initially in mock-ups, but must eventually be proven in underground environments of equivalent harshness to that expected in a repository at the time of retrieval. Examples are performance of radiological monitoring and hydraulic actuating systems in hot, dusty environments; performance of overcoring and liner cutting equipment; development of maintenance, repair, and decon procedures covering a very large number of individual container retrieval cycles. Most of the very basic design parameters for these studies are already known or will be generated by site characterization activities, such as rock hardness, drillability, dust generation, and so on. However there may be data, particularly in terms of heat release and effects of heat on porosity/saturation, that are important to fundamental design concept development and may not be sufficiently covered in general site characterization activities unless they are identified in advance and factored into the site characterization plan. The concept development and system design of equipment that is non-site-specific or not highly site-dependent could be begun off-site and be contemporaneous with site characterization, to the extent that satisfaction of data needs allows.

Sufficiently-comprehensive proofs-of-principle and prototype testing would be adequate for authorization of construction. In situ demonstrations and tests of fully-integrated retrieval systems should be performed to support license issuance.

The repository design process should accommodate updates based on retrievability needs just as it would accommodate updates for any other design.
features. Interface controls, design change reviews, and technical developments used in the design process should incorporate retrievability criteria in a useful and enforceable way.

Retrievability depends in large part on site-specific environmental and rock behavior factors. The ability of the design to effect the needed rock behavior and environmental conditions under which the proposed retrieval system would operate, is a design parameter in itself. For example, the reliable operating range of each piece of retrieval equipment with respect to drift temperature and accumulated rock fall should be defined. This sets a performance requirement for both the ventilation and rock support systems with respect to retrievability. It is therefore incumbent on the designers to assure, through analyses and demonstrations, that the ventilation system will achieve the design goals and that the design goal rock mass behavior (which may depend in part on temperature and therefore ventilation) will be achieved, for a range of retrieval scenarios.

Performance factors that could give rise to retrieval, and performance indices governing retrieval (continued maintenance of containment, isolation, and retrievability as appropriate during and following retrieval) need to be encompassed by demonstrations. These will be partially, and in some cases entirely, site-specific. Performance expectations of the retrieval system may govern concept development: certain conceptual approaches to waste location and removal may be technically feasible for those purposes, but may pose such a threat to repository performance that it is unsuitable for detailed design.

Demonstrations and proofs-of-principle must be able to accommodate a retrieval decision; that is, the risks and benefits of retrieval or non-retrieval should be assessable before retrieval takes place. This impacts both the breadth and reliabilities of the demonstrations planned. Risks of leaving the waste in place should be assessable from the performance confirmation program. Risks of retrieval should be predictable from retrieval-specific demonstrations, as to the reliability of the retrieval system (ability to consistently achieve the design goals), and as to the performance goals claimed for the retrieval system. This will require a high level of operational analysis for a broad scope of retrieval scenarios to adequately document the reliability of the proposed system.

Tests to demonstrate both effects on performance measures and the reliability of the retrieval system will require proofs of different sets of principles initially. Retrieval should be incorporated into repository performance analyses for the waste package, worker and public preclosure safety, and post-closure impact. Failure analyses should be performed conservatively to provide initial reliability estimates because the reliability of an integrated system may be much less than the reliabilities of its component parts. Prototype and in situ demonstrations must then be developed to check the results of these proofs-of-principle.