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SELECTION CRITERIA FOR CONTAINER MATERIALS AT THE PROPOSED YUCCA MOUNTAIN HIGH LEVEL NUCLEAR WASTE REPOSITORY

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ABSTRACT

A geological repository has been proposed for the permanent disposal of the nation's high level nuclear waste at Yucca Mountain in the Nevada desert. The containers for this waste must remain intact for the unprecedented service lifetime of 1000 years. A combination of engineering, regulatory, and licensing requirements complicate the container material selection. In parallel to gathering information regarding the Yucca Mountain service environment and material performance data, a set of selection criteria have been established which compare candidate materials to the performance requirements, and allow a quantitative comparision of candidates. These criteria assign relative weighting to varied topic areas such as mechanical properties, corrosion resistance, fabricability, and cost. Considering the long service life of the waste containers, it is not surprising that the corrosion behavior of the material is a dominant factor.

INTRODUCTION

The Department of Energy's Yucca Mountain Project (YMP) is evaluating a site at Yucca Mountain in Nevada for a proposed geological repository for the storage of high-level nuclear waste. High-level nuclear waste includes the most radioactive forms, such as spent reactor fuel and reprocessed defense program waste. The LLNL Nuclear Waste Management Program (NWMP) has responsibility for the testing, model development, and performance assessment of conceptual designs of the waste package. One portion of this work, the selection, modeling and testing of the container material, is being performed by the Metal Barrier Selection and Testing Task (MBST).

The primary performance requirement for the waste package is stated in NRC regulation 10CFR Part 60 [1] as "substantially complete containment" for a period of up to 1000 years. This is an unprecedented design lifetime for engineered materials and represents a substantial performance assessment challenge. Other requirements on the container include retrievability for fifty years, compatibility with the waste forms and other repository components, provision for transportation and handling, reasonable cost and readily available technology.

As described in the YMP Site Characterization Plan (SCP) [2], the proposed repository would be mined in volcanic rock about 300 meters below the ground surface and about 300 meters above the water table. This relatively dry environment without hydrostatic or significant lithostatic loads permits a thin-walled, corrosion resistant container. Decay heat from the spent fuel will warm the containers and the rock to as much as 250 C after the repository is closed, resulting in a 'warm' air-steam environment for several hundred years. Eventually the containers will cool enough to allow the possibility of water contact. The groundwater at Yucca Mountain is near neutral in pH and fairly low in ionic content. The gamma radiation from the waste decay will produce radiolytic alterations in the local environment in the early time period. A conceptual waste package design is a closed metal cylinder about 65 cm in diameter and 300 - 500 cm long with walls about one centimeter thick. The container will be sealed, probably with a closure weld.

The goal of the MBST task is to establish selection criteria for the container material, evaluate the candidate materials, select a material for advanced design studies, and provide performance models and test data for the selected material to allow performance assessment over the design lifetime.

MATERIAL SELECTION

The material selection is one portion of a unified program of selection, testing, model development and performance assessment [3]. Prior to the material selection, supporting information has been gathered, including existing data on material performance, conceptual container designs, fabrication and closure processes, and the Yucca Mountain environment. A formal set of selection criteria is being established to allow evaluation of candidate materials. Next, the established criteria will be applied to the gathered information to select the material for advanced studies. Advanced studies will include performance confirmation tests on the selected material and long-term degradation model development and validation to support the performance assessment of the waste package. The process of selecting a container material must consider both the engineering aspects and the unprecedented service lifetime required. The process must be well documented and conducted under a rigorous Nuclear Quality Assurance (QA) program to support the NRC licensing process.

The material selection itself will be a two-part process: a pass/fail decision and a quantitative scoring. First, the candidate materials will be judged against minimum acceptable parameters to meet regulatory requirements. Any material failing a minimum score will be eliminated. Second, the acceptable materials will be graded with a quantitative figure of merit for each parameter to allow comparison of the candidates. This type of selection process, of assuring first the minimum requirements are satisfied, then quantitatively comparing candidates, is similar to the Kepner-Tregoe [4] decision process of listing "Must Haves" and "Wants". This selection process partially determines the format of the selection criteria, requiring each criterion to have a weighting factor, a minimum requirement for acceptability, and a quantifiable parameter.

Many of the criteria are subjective in nature and there is likely to be a range of professional opinion on details of the selection process. Because of this, it is intended to obtain an independent opinion of both the selection criteria and the material selection by the process of Peer Review. A panel of experts in technical fields relevant to the selection has been established to perform this review.

SELECTION CRITERIA

A draft of the selection criteria has been prepared and subjected to an independent peer review. The draft criteria are divided into seven topic areas and contain 34 separate parameters. Each has a relative weighting factor, a minimum acceptable score and a quantitative scale. There are four performance-related topic areas and three topics related to other issues such as cost and fabricability. The topic areas and their proposed weighting factors are:

Weighting Factor	MATERIAL PERFORMANCE
14	A) Mechanical performance
30	B) Chemical performance (corrosion)
16	C) Predictability of performance
10	D) Compatibility with other materials
	FABRICABILITY, COST, AND OTHER CONSIDERATIONS
20	E) Fabricability
5	F) Cost
5	G) Previous experience with the material

The easiest and first division of the criteria was into the categories of material performance and non-performance topics. One of the major controversies involves choosing the relative weighting of the two categories. This relative weighting between performance and non-performance areas was argued back and forth quite a bit before settling into the current 70-30 split in favor of performance. Some have argued that performance should be primarily Pass/Fail and the Quantititive Score of those passing the performance requirements should be heavily weighted on other issues, primarily cost. Others have argued that material performance should outweigh everything else. The weighting factors selected are a compromise between more extreme opinions.

The seven areas listed above are condensed from a larger, more comprehensive set of topics included in the SCP which was generated by listing factors affecting performance, regulatory requirements and practical engineering concerns. The weighting factors are a compromise among a variety of opinions.

Within each of the seven topical areas there are several specific sub-topics, each of which receives a share of the topic area weighting. At this level the criteria are material-independent and are equally applicable to any candidate container material. It should be noted that each of the performance criteria must be considered for a variety of combinations of material conditions and environments (including irradiation). The "worst-case" combination for each material and criterion is the one used for evaluation. If the "worst-case" for a criterion is not readily identifiable, it may be necessary to evaluate several or all combinations of material condition and environment. The combinations of conditions and environments include the following:

Base material/Closure material (i.e. base metal/heat affected zone/weld)
As fabricated/Aged condition (effects of long-term low-temperature anneal)
Nominal environment/Potential environment (water quantity/composition)

Note also that many of the criteria are interrelated and may overlap in some areas. Synergistic interactions of the parameters must be considered in all cases, which greatly complicates the selection process.

At the next level of detail, the criteria are described by scalable parameters that can be quantified. This quantification may be either objective (such as relating a physical parameter to a score) or subjective (by professional judgement). In some cases a topic is described by only one parameter, for example A1) Strength is described by the parameter "yield strength":

A) Mechanical Performance
  A1) Strength
    Weighting Factor: 6
    Parameter: Yield strength

In other cases several parameters may be used to describe a topic, for example B1) General corrosion is divided into oxidation and aqueous corrosion:

B) Chemical performance
  B1) Resistance to general corrosion (oxidation, aqueous corrosion).
    Weighting Factor: 8

    B1a) Oxidation
      Weighting Factor: 4
      Parameter: Time average oxidation rate (micrometers/year)

    B1b) Aqueous corrosion.
      Weighting Factor: 4
      Parameter: Time average dissolution rate (micrometers/year)

While the criterion topic is material-independent, the scalable parameters, which describe the criteria, will vary with the material being evaluated, particularly in the performance topics. This is true because different materials have different properties and different susceptibilities to degradation. An example of this is found under the topic of localized corrosion, where one parameter is the likelihood that the repository environment contains an ionic species that is known to promote pitting attack in a concentration sufficient to cause a performance problem. Different types of metal are pitted by different ionic species. Therefore, the parameter would vary for different materials, but the intent of the criterion is the same, that is, to evaluate the degree to which pitting attack is a performance-limiting problem.

It should be noted that these selection criteria endeavor to condense a complicated set of interrelated phenomena and conditions into a sufficiently simple set of parameters to allow objective comparison of different materials. It is not intended to discuss in this document all of the details which must be considered during the selection. It is intended to provide the topic areas and quantitative framework for the selection.

It should be noted that this selection process is being performed in the interim between the first and second phases of a multi-phase iterative design process. The inputs to the selection are the products from the first "Conceptual Design" (CD) phase, and the material selection itself is an input into the second "Advanced Conceptual Design" (ACD) phase. Further material testing, container design and analysis, and repository environment determination will be performed during the ACD phase. After ACD the design and material performance will be assessed for adequacy prior to the start of the "License Application Design" [LAD] phase. Detailed description of the container performance requirements can be found in the SCP [2]. Container material degradation is discussed in the Degradation Mode Surveys [5]. Program documents which describe the results of the CD phase include results of material testing found in UCID-21044 [6] and engineering analyses of the CD container designs found in UCRL-53595 [7]. A separate program of Alternate Barrier Materials and Designs is also being pursued during ACD and will be evaluated as an alternative to the metal barrier prior to LAD. In such an iterative design process it is possible to begin with limited information regarding design, service environment, and material performance. As information is obtained in each of these areas and included in the next iteration, the level of detail and performance confidence increase.

As stated above, it is intended to have a two-part selection process. The first part is a "Pass/Fail" (P/F) to determine whether each candidate meets the minimum performance goals for the waste package, and whether it is a practicable material to use in this application. The second part is a "Quantitative Score" (QS) to determine a numerical value for each candidate, allowing the relative merit of each to be compared in order to select the "best" candidate. To support these goals, each parameter requires a passing score and a quantitative scale. In some cases, it is possible to correlate a measurable material parameter to the quantitative scale, and to identify a minimum or maximum passing value of that parameter. These passing scores should be values beyond which the material would not be acceptable for use. In other cases it is not possible to have such a closed set of parameter, scale, and passing score for one of three reasons: 1) the parameter may not be fully quantifiable, 2) a quantitative pass/fail mark may not be identifiable, or 3) there may not be sufficient data available at the time of material selection to rigorously score a candidate material on the parameter. In these cases, a subjective judgement of acceptable/unacceptable must be used. The collective professional judgement of a number of knowledgeable persons will determine the Pass/Fail portion of such criteria. The Pass/Fail will be a determination of adequate/inadequate for each material on the given property rather than a minimum or maximum passing score for the quantifiable parameter associated with that property. Any opinion of inadequate must be supported by a written explanation and if agreed upon by a consensus of knowledgeable persons will disqualify that material from further consideration.

With all of this included, the parameter example used before for oxidation looks like this:

B1a) Oxidation
Weighting Factor: 4
Parameter: Time average oxidation rate (micrometers/year)
Passing score: 1.0 micrometer/year maximum

Score:	1....2....3....4....5....6....7....8....9....10				
Scale:	100.	10.0	1.0	0.1	0.01
Units:	micrometers/year				

Note that the passing score would allow oxidation of 1mm, or 10% of the 1cm thick conceptual design wall during the first 1000 years as stated in the SCP[2] as the goal for oxidation resistance.

In presenting the criteria, additional commentary is often needed to explain the parameter or scale. In the example above, comments add that the averaged oxidation rate is for the expected temperature and gas-phase environment as a function of time during the containment period. Thus, the oxidation rate in the early years, when the container is hottest and the radiation field is highest, might exceed one micrometer/year, but the maximum oxidation expected over a 1000-year containment period would be limited to 1000 micrometers. This one parameter then involves the effects of time, temperature, radiation, chemical environment, and material condition. As stated earlier, the performance criteria should be judged for the worst-case combination of:

Base material/Closure material
As fabricated/Aged condition
Nominal environment/Potential environment

While it would seem consistent to have both a passing score and a quantitative scale for each criterion, in some cases it is appropriate to eliminate one or the other. Some topics do not really have a "passing score" below which the material is not usable. In these cases, only the quantitative score is established, and the passing score is marked "NA" for "not applicable". An example of this is <u>Previous experience</u>. There is really no minimum experience required, but a material with many established applications and standards should be more readily accepted in the licensing process. In other cases, there is a minimum requirement, but having more than that requirement does not really add to the usefulness of the material. An example of this is <u>Strength</u>. The container must be strong enough to handle all anticipated loads with a reasonable safety factor, but beyond that, great strength does little good. In these cases, the quantitative scale is omitted with an entry of NA.

It should be noted that the topic areas were selected to answer the questions of required performance and practicability and are material-independent. The candidate materials have received considerable thought and examination prior to being included in the candidate list. Therefore, it should be expected that most of the candidates will pass all of the minimum score (or adequacy) tests, and will score high on the quantitative scales. Indeed, some criteria or entire topic areas may yield no differentiation between the candidates. These criteria are still included in the process to document that the candidates meet performance or practicability requirements.

CONCLUSION

A draft set of selection criteria have been developed for selecting a container material to isolate high-level nuclear waste at a proposed repository at Yucca Mountain. There are currently 34 separate parameters considered, and it is expected that the criteria will evolve as additional information is obtained. The criteria parameters are shown in the detailed outline on the next page:

SELECTION CRITERIA OUTLINE (DRAFT)

A) Mechanical Performance
   A1) Strength
   A2) Toughness
   A3) Phase stability
B) Chemical performance
   B1) Resistance to general corrosion (oxidation, aqueous corrosion).
   B2) Resistance to pitting, crevice, or other localized attack.
   B3) Resistance to environmentally accelerated cracking EAC (stress corrosion cracking and hydrogen embrittlement).
      B3a) Threshold stress intensity for stress corrosion cracking
      B3b) Degree of sensitization (austenitic alloys/SCC)
      B3c) Threshold potential (austenitic alloys/TGSCC)
      B3d) Smooth specimen stress corrosion cracking.
      B3e) Likelihood of sufficient concentration of chemical species for stress corrosion cracking (for example: chloride for austenitic alloys, ammonia or nitrite for copper alloys)
      B3f) Likelihood of sufficient hydrogen concentration to cause degradation
      B3g) Hydrogen-sensitive phases (for example: martensite or sensitized material for austenitic alloys, oxide inclusions for copper alloys)
   B4) Resistance to microbiologically influenced corrosion
C) Predictability of performance
   C1) Existence of predictive methods to extrapolate degradation phenomena, and methods to extrapolate existing performance data to repository time scales and conditions, or ability to develop such methods.
   C2) Existence of long-term performance data.
   C3) Ability to generate required data.
   C4) Relative licensability of the material.
D) Compatibility with other materials
   D1) Interactions with waste form.
   D2) Interactions with the package environment and borehole liner.
E) Fabricability
   E1) Fabricability of container body.
      E1a) General formability
      E1b) Product qurlity
      E1c) Inspectability
   E2) Closeability of container.
      E2a) General process considerations
      E2b) External process influences
   E3) Inspectability of closure.
      E3a) General process considerations
      E3b) Detectability
   E4) Damage tolerance of the fabricated and closed container.
F) Cost
   F1) As-fabricated container costs.
   F2) Associated exceptional repository handling costs.
   F3) Strategic availability of raw material.
G) Previous experience with the material.
   G1) Previous relevant engineering experience with the material and closure.
      G1a) Variety of applications
      G1b) Years of experience
   G2) Existing engineering standards for the material and closure.
      G2a) ASTM Standards
      G2b) Other Standards

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