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U.S. DEPARTMENT OF ENERGY

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YUCCA MOUNTAIN

YUCCA MOUNTAIN SITE CHARACTERIZATION PROJECT

EXTENDED SUMMARY REPORT ON ENGINEERED BARRIER SYSTEM CONCEPTS WORKSHOP

JUNE 18-20, 1991
DENVER COLORADO

PREPARED BY

SCIENCE APPLICATIONS INTERNATIONAL CORPORATION

and

WESTON TECHNICAL SUPPORT TEAM

for

YUCCA MOUNTAIN SITE CHARACTERIZATION PROJECT

U.S. DEPARTMENT OF ENERGY

LAS VEGAS, NEVADA

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ACKNOWLEDGMENTS

The U.S. Department of Energy (DOE) wishes to acknowledge the following individuals who planned, organized, and reported the Engineered Barrier System (EBS) Workshop.

Planning for the workshop was accomplished by representatives from several organizations involved in developing and reviewing the EBS. These representatives included:

- Diane J. Harrison-Giesler, Yucca Mountain Site Characterization Project, DOE
- Alan Berusch, Office of Geologic Disposal, DOE/HQ
- Richard P. Morissette, Science Applications International Corporation (SAIC)
- Willis L. Clarke, Lawrence Livermore National Laboratory (LLNL)
- Paul Childress, Babcock & Wilcox Fuel Company

Organization and logistics for the workshop were managed by R. Morissette with assistance from Judy Youngs and Mary Brodeur, both of SAIC. The facilitator of each workshop session was Holmes Brown of Afton Associates. Andrea Jennetta, SAIC, recorded each session on audio tape.

Transcription of the audio tapes was performed by Mary Brodeur. The extended summary was prepared by R. Morissette and Gregory P. Fehr, SAIC, and Harold Cleary, Weston Technical Support Team.

The DOE would also like to acknowledge the efforts put in by those outside organizations who, without any funding from the Yucca Mountain Site Characterization Project, developed concepts, prepared technical submittals, and made presentations at the workshop. The participation of these outside organizations was crucial to the workshop's success.

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EXECUTIVE SUMMARY

The Yucca Mountain Site Characterization Project (YMP) held a workshop on EBS concepts June 18-20, 1991, in Denver, Colorado. The objectives of the workshop were to (a) provide an opportunity for outside organizations to present their ideas on EBS design, (b) provide a forum for the discussion of EBS concepts and the applicability of these concepts to extended life performance, and (c) solicit opinions from experts outside the program regarding the technical feasibility of an extended life EBS.

Thirteen concepts were presented by twelve outside organizations, and six independent technical experts provided their assessments of the concepts, extended life, and EBS development in general. The presentations stimulated technical discussion by both the independent experts and other experts in the audience. Participating in the workshop were over 100 attendees including representatives from the Nuclear Regulatory Commission (NRC), Nuclear Waste Technical Review Board (NWTRB), City of Las Vegas, Nye County, and State of Nevada. An independent facilitator kept the workshop focused and on schedule.

SESSION 1

The workshop was divided into three sessions. During the first session background information was provided by the DOE and LLNL on engineered versus natural systems and a systems engineering approach, which included examples of EBS concepts. This was followed by an NWTRB presentation which highlighted concerns with the EBS program and expectations from the workshop. Dr. Ellis Verink gave the NWTRB perspective on "extended life" as "a redundant, robust engineered barrier, which when used in conjunction with geologic barriers, would serve to increase confidence in the projections of repository performance."

Dr. Thomas Pigford of Berkeley compared the United States perspective on extended life to that of the Swedish and Swiss programs. Both the Swiss and the Swedes have developed sound EBS approaches based on good technical principles. However, because their repositories are in saturated zones, these approaches are not applicable to Yucca Mountain. Dr. Pigford recommended that the U.S. program look beyond the requirements for "substantially complete containment" and determine what the container can do to control radionuclide release.

The discussion period was focused on the performance of containment barriers, especially in the area of corrosion. It was pointed out that the issues of oxidizing versus reducing environments, kinetics versus thermodynamic equilibrium, and localized versus uniform corrosion should not be oversimplified. Predicting with confidence to 10,000 years may be difficult, and extended monitoring of the waste packages should be considered.

SESSION 2

Session 2 was dedicated to presentations and discussion of EBS concepts proposed by the outside organizations. The presentations included concepts for waste packages and approaches for modifying the surrounding near-field environment. The waste package concepts included both metallic and nonmetallic containers used as single or multiple barriers. Internal fillers and external packing concepts were also presented.

In addition to describing the design features of their concept, each presenter was asked to discuss processes relied on for containment, performance considerations, sensitivity to changes in service environment, fabrication, emplacement, and cost.

Although concern was expressed over the lack of data for the proposed nonmetallic and metal matrix materials, participants nevertheless agreed that several container, filler, and packing materials should be given consideration. Costs of the nonmetallic materials were considerably higher than the Site Characterization Plan (SCP) reference design concept with the exception of granite. Considerable interest was apparent for the thick wall, self-shielded concepts, especially if packaging could be done at the utility's power plant or at interim storage facilities. High package costs for these concepts were said to be offset by reductions in total system costs.

Extensive discussion during this session focused on the behavior of various materials in existing or engineered environments. Responses from the experts and other participants indicated many concerns which would need to be addressed on each concept presented. These concerns included fabrication and closure, cost, galvanic protection, localized corrosion, and stability of nonmetallics.

SESSION 3

Four of the six technical experts said that a 10,000-year waste package could be developed. The other two did not respond to this question. Each expert discussed the applicability of the concepts to extended life and provided general responses to the concept presentations. The following key points were made by the experts and other workshop participants:

- Concepts which have a distributed failure were considered more applicable.
- Multi-barrier and multi-purpose waste packages were favored. The latter could be utilized for storage, transport, and disposal.
- Material selection depends on how much time and money is available, and corrosion allowance materials tend to minimize both.
- Galvanic reactions are extremely unpredictable, and labeling of systems as thermodynamically stable or reducing should be done with caution.
- Ceramics are not necessarily thermodynamically stable or inert.
- Relying on natural analogues can be misleading because conditions are never exactly the same.
- Probabilistic approaches should be employed to perform comparative analysis on different EBS concepts.

- The modeling approach should be combined with a long-term (100-200 years) monitoring approach.

- Simplicity of the concept is needed.

- Developing accepted and well-understood solutions requires major sustained funding.

CONCLUSIONS AND RECOMMENDATIONS

The YMP can make the following general conclusions and recommendations from the completed EBS Concepts Workshop.

CONCLUSIONS

The objectives of the workshop were successfully achieved, and a broad range of concepts and approaches was presented and discussed. No changes in the Waste Package Plan resulted from the workshop. Development of a 10,000-year EBS is technically feasible, but a decision to pursue a more redundant and extended life EBS has not been made at this time.

Most conclusions made by the participants at the workshop appear reasonable. Disagreement among experts will make consensus difficult, and this suggests that the EBS design selected be well-understood and simple.

Major sustained funding is needed if the EBS program is to be successful and timely.

RECOMMENDATIONS

Most recommendations made by the participants at the workshop appear reasonable and will be considered by the DOE. Evaluating specific concepts may be difficult without more quantitative data.

Attractive features of different concepts should be considered in developing alternative concepts for the next design phase. At least one EBS approach should be selected now, and the data necessary for its evaluation should be developed. The approach should be simple, but robust, with potential for extended life well beyond 1,000 years.

Another EBS Concepts Workshop should be scheduled during 1993 which would focus on those concepts selected by the DOE for advanced conceptual design.

1.0 INTRODUCTION

In its Second Report to Congress and the U.S. Secretary of Energy, the NWTRB recommended that the DOE hold a workshop to investigate the possibility for developing a robust, extended life EBS that would contribute to containment beyond 1000 years. The DOE concurred with this recommendation and also considered such a workshop an opportunity to allow interested parties, outside the program, to submit concepts with potential for extended life. An announcement seeking participants in the workshop was released by the DOE on February 17, 1991, and published in the Federal Register on February 25, 1991 (Appendix A). Copies of the announcement were also sent to known potential participants.

Since the workshop could only handle a limited number of proposed concepts, the announcement requested that interested participants submit a short statement of their qualifications. Technical submittals would then be requested from qualified respondents. An information package (Appendix B) was sent with this request. Fifteen qualification statements were received, and all were accepted. Fourteen technical submittals were then received, and all were accepted for presentation at the workshop. Prior to the workshop, two respondents were unable to participate and their submittals were withdrawn. Acceptance of the technical submittals by the DOE was not to be construed as acceptance of the concept's technical feasibility.

To ensure open discussion and independent participation, the DOE retained a professional facilitator and outside experts in six relevant technical areas. A list of the experts is provided in Appendix C, and a list of attendees is included in Appendix E. Appendix D is the Workshop Agenda. The workshop was structured to allow 35 percent of the agenda for open discussion.

The workshop was divided into three major sessions: background information, concept presentation, and expert opinions. The intent of this summary is to extract and synopsize the many ideas, suggestions, and issues which were expressed during each session. The summary can then be used to update the Waste Package Plan, if necessary, and develop more detailed implementation plans. The entire workshop was recorded on audio tape; this tape has been transcribed and is the basis for this extended summary report. The audio tape or the written transcript will not be available for general distribution.

Opinions, claims, and other statements included in this report are those of the persons who made them at the workshop and do not necessarily represent views, positions, or policy of the DOE. Claims made on concepts are strictly those of the presenter of the concept and have not necessarily been reviewed or accepted by the DOE.

The DOE also plans to further evaluate the concepts presented, and all information provided by the participants will be used for this evaluation. This includes the written technical submittals, viewgraphs, audio tapes, and written transcripts of the verbal presentations. The presenters may be contacted if further information or clarification is needed. Results of these evaluations will be documented in other reports.

2.0 SUMMARY OF WORKSHOP

SESSION 1 - BACKGROUND

INTRODUCTION

Carl Gertz, YMP Project Manager, began by noting that the starting point for waste package discussions was the SCP, which contains a conceptual design for a reference configuration.

Gertz said past work had emphasized four areas:

1. Characterization of near-field environments.
2. Characteristics of spent fuel and high-level waste glass.
3. Studies of preliminary metallic containers.
4. Feasibility studies for fabrication and closure.

Gertz then said the YMP was getting ready to move to the next design phase, the Advanced Conceptual Design, scheduled for FY 1992. This required the YMP to identify and select concepts.

Gertz noted that the specific objectives for the workshop were the following:

1. Provide a forum for discussion of the concepts without any ranking.
2. Solicit opinions on extended life performance and its feasibility.
3. Provide an opportunity for outside organizations to present design concepts.

Gertz then introduced the Moderator, Holmes Brown. Brown noted there were four participating entities in the workshop:

1. The DOE and its contractors, who would explain objectives and goals of the workshop and the current status of the EBS.
2. Experts to critique presentations, ask questions, evaluate concepts relative to the checklist criteria, and provide personal evaluations of a 10,000-year waste package.
3. Presenters of alternative concepts.
4. Audience.

BACKGROUND

Michael O. Cloninger, DOE, provided key definitions:

1. The Disposal System (from the U.S. Environmental Protection Agency) is a combination of engineered and natural barriers.
2. The EBS includes all the waste packages, any emplacement boreholes, and the underground excavation, not including the seals.
3. Primary requirements for the EBS are specified by 10 CFR Part 60.
4. Extended life means containment of radionuclides for periods well beyond 1,000 years.

Cloninger then asked the workshop to consider the following questions:

1. What becomes important to materials systems performance behavior in the following time frames?
   a. 1,000 years
   b. 10,000 years
   c. 100,000 years
2. What impacts may the engineered and natural systems have on one another's performance for these periods?
3. What are acceptable performance levels for both the engineered and natural systems?
4. What are the standards of proof for performance?

Leslie Jardine, LLNL, explained the Waste Package Plan goal to develop two or more design concepts for further development in the next design phase. These concepts will result from a systems engineering analysis of all proposed designs.

Jardine refined the waste package definition to be the waste form, containers, shielding, packing, and other absorbent materials immediately surrounding the individual containers; the EBS was the underground structure, waste package, backfill, and possibly near-field host rock.

Jardine then described the repository environment:

1. Located above water table.
2. Desert environment.
3. Unsaturated overburden rocks above.
4. Possible water percolation through repository.

He also explained that work to date included:

1. Investigations in waste form characteristics.
2. Investigations of near-field rock-flow, transport, geochemistry, geomechanics, and hydrology.
3. Materials characterization.
4. Defining requirements and interfaces.
5. Testing.

Jardine then explained how the workshop's information would be integrated into the program, and this was continued by Donald Ruffner with more functional analysis and EBS mission information. [Requirements and constraints are evolved from broad to specific. Over 80 constraining requirements have been determined for the waste package and the EBS. Performance shall be verified.]

David Short explained 10 steps to generate preliminary concept descriptions:

1. Deal with constraints.
2. Focus on environment - four fields: hot/dry, cold/dry, hot/wet, cold/wet. (hot >100°C, dry = no liquid water)
3. Environmental processes and phenomena.
4. Provide for mitigation or enhancement of processes.
5. Identify information needs, develop models, test.

6. Synthesize - alternate engineered sketches.
7. Feasibility.
8. Summarize results after step 7.
9. Review work, documentation, traceability.
10. Collect preliminary concept descriptions for subsequent processing, ranking, etc.

Interaction of design factors was addressed with respect to hydrology: liners, sealants, packing, containers, and drainage. Similar interactions with radiation and thermal factors were presented. Several previous design concepts were highlighted showing how the above interactions and 10 steps have been considered to date.

Short emphasized that the Mission Requirements and the functional analysis from DOE Headquarters had not yet been finalized.

Donald Ruffner provided a list of non-container performance enhancements for consideration: liners, melt boring, sealants, drainage, mechanical and pH stabilizers, low permeability packing, air gap, ion exchange, precipitants, sorbents, flocculents, heat sealants, and umbrellas. He also emphasized the difficulties associated with developing an appropriate statistical probability model for life expectancy determination.

Ellis Verink, University of Florida, presented the NWTRB perspective on extended life performance; i.e., a "redundant robust engineered barrier, when used in conjunction with geological barriers, would serve to increase confidence in the projections of repository performance." Also, Verink indicated the NWTRB believed that, heretofore, the DOE had not adequately considered the possibility of developing and incorporating long life packages in the EBS design. Prior to this time, due to interpretation of 10 CFR Part 60, the waste package could not be considered to contribute to retention of radionuclides beyond 300 to 1,000 years. The DOE Waste Package Plan involved only a portion of the elements which normally constitute the overall barrier system; it did not consider filler materials or backfill. The NWTRB strongly supports the development of an EBS, and believes issues related to thermal loading should not be neglected.

Thomas Pigford, University of California at Berkeley, began his presentation by stating that the U.S. program requirements were unique when compared to those of other countries, and the National Academy of Sciences had been critical of some of these requirements. This was partly due to not knowing what constitutes failure of containment.

Pigford then presented significant features of the Swedish and Swiss programs. He stated that approaches in Sweden and Switzerland could not be readily adapted to Yucca Mountain because of the different chemical environments. [Yucca Mountain is oxidizing.]

Sweden:

1. Does not have "such specific requirements on containment" as the U.S.
2. Their requirements, however, are not yet official.

3. Their extended life calculation is on the order of 100,000 to over 1 million years and has been favorably reviewed by the National Research Council and others in 1983.
4. Repository is planned for granite. Sweden is looking at five or six sites.
5. Possible water leaking from repository to surface in a few hundred years - therefore, substantial emphasis on container.
6. They expect failures of container to be distributed over a period of 100,000 to 1 million years. This model shows a greatly diluted effluent with low concentrations of radionuclides when it reaches the environment due to the different instances of dissolution. Predicting that time spread of failure is a far more difficult problem than predicting how long the container will last.
7. Container must withstand hydrostatic pressure.
8. Current design is a copper container.
9. Emphasis on uniform corrosion and pitting.
10. Steel support inside container.
11. After resaturation, corrodent of the copper container is sulphide, expected in the order of 15 ppm, and the convective, diffusional transport rate of sulphide coming from far field towards the canister is a key variable.
12. They do not expect much radiolysis, but after container is breached, there will be intense but localized peroxide due to radiolysis from alpha tracks from the actinides.
13. Bentonite buffer has little effect on corrosion mass transfer which is used for life prediction, and performance might be better if it was not used.
14. Wide range of water flows in fractures of the saturated rock.

Switzerland:

1. Saturated environment - like Sweden.
2. Iron container.
3. Expected life of iron container is 1,000 to 10,000 years.
4. Waste form is borosilicate glass in a stainless steel pour container; pour container expected not to fail for 100,000 years.
5. Ground-water travel time is much slower than Sweden's.
6. Emphasis is on near-field containment; redundant barrier allows less emphasis on proving far-field performance; the Swiss "distrust" the complexities of hydrogeologic transport.
7. One important aspect is not so much containment, but maintaining a reducing environment in the near field. They expect that the time to corrode all the iron is about 1 million years.
8. Container must withstand hydrostatic pressure.
9. Models uniform corrosion, 25 cm wall thickness for buckling strength is much thicker than the corrosion allowance of 5 cm.
10. Since an iron-water system is modeled, simple diffusional mass transport cannot be used for life prediction. Laboratory studies are based on trapped oxygen being consumed over 500 years, resulting in a wet reducing environment, allowing 5 microns per year corrosion.

11. Extended life may be enhanced by surrounding the container with sand, and then bentonite allowing hydrogen from the corrosion process to be trapped near the container surface at pressures of 100 to 300 bars, but there are problems with diffusion rate of hydrogen vs. the production rate. Also, pressures of 300 bars or more may rupture the bentonite.
12. The ferritic outer canister will act as a sacrificial anode to the stainless pour container for approximately 1 million years.

Pigford offered some observations and comments for Yucca Mountain:

One of the most important functions of the Swiss and Swedish container is not substantially complete containment, but the long time over which it controls the chemical environment. Pigford urged YMP investigators to look upon the Yucca Mountain container and determine what it can do for them.

1. Hydrostatic pressure is not a Yucca Mountain problem.
2. "Loss of containment" has not been defined; if the SCP criterion is used, which amounts to an allowable gas leak rate, a single 5 to 10 micron penetration could constitute failure. Let it fail and predict diffusive transport.
3. The Swedish and Swiss prediction models cannot readily be adapted to Yucca Mountain due to differences in the environments.
4. Analyze container based on release rates -- not perforation. A perforated container is still a very effective barrier.
5. NASA did not build the best possible Apollo; it built the one it could predict most reliably and that is what the YMP has to do at Yucca Mountain.

The following briefly summarizes relevant comments:

Shoesmith:

1. If container is not the probable failure for EBS based on corrosion, shouldn't you consider potential failure via mechanical processes?
2. Warm saline oxidizing environments with potential crevices can be very aggressive.
3. Small point failures are in conflict with the uniform corrosion models.
4. Long-term predictions are part of the multi-barrier process. Any prediction is going to be a probability distribution from early to long-term failure.

Staehle (submitted written input following workshop which is included in Appendix F):

1. Look for simplifying ideas that permit us to engineer better.
2. Three things that make metals work - multiple low probabilities, working in the range of low solubility, and minimizing residual stresses.
3. Major concern is absence of accelerated testing.
4. Corrosion rates may be parabolic, not linear.

5. Recommends study by Melvin Romanoff: "Underground Corrosion," National Bureau of Standards Circular 579, April 1957.
6. Surround metal with something that makes solubility minimal.
7. Minimize residual stress.

Einziger:

Don't forget cladding as a barrier.

Bolmgren:

The radionuclide inventory decreases very little during the 1,000-year to 10,000-year period. The release rate upon any failure within this period would be the same. Therefore, if extended life is considered, the desired life should be significantly longer than 10,000 years.

Cloninger:

As you extend the mean time to failure, you probably also broaden the range of failure times (as a function of the mean time to failure), so you distribute the failures in time, yielding an overall lower release rate, for the rapid release fraction of the spent fuel radionuclides. This is the real advantage to the long-life containment function.

Pigford:

Concurs with point made by Cloninger.

Andresen:

1. I think we realize in all of those models we don't have the ability to accurately predict with complete confidence out to 10^4 or 10^6. We should aim toward some sort [of]...monitoring.
2. Has concern that true reducing atmospheres cannot be obtained.

SESSION 2 - CONCEPTS

This session lasted for a day and a half and included presentations from 12 organizations not currently working on the YMP. Each organization provided one or more persons to the workshop, and the designated presenter described the features of his or her particular concept. Each concept was unique and was developed without funding from the YMP. The presentations varied in detail depending on the resources available to each organization.

A summary of each presentation has been made using topic areas which were provided to each organization when the organization was selected to participate in the workshop. The statements made in the summary represent those of the presenter and any responses from the experts and other participants at the workshop. If a particular topic was not addressed by either the presenter or the other participants, then the summary was left blank for that topic. The DOE has not evaluated any of these concepts as of the writing of this report and, consequently, has not developed any responses to these topic areas.

Following the workshop, each presenter was asked if he or she would like to submit a short statement on his or her concept. Those statements which were received have been included in Appendix F. Contributions were also made by Roger W. Staehle, University of Minnesota, and Donald Langmuir of the Nuclear Waste Technical Review Board, and these have been included in Appendix F.

SILICON CARBIDE REINFORCED ALUMINUM MATRIX COMPOUND

Presenter:

Rick D. Gonzales
ASC/Advance Composite Systems
13825-B Alton Parkway, Irvine CA, 92716
(714) 859-0662

Key Design Features:

A thick wall (4-inch) metal-matrix composite system. Design includes a cylinder, lid, and bottom. The composite consists of Type 385 cast aluminum reinforced with silicon carbide (SiC) (20% by volume). The SiC is concentrated on the outside diameter of the cylinder giving it enhanced properties. See Figure 1.

Physical and/or Chemical Processes Relied on for Estimated Containment Lifetimes and Degree of Isolation:

The presenter based containment and isolation on the mechanical strength of the material.

Performance Considerations:

Containment -

Isolation -

Estimate of Ability to Model -

Analogs -

Degree of Insensitivity to Variations in Service Environment:

Temperature - The material can perform at the proposed temperatures.

Water Quantity -

Water Quality - The material is claimed to be inert to J-13 water, but concerns were expressed that the microstructure of the degradation is not well understood.

Fabrication and Emplacement Considerations:

Available Technology - The cylinder is manufactured with a centrifugal casting process, and high pressure casting is used for the lid and bottom sections. SiC is actually sintered, not melted, into the aluminum. The container can be fabricated using available technology. Six-inch diameter and four-foot long samples have been fabricated.

Remote Handling - Fracture toughness may not be high, raising concerns for remote handling during transport and emplacement.

NDE -

Cost Estimates:

Production costs per unit are estimated at $275,000.

Summary of Weaknesses:

Not being a solid solution, there could be corrosion and welding problems. (Andresen)

No corrosion, fatigue, or creep data for application. (Andresen)

Erratic mechanical test results. (Andresen)

Welding could be a problem. The behavior of the material in the weld area not known. (Shoesmith) The material can be arc-welded. Friction welding should be considered. (Cloninger)

Concern was expressed over the effect of internal porosity on corrosion. (Wagh)

Summary of Strengths:

High wear resistance, contamination, and corrosion resistance.

SiC resists crack propagations.

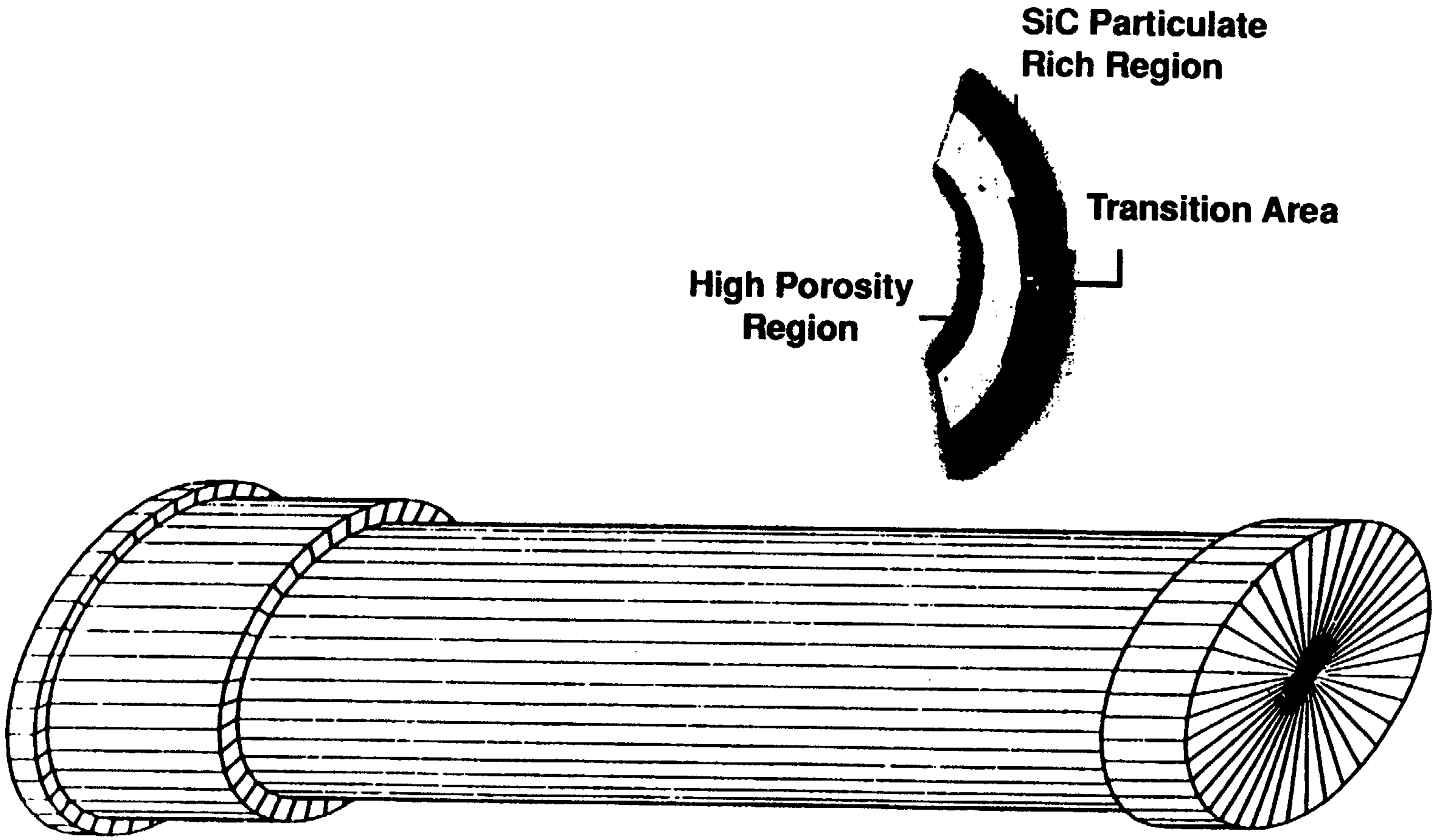
Lower coefficient of thermal expansion (no reference material).

Better fatigue resistance (no reference material).

Can adjust mechanical properties to meet requirements.

Figure 1

ADVANCED COMPOSITE SYSTEMS



CENTRIFUGALLY-CAST CYLINDER
CROSS SECTIONOF A1-SiC MATRIX

SUMENGP.122/9-26-91

FILAMENT-WOUND CERAMIC MATRIX COMPOSITE

Presenter:

E. L. "Ted" Paquette
Technology Assessment and Transfer, Inc.
133 Defense Highway, Suite 212, Annapolis, MD 21401
(301) 224-3710

Key Design Features:

A filament-wound ceramic matrix composite container that is based on corrosion resistant glass fibers or high alumina ceramic fibers and a solution gelation or sol-gel based aluminum oxide matrix. It would include a metal outer shell and a porous bead pseudo-honeycomb between the metal and ceramic for shipping and emplacement protection.

Physical and/or Chemical Processes Relied on for Estimated Containment Lifetimes and Degree of Isolation:

The materials are inert to the environment and have high radiation resistance. The metallic outer shell and honeycomb impact structure ensure good impact capability.

Performance Considerations:

Containment - This type of material is corrosion resistant in both acidic and alkaline solutions; therefore, it is assumed that the container would be inert to the expected environment at Yucca Mountain.

Isolation -

Estimate of Ability to Model - Limited radiation data limits the current modeling capability for extended life

Analogs -

Degree of Insensitivity to Variations in Service Environment:

Temperature -

Water Quantity - The materials are not impermeable, and large quantities of water could lead to exposing the waste form to high moisture levels.

Water Quality - The inert nature of the material makes it insensitive to the potential corrosive nature of the water contacting the package.

Fabrication and Emplacement Considerations:

Available Technology - Filament-wound corrosion resistant storage tanks are made in large quantity. A ceramic composite version would require sub-scale prototype. Development is necessary to reduce porosity, leak testing, and final closure methods. Pressure impregnation will be required to achieve > 90% density on solution gelation pre-impregnated glass. Oxide and nonoxide materials should be considered.

Remote Handling - The honeycomb material and outer metal shell will provide protection during remote handling.

NDE - There are no NDE techniques available currently that will show the types of defects which need to be found. The DOE is funding national lab work in this area and techniques may be available in five to ten years.

Cost Estimates:

The filament-wound container is between $26,000 and $56,000 per unit. This does not include the honeycomb, metal covering, and the costs for final closure.

Summary of Weaknesses:

Porosity may still be too high even with impregnation, local failure could allow fluid access.

Currently, machines are not large enough to wind these containers.

The process for making the final closure may require metallics which are susceptible to corrosion.

It is not known if recrystallization can be driven by radiation. (Shaw)

"You have already described so many unknowns about the materials, there is not much left to ask about." (Andresen)

Summary of Strengths:

The container is expected to have high gamma radiation resistance, low aqueous corrosion, a "long life" impact structure, 95% density with impregnation, and tensile strengths of 100-170 MPA.

After impregnation, the structure is stable. To get recrystallization, "you have to drive the temperatures way up."

TRICAP - HAZARDOUS MATERIAL ENCAPSULE

Presenter:

William Triplett, MD
Entrepreneurs Nuclear de las Americas
Camp Wood Convalescent Center
Camp Wood, TX 78833

Key Design Features:

TRICAP is a multi-layer concept with three or four encapsulations. It utilizes a solid waste billet in a one-inch thick metal container. The container is given a one-inch thick ceramic overcoat, followed by a filament winding which is coated with a zirconium type ceramic cement, followed by a pyrolytic graphite coat. The outer three layers add another inch to the thickness. The metal container can be Hastelloy or stainless steel. Aluminum oxide is proposed for the ceramic overcoat. The ceramic is sealed with a threaded plug and ceramic cement. See Figure 2.

The Physical and/or Chemical Processes Relied on for Estimated Containment Lifetimes and Degree of Isolation:

The multi-layer approach increases the redundancy of the package. Containment is provided initially by the inner metal container. The ceramic overcoat protects the metal container and provides increased strength. The filament winding is to provide additional strength to the ceramic. The zirconium cement makes the package as impervious as possible and the pyrolytic graphite provides an additional seal which can withstand very high temperatures.

Performance Considerations:

Containment - Containment of the nuclear waste is provided by the metallic container. The other layers protect the metal container from the surrounding environment.

Isolation -

Estimate of Ability to Model -

Analogs -

Degree of Insensitivity to Variations in Service Environment:

Temperature - The concept can withstand the highest temperatures anticipated for the application. Concern was expressed about the reduced thermal conductivity of the nonmetallic layers, which will result in reduced waste loadings.

Water Quantity - The outer layers of pyrolitic graphite and zirconium cement will make the concept impervious to large amounts of water.

Water Quality - The three non-metallic layers will be inert to all possible environments.

Fabrication and Emplacement Considerations:

Available Technology - All processes proposed are currently available. Friction welding could be used to close the metallic container. Concern was expressed about the temperature necessary for vapor deposition of the pyrolytic graphite, 1000 degrees centigrade, which would damage the spent fuel waste.

Remote Handling - Concern was expressed about pickup points and maintaining total coverage with each layer. Remote handling will be required which may put the outer non-metallic layers at risk.

NDE -

Cost Estimates:

Depending on the types and number of layers, the first unit would cost $105,000 to $213,000.

Summary of Weaknesses:

Any breach of the outer layers would jeopardize performance of Hastelloy C metal container. (Andresen)

Compatibility of thermal expansion of metal, ceramic, and windings could be a problem.

Hastelloy is not super stable at high temperatures with a resultant loss in fracture toughness. (Andresen)

Putting the metal on the inside and the ceramic on the outside has potential for a localized, crevice corrosion process. (Shoesmith)

The variability of the properties of each material must be known. Difference in thermal conductivity between the layers could delaminate one layer from the other. (Harr)

Summary of Strengths:

The multi-layer provides a robust system if each layer remains intact.

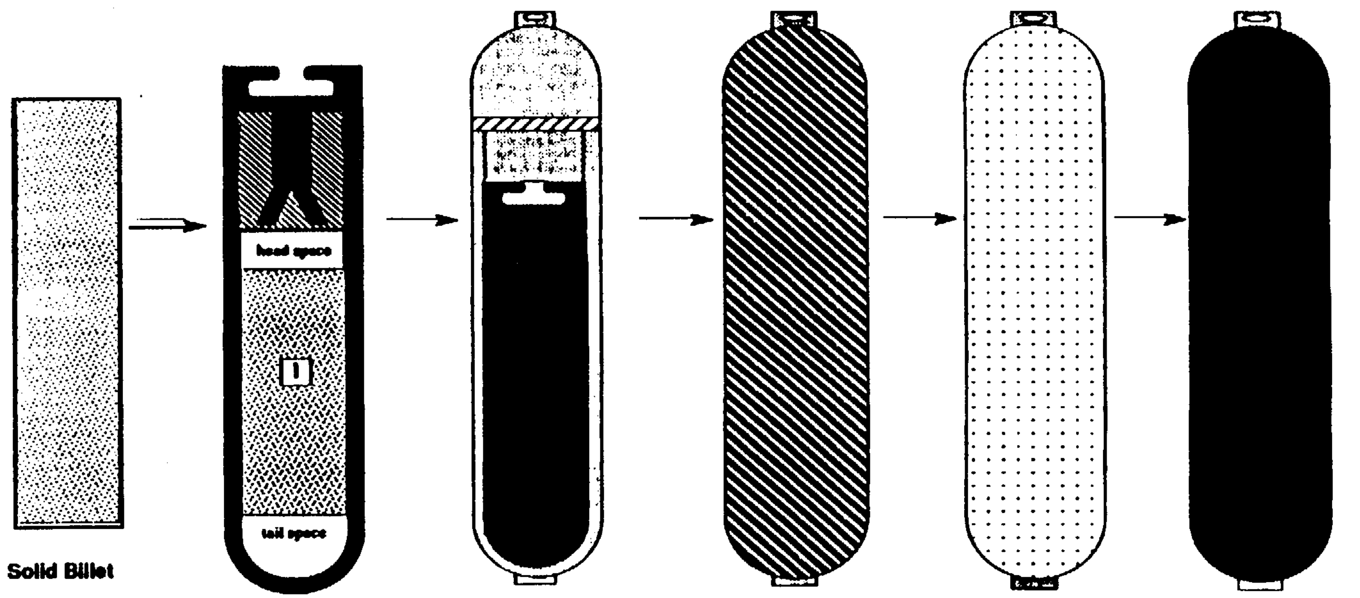
The completed package has the required strength for potential impact during handling and can withstand 2400 minimum degrees Fahrenheit.

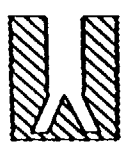
It could potentially be used as a shipping container.

The robust nature may result in greater public acceptance.

Figure 2

ENTREPRENEURE NUCLEAR DE LAS AMERICAS





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"TRICAP" - HAZARDOUS MATERIAL ENCAPSULE		
Improvement Re 6-9-89		DRAWING NUMBER M-62189

SUMENGP.122/9 26 91

EBS CONCEPT FOR EXTENDED LIFE PERFORMANCE

Presenter:

James C. Cunnane
Argonne National Laboratories
9700 South Cass Avenue
Argonne, IL 60439
(708) 972-4541

Key Design Features:

A functionally based concept which includes an encapsulation/stabilization chemically bonded ceramic (CBC) filler surrounding the spent fuel inside an Incoloy 825 container. An air gap surrounds the metal container and is maintained using a CBC liner. Coarse crushed tuff inserted between the liner and the emplacement hole wall provides a hydraulic bypass. The emplacement hole shielding plug and cap is also made from CBC material and shaped to minimize water dripping on the metallic container. A tailored backfill of crushed tuff, zeolite, and iron oxide is placed in the bottom of the emplacement hole. See Figure 3.

The Physical and/or Chemical Processes Relied on for Estimated Containment Lifetimes and Degree of Isolation:

Containment lifetime uses enhanced approaches to keep liquid water from contacting the metallic container. This includes a hydraulic bypass and a dome-shaped shielding plug. Isolation is enhanced with the ceramic filler, which provides a redundant barrier, and the tailored backfill, which includes minerals that are known to retard radionuclides.

Performance Considerations:

Containment - The multi-barrier provided by the metallic container and the CBC filler provides extended life containment.

Isolation - Gradual release is reduced with materials which will remain stable long after they are breached. Retardation is enhanced with the tailored backfill.

Estimate Ability to Model - The engineered features of this concept could enhance ability to model.

Analogs -

Degree of Insensitivity to Variations in Service Environment:

Temperature - The materials will not exceed any temperature limits. Thermal stresses are insufficient to induce failure of the ceramic materials.

Water Quantity - The metallic container can accommodate any quantity of water if its composition is benign.

Water Quality - The metallic container is sensitive to corrosion under certain water chemistries. The CBC filler should be insensitive to the quality of the water.

Fabrication and Emplacement Considerations:

Available Technology - Although CBC processes are available, a limited development program would be required for identification of specific parameters for tailoring this application. The fuel is lowered into the CBC before it sets up.

Remote Handling - The metal container allows handling as currently planned.

NDE -

Cost Estimates:

No estimates provided, but the CBC materials are considered inexpensive.

Summary of Weaknesses:

The feasibility of CBC's and the long-term durability remain to be demonstrated.

Long-term testing required to expand the experience of CBC's.

Massive accumulation of evaporation products may affect your selection of materials. An analysis needed on how much water might appear after cool down and what concentrations will occur. (Andresen)

Distillation of moist oxidizing atmosphere into the air gap between the container and the chemically bonded ceramic may affect container. (Shoesmith)

Summary of Strengths:

The CBC filler provides a redundant barrier.

Chemically-bonded ceramics with low porosity can be formed at low temperatures with acceptable toughness and tensile strength, especially with fiber reinforcement.

Phosphate-based materials are very insoluble and expected to be impervious to water and have potential for holding up actinides.

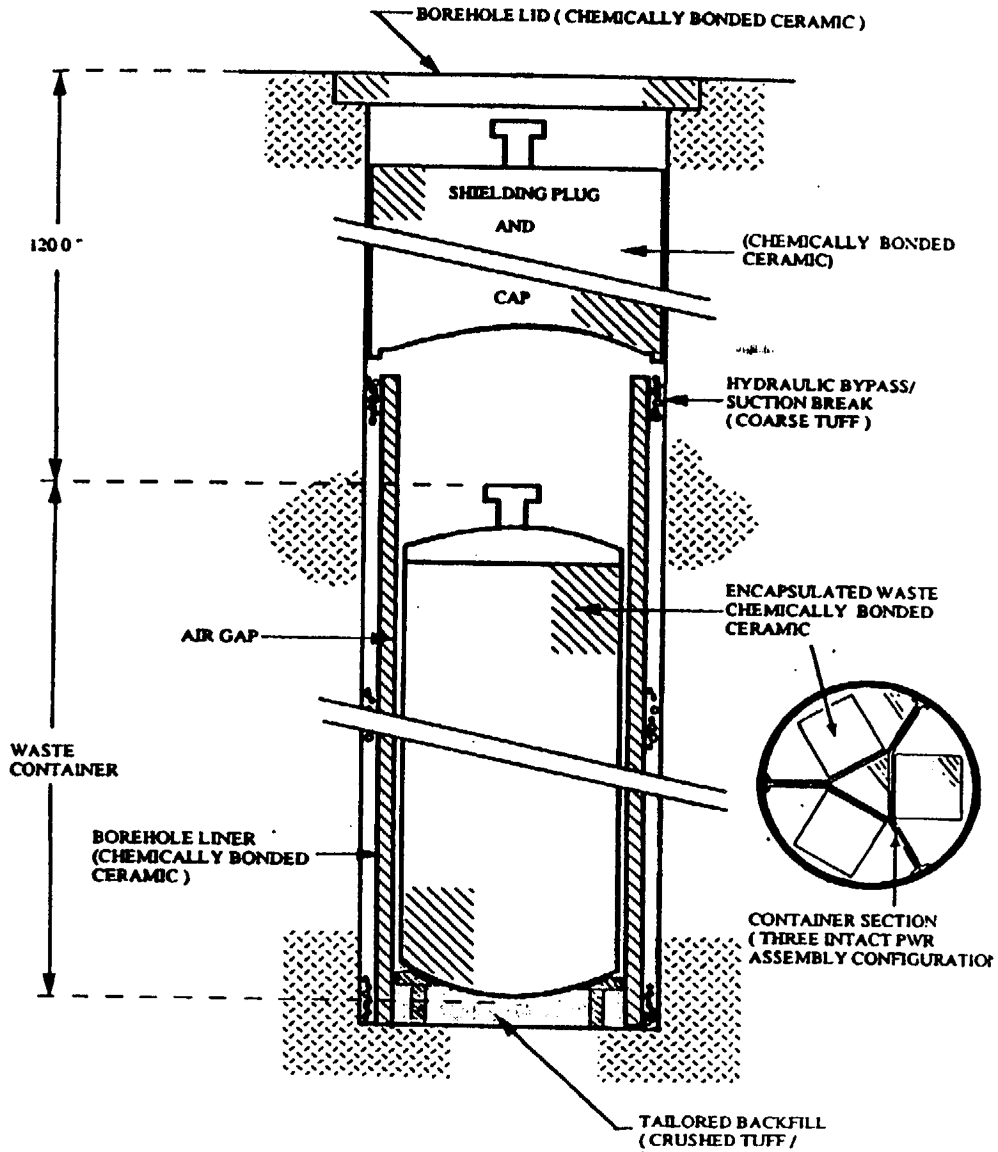
The design provides methods to divert water away from the package.

Moist air will contact the container; dripping will not impinge on the container; the chemically-bonded ceramic filler inside the container is impervious to moist air. Expect colloids from the reaction process of the waste to seal fractures in the CBC.

Figure 3

ARGONNE NATIONAL LABORATORY

CHEMICALLY BONDED CERAMIC



SUMENGP 122/9.26.91

GRAVEL BACKFILL AS A HYDRAULIC AND DIFFUSION BARRIER

Presenter:

Patricia R. Salter
Intera Sciences, Inc.
3609 South Wadsworth Blvd.
Denver, CO 80235
(303) 985-0005

Key Design Features:

A two-layer barrier of tuff gravel (about one-inch diameter) and sand with a sloping boundary to form a capillary break between the host rock and the EBS, and to prevent advective water flow across the boundary. Transport is limited to molecular diffusion and vapor transport. A tent design and a borehole design were proposed. See Figures 4a and 4b.

The Physical and/or Chemical Processes Relied on for Estimated Containment Lifetimes and Degree of Isolation:

Diverts water flow around the gravel barrier, thereby protecting the waste package. Provides aqueous diffusion coefficient below 10^{-11} centimeters square per second.

Performance Considerations:

Containment -

Isolation - Increases isolation time of aqueous species in the EBS by over 70,000 years.

Estimate of Ability to Model - Eliminates the need to model "drip or periodic" wetting scenarios. Modelable and testable.

Analogs - Natural analogs exist in some archaeological burial grounds in Japan in which metal and other artifacts were kept for 1,300-1,500 years (at relatively low temperatures), and their condition was correlated to the presence of an intact gravel barrier.

Degree of Insensitivity to Variations in Service Environment:

Temperature - Not sensitive to temperature, radiation, waste package materials, or emplacement configuration.

Water Quantity - Sensitive to water quantity if recharge exceeds one milliliter per square centimeter per hour, which is above normal rainfall anywhere.

Water Quality - Not sensitive to water composition.

Fabrication and Emplacement Considerations:

Available Technology - Minimal engineering development; readily available materials and technology.

Remote Handling -

NDE -

Cost Estimates:

"Inexpensive."

Summary of Weaknesses:

Sensitive to water quantity if recharge exceeds one milliliter per square centimeter per hour.

System does not address vapor transport.

Tent design can give water flow (rivulets) at the bottom. (Simons)

Gravel can rapidly clog up. (Harr)

Long-term potential for earth movement, water pockets, channeling, and therefore borehole instability. (Shaw)

Not being used with low-level wastes because of vapor transport problems. (Conca)

Episodic recharge can cause barrier breakdowns. (Shaw)

Summary of Strengths:

Diverts water from waste package.

Increases isolation by 70,000 years.

Not sensitive to temperature, radiation, water composition, waste package materials, or emplacement configuration.

Modelable and testable.

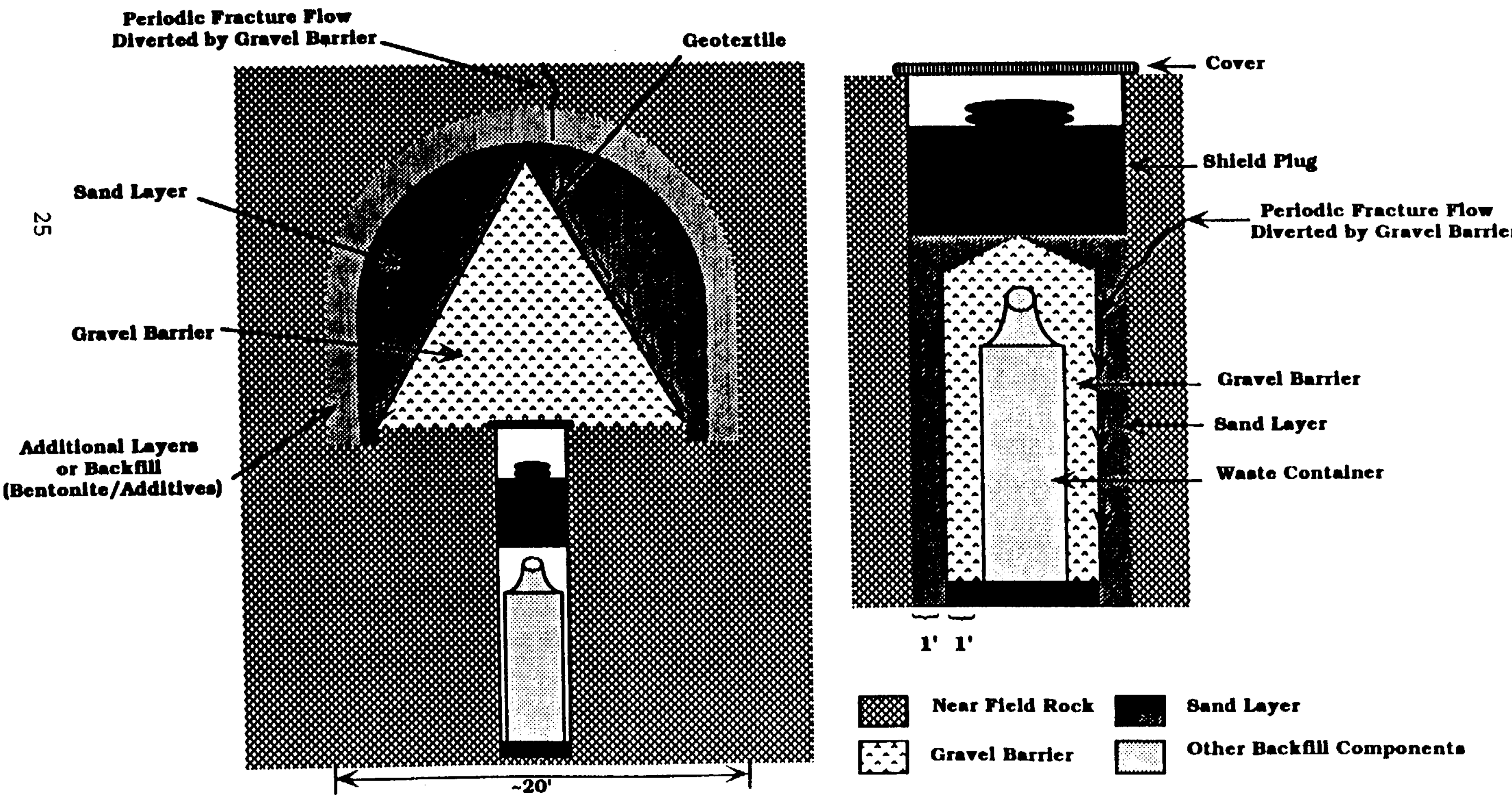
Minimal engineering development and inexpensive; readily available materials.

Impervious gravel can be employed to eliminate the concern about wicking onto the waste packages.

Figure 4a

INTERA SCIENCES, INC.

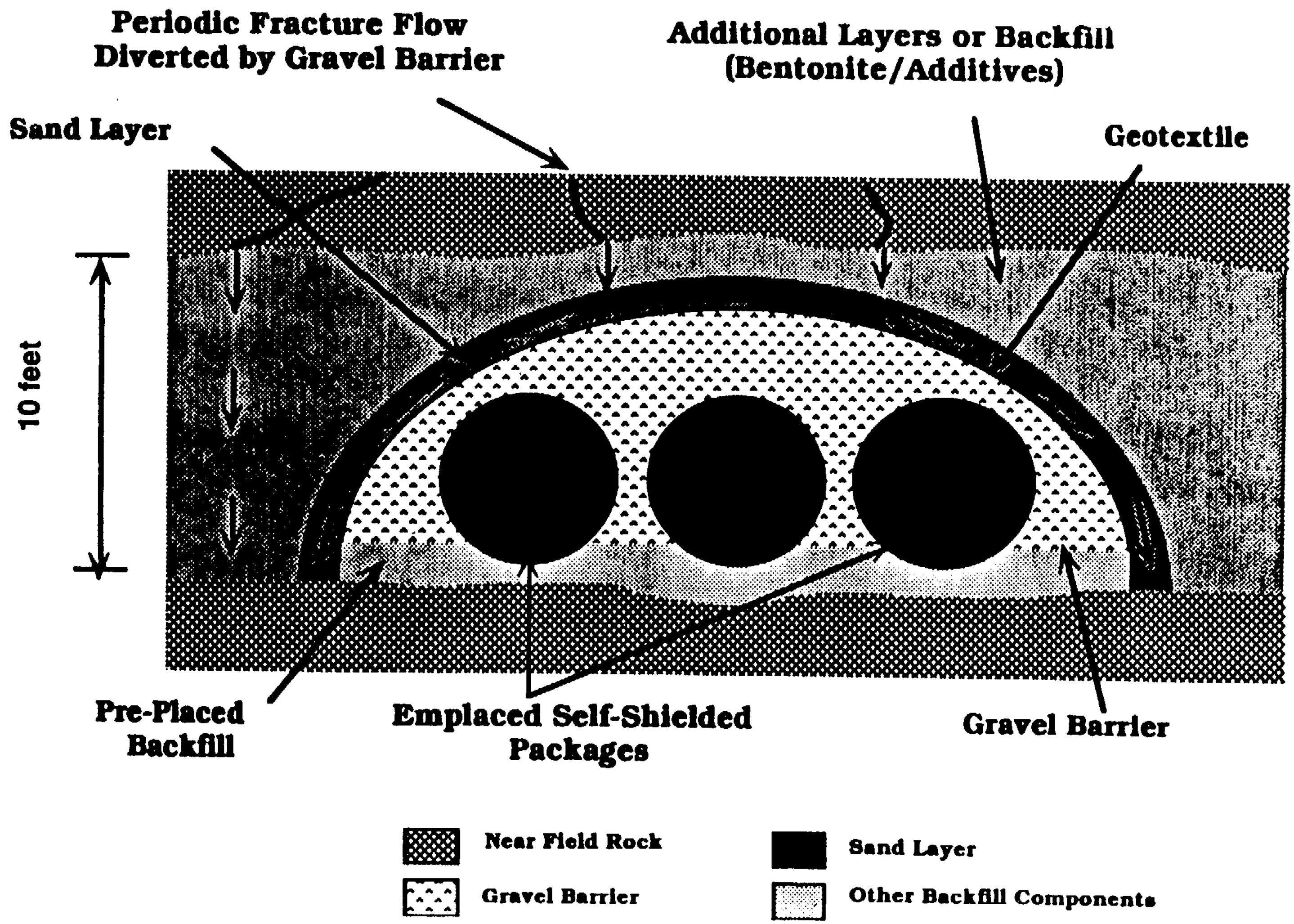
EXAMPLES OF GRAVEL BARRIERS FOR POSSIBLE VERTICAL WP EMPLACEMENT



SUMENGP 122/9 26 91

INTERA SCIENCES, INC.

EXAMPLES OF GRAVEL BARRIERS FOR POSSIBLE VERTICAL WP EMPLACEMENT



SUMENGP 122/9 26 91

SPENT FUEL STABILIZERS IN WASTE PACKAGE DESIGN

Presenter:

Patricia F. Salter
Intera Sciences, Inc.
3609 South Wadsworth Blvd.
Denver, CO 80235
(303) 985-0005

Key Design Features:

A solid matrix (i.e., filler) material is used to fill the empty volume inside the spent fuel waste container. Metals, ceramics, composites (metal or ceramic matrices) can be employed using casting, sintering, or hipping techniques. See Figure 5.

The Physical and/or Chemical Processes Relied on for Estimated Containment Lifetimes and Degree of Isolation:

Improves heat transfer and overcomes fuel cladding temperature limitations. Increases lithostatic load bearing capacity of container. Provides galvanic protection for metallic waste package components. Limits radionuclide release rates by ensuring matrix diffusion or solid matrix dissolution. Waste package reliability is improved because stabilizers can be characterized more easily than rock or spent fuel. Reduces container surface radiation and spent fuel criticality potential. Preserves cladding during waste handling, emplacement, and retrieval operations.

Performance Considerations:

Containment - Distributes cladding failures in time.

Isolation - Decreased stabilizer porosity will give improved performance in terms of lower fraction release rate, e.g., porosities of ten to the minus three or four should be the goal.

Estimate of Ability to Model -

Analogs -

Degree of Insensitivity to Variations in Service Environment:

Temperature -

Water Quantity -

Water Quality -

Fabrication and Emplacement Considerations:

Available Technology - Adaptable commercial technologies are available.

Remote Handling -

NDE -

Cost Estimates:

Increased waste package development, fabrication, and material costs. \$44,000 - \$71,000 per package (design dependent) versus \$31,000 for stainless steel SCP reference container.

Summary of Weaknesses:

Increased waste package development, fabrication, and material costs.

Need more information on material properties.

Gaps will form if material is poured in; stresses can build up and can easily cause cracking. (Shoesmith)

Ceramic coatings on metals are not good because of crevice formation. (Shoesmith)

Galvanic protection of both the container and the cladding is not possible. (Shoesmith)

Summary of Strengths:

Stabilizers are more readily characterized than the host rock and long-term spent fuel behavior.

Improves heat transfer and overcomes fuel cladding temperature limitations.

Increases lithostatic load bearing capacity of container.

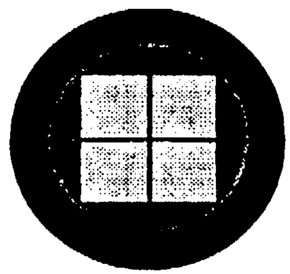
Limits radionuclide release rates by ensuring matrix diffusion or solid matrix dissolution.

Reduces container surface radiation and spent fuel criticality potential.

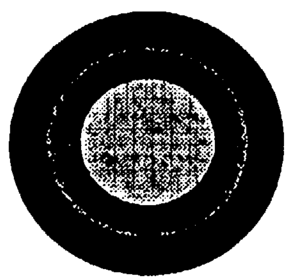
Preserves cladding during waste handling, emplacement, and retrieval operations.

Figure 5

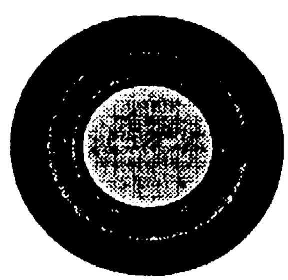
INTERA SCIENCES, INC.
INTERNAL STABILIZERS



Intact Assemblies



Consolidated Rods



Pre-Canistered Rods

- **DEFINED AS: A solid matrix (i.e. filler) material used to fill the volume remaining inside the spent-fuel waste container.**

- **CANDIDATE MATERIALS INCLUDE:**

  METALS
  - Al, C, Cu, Fe, Pb, Zn

  CERAMICS
  - Alumuna, Mullite, etc.

- **COMPOSITES**
  - Metal/Ceramic Matrix

SUMENGP 122/9 26 91

SURFACED SEALED COMMERCIAL GRAPHITE DESIGN CONCEPT

Presenter:

Glen Engle
16716 Martincoit Rd.
Poway, CA 92064
(619) 487-0325

Key Design Features:

Graphite container made from two crucible shapes and one hollow cylinder, with surfaces sealed via chemical vapor deposition with pyrolytic carbon. Closure of joints would be by graphite cement seals heated to about 525°C. Wall thickness undetermined. Graphite cylinders can be extruded or isostatically molded. See Figure 6.

The Physical and/or Chemical Processes Relied on for Estimated Containment Lifetimes and Degree of Isolation:

Inertness, long life potential. Fission product trap, based on data at higher temperatures. High temperature stability. Sufficiently rugged. Surfaces sealed via chemical vapor deposition with pyrolytic carbon.

Performance Considerations:

Containment -

Isolation -

Estimate of Ability to Model - Modelable performance except for low temperature radiolytic oxidation performance (data needed).

Analogs - Natural analogs exist, e.g., coal in the ground for millions of years, and roads and ancient aqueducts.

Degree of Insensitivity to Variations in Service Environment:

Temperature - Thermal stability is not a problem.

Water Quantity - Water should not have an effect.

Water Quality - Water should not have an effect.

Fabrication and Emplacement Considerations:

Available Technology - Technology available. Closure seals must be demonstrated, and closure would have to be done quickly for proper setting of the cement.

Remote Handling - Graphite is a very rugged material, although brittle.

NDE -

Cost Estimates:

$89,000 per container, but this could be lower if made in production quantities. This does not include the costs of remote sealing.

Summary of Weaknesses:

Closure seals must be demonstrated, and closure would have to be done quickly for proper setting of the cement.

Long term radiolytic oxidation uncertain.

Most information on graphite has been obtained at high temperatures (> 350°C), i.e., well above the temperatures of this application.

Final closure is a key item. (Basham)

Remote final assembly handling can cost several tens of thousands of dollars, and you must figure out total system costs. (Basham)

Improperly sealed containers could pose recovery problems. (Van Konynenburg)

Thermodynamics are against you regarding carbon in aqueous solutions (limited stability) and boron additions would probably make it worse. (Staehle)

Carbon is an active cathode when galvanically coupled to metals. (Staehle)

Sealing may require heating to 600°C for several hours, which could lead to mechanical problems. (Andresen)

Criticality may be a problem. (Van Konyenburg) Response was that boron could be put in to take care of the criticality question.

If no gap exists between the graphite and inner metallic container, there will be a crevice problem. If a gap exists, there will be a mechanical problem for the graphite. (Andresen)

The likely oxidation products could feed microbes, or facilitate transport of species you want to retard. (Shoesmith)

Bench scale experiments should be employed to demonstrate how the entire system hangs together. (Simons)

Summary of Strengths:

Inertness, long life potential.

Fission product trap, based on data at higher temperatures.

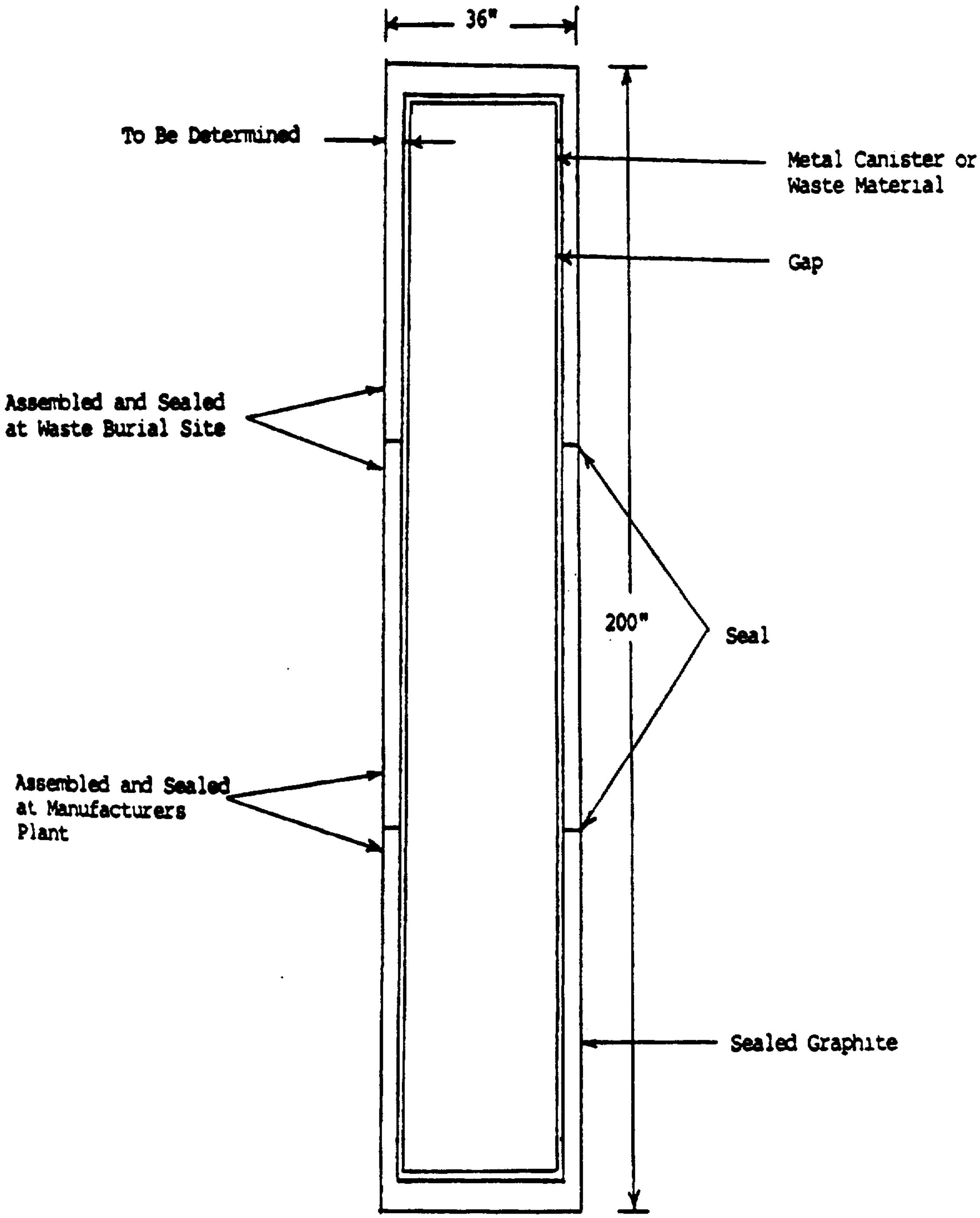
Technology available.

Heating the fuel to 550°C for short periods may not be harmful. (Einziger)

Figure 6

NUCLEAR AND AEROSPACE MATERIALS CORPORATION

GRAPHITE CONCEPT



MULTI-BARRIER CONTAINER CONCEPT

Presenter:

Bruce P. Miglin
Babcock and Wilcox Company
1562 Beeson Street
Alliance, OH 44601
(216) 821-9110

Key Design Features:

1. Metal/Metal Concept (Figure 7) - Outer corrosion-resistant shell (variety of candidate alloys, with titanium alloy favored). Electrical insulation between inner and outer metallic containers. Inner thick metal container. Chemical barrier of cementatious fillers. Bentonite layer and borehole liner (of unspecified material) are included.

2. Metal/Ceramic Composite Concept (Figure 8) - Inexpensive, strong outer metal barrier (e.g., steel). Air gap inside metal barrier. Immune ceramic composite barrier. Chemical barrier of cementatious filler. Bentonite layer and a borehole liner (of unspecified material) are included.

1. Metal/Metal Concept

The Physical and/or Chemical Processes Relied on for Estimated Containment Lifetimes and Degree of Isolation:

Outer barrier - Corrosion-resistant materials. Good heat transfer.

Inner barrier - Strong, good heat transfer.

Chemical barrier of cementatious filler - Reacts with C-14, neutralizes nitric acid (radiolysis product). May slow radionuclide transport.

Performance Considerations:

Containment - Inner barrier - Some containment or controlled release credit.

Overall - Concept can be developed to give 10,000-year containment.

Isolation -

Estimate of Ability to Model - Outer barrier - Good modelability.

Analogs -

Degree of Insensitivity to Variations in Service Environment:

Temperature - Sensitive to temperature.

Water Quantity -

Water Quality - Sensitive to water quality.

Fabrication and Emplacement Considerations:

Available Technology - Outer barrier - Closure and fabrication are well understood.

Remote Handling - Outer barrier - Well understood.

NDE - Outer barrier - Well understood.

Cost Estimates:

Inner barrier - Inexpensive.

Outer barrier - Relatively expensive (compared to steel). A study about two years ago indicated about $64,000 for an Alloy 825 container, of which 30-40% is material cost. No other information was provided, but cost was said to be quantifiable.

Summary of Strengths/Weaknesses for Metal/Metal Concept:

See below.

2. Metal/Ceramic Composite Concept

The Physical and/or Chemical Processes Relied on for Estimated Containment Lifetimes and Degree of Isolation:

Outer metal barrier - Strong.

Inner ceramic barrier - Immune to corrosion. Strong, lightweight. Radiation resistant.

Chemical barrier of cementatious filler - Reacts with C-14, neutralizes nitric acid (radiolysis product). May slow radionuclide transport.

Performance Considerations:

Containment - Overall concept can be developed to give 10,000-year containment.

Isolation -

Estimate of Ability to Model - Modelability of inner ceramic barrier needs development.

Analogs -

Degree of Insensitivity to Variations in Service Environment:

Temperature - Ceramic insensitive to temperature.

Water Quantity -

Water Quality - Ceramic insensitive to water quality.

Fabrication and Emplacement Considerations:

Available Technology -

Inner ceramic barrier - Sealing technology needs optimization. Fabrication needs development. Mechanical properties might be a problem and be difficult to quantify.

Remote Handling - Needs development.

NDE - Needs development.

Cost Estimates:

Outer metal barrier - Inexpensive.

Overall - Not quantifiable yet.

Summary of Weaknesses:

Outer barrier - Need long-term corrosion data (localized corrosion possible).

Relatively expensive (compared to steel).

Air gaps limit heat transfer. (Simons)

Air gap can lead to differential stresses if anything shifts which could cause cracking in a ceramic. (Shoesmith)

Closure may be a problem. (Andresen) Response was that closure is not simple, and that friction welding is preferred.

Metal corrosion modeling is not simple, especially for localized corrosion. Analysis of the whole system will be needed. (Shoesmith)

Crack growth rates in ceramics can't be measured. (Shoesmith)

Ceramics cannot be assumed to be chemically stable; solubility and crack propagation have to be considered. (Staehle)

Quantitative assessment of performance using a probabilistic basis is needed here. (Harr)

The thermal conductivity of the cementatious filler may be inadequate and cause problems; also, porosity may allow water in. (Wagh)

Concerns about radiation dose effects for both gamma and particularly for alpha radiation have not been dealt with, especially regarding the chemical reactions that can occur. (Reed) The responses indicated little, if any, radiation damage occurs by alpha, except internally in the fuel when it gets wet. (Shoesmith, Smith)

Inner ceramic barrier - Sealing technology needs optimization.

Lower heat transfer than metals.

Fabrication, remote handling, and NDE need development.

Summary of Strengths:

Multi-barrier approach is very licensable.

Overall concept can be developed to give 10,000-year containment.

Titanium has a lot of merit. It forms a protective film which is not a good cathode to steel. (Staehle)

Figure 7

BABCOCK AND WILCOX
METAL/METAL CONCEPT

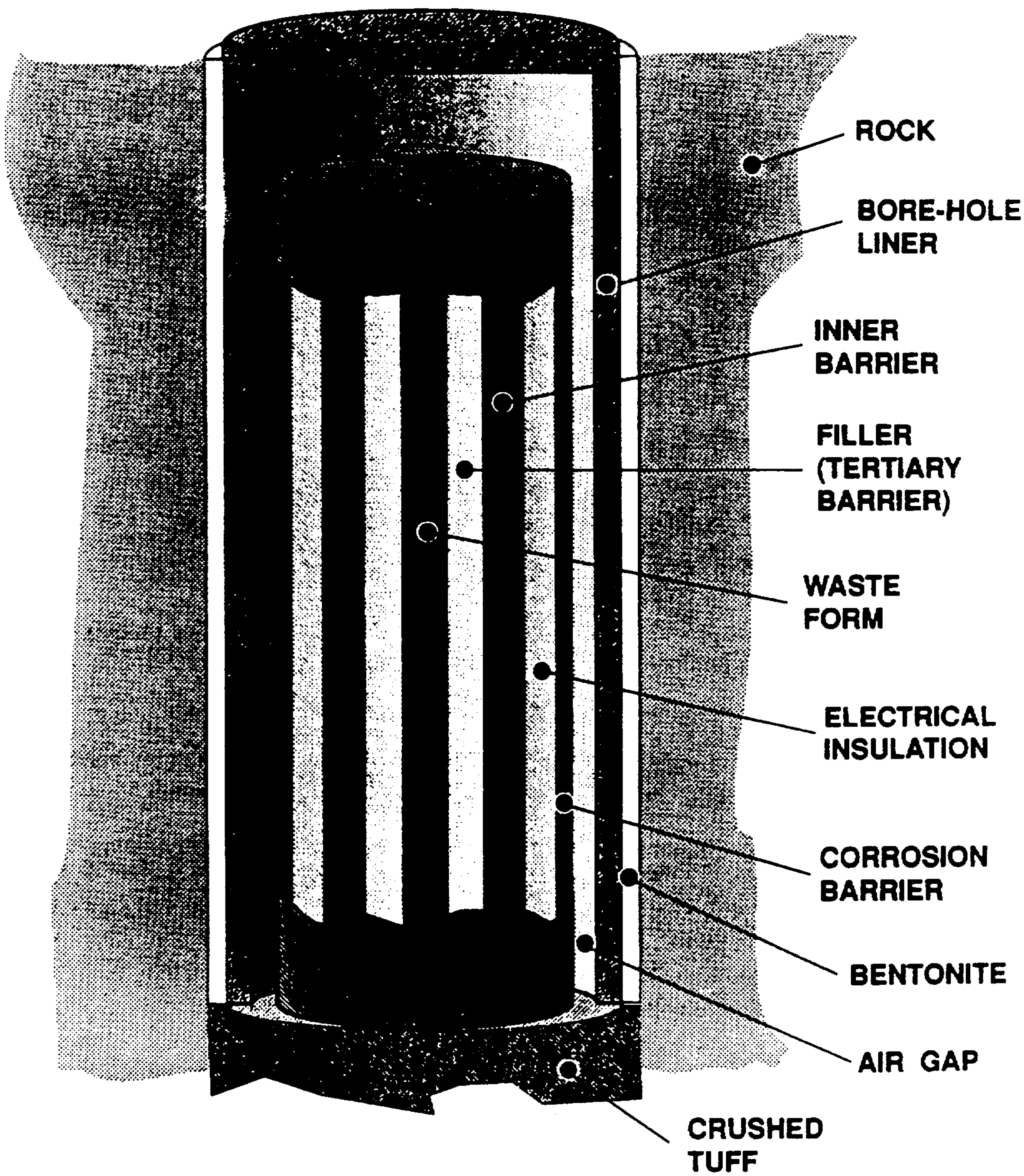


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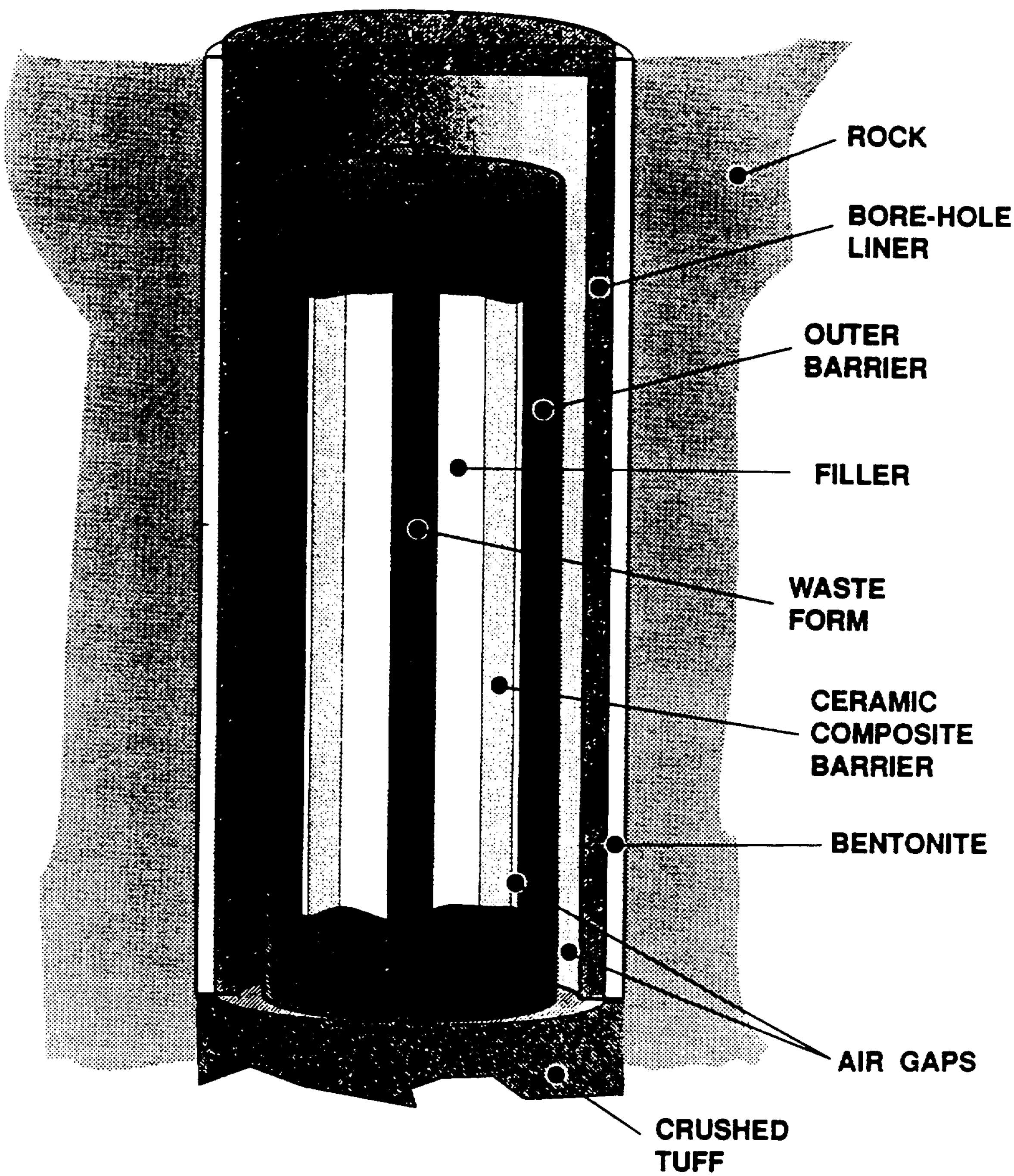
Figure 8

BABCOCK AND WILCOX
METAL/COMPOSITE CONCEPT



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THE NATURAL ANALOG COPPER COMPOSITE CONTAINER

Presenter:

Dale T. Peters
Copper Development Association
2 Greenwich Office Park
Greenwich, CT 06836
(203) 625-8210

Key Design Features:

Oxidation- and corrosion-resistant heavy copper wall (two-inch) outer container; high strength aluminum bronze inner liner (one-inch thick) for mechanical rigidity; particulate filler material (leaded glass frit) for gamma radiation absorption; horizontal emplacement with crushed basalt backfill to control ground-water chemistry. Optional cast bimetallic to replace the outer and inner containers appears attractive. No boreholes with this design. See Figure 9.

The Physical and/or Chemical Processes Relied on for Estimated Containment Lifetimes and Degree of Isolation:

Robust, corrosion-resistant bimetallic wall should have life expectancy greater than 10,000 years (i.e., no failure of copper by oxidation, stability in a flooded environment, and no localized corrosion, i.e., pitting or stress corrosion cracking). No radiolytic corrosion. Good thermal conductivity.

Performance Considerations:

Containment - Robust, corrosion-resistant bimetallic wall should have life expectancy greater than 10,000 years.

Isolation -

Estimate of Ability to Model - Absence of non-uniform corrosion enhances modelability.

Analogs -

Degree of Insensitivity to Variations in Service Environment:

Temperature -

Water Quantity -

Water Quality -

Fabrication and Emplacement Considerations:

Available Technology - Copper (e.g., phosphorus deoxidized copper) is a readily available commercial material. Easy fabrication options by established techniques. Fabrication development is required for centrifugal casting of bimetallic.

Remote Handling -

NDE -

Cost Estimates:

Approximately $24,000 for a centrifugal bimetallic casting and $2,000 for lids.

Summary of Weaknesses:

Increased complexity, weight, and cost.

Research required on stability of copper in Michigan basalt and Yucca Mountain waters.

Fabrication development is required for centrifugal casting of bimetallic.

Pure copper is susceptible to creep at the temperatures of interest.

There is a potential for localized corrosion; surface deposits in an oxidizing environment can lead to pitting of copper with possible fast penetration. (Shoesmith)

Stress corrosion cracking is also a possibility in oxidizing environments. (Andresen, Staehle)

Galvanic protection can give a hydrogen generation problem. (Staehle)

Complex formation due to the presence of organics can lead to lowering the stability of copper to where it can be oxidized in water. (Staehle)

Copper is a very effective cathode, which can be a problem. (Staehle)

Remote handling and assembly (for any of the concepts) will not be a trivial problem and will cost a fairly enormous price. (Basham)

Summary of Strengths:

Enhanced public acceptance.

No radiolytic corrosion.

Absence of non-uniform corrosion enhances modelability.

Versatile container (no inner liner required for high-level waste).

Easy retrieval.

Easy fabrication options by established techniques.

Boreholes eliminated.

Corrosion-resistant bimetallic wall.

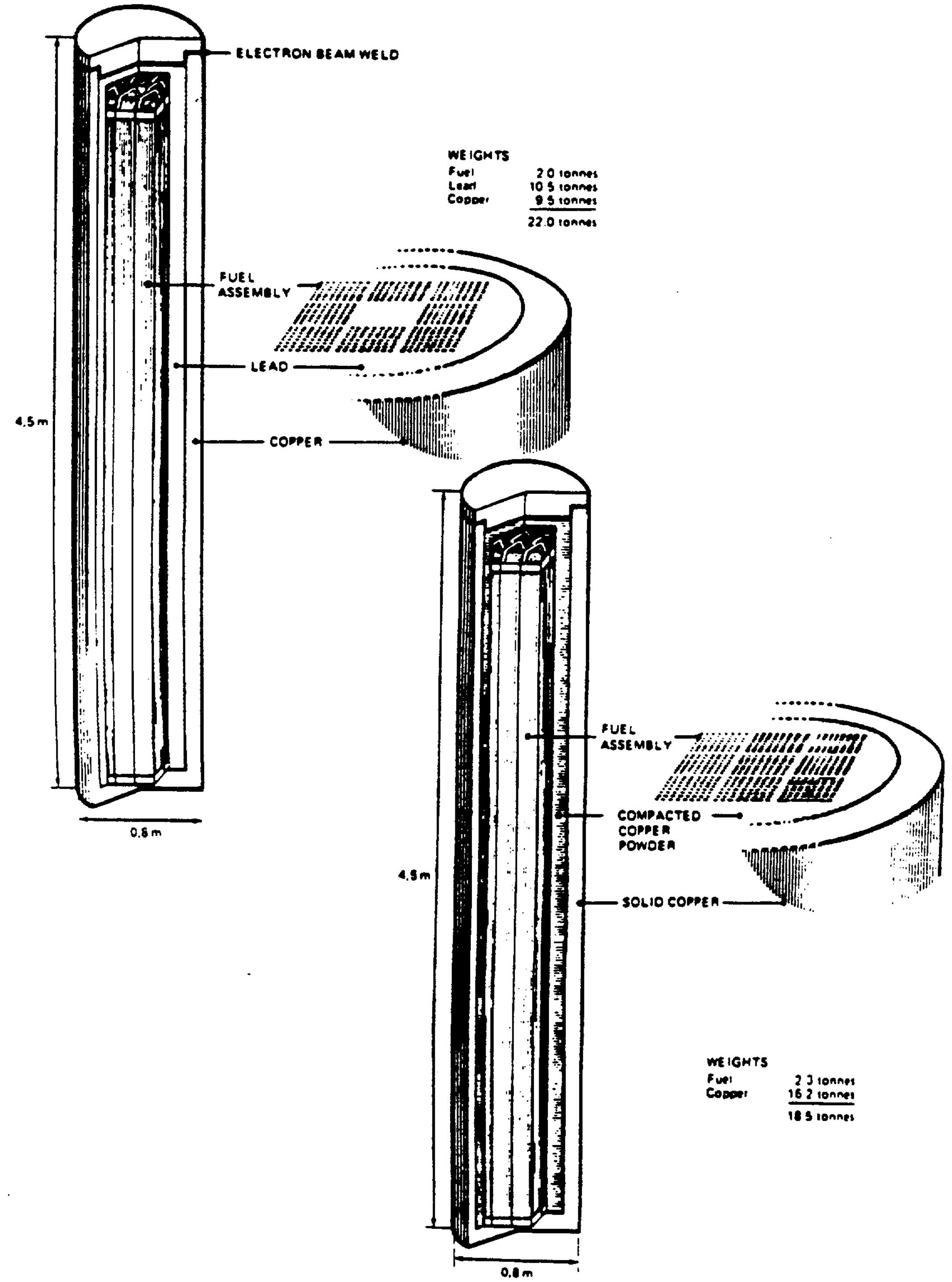
Good thermal conductivity.

Radiation has been found to significantly inhibit corrosion of copper. (Shoesmith)

Figure 9

COPPER DEVELOPMENT ASSOCIATION INC.

COPPER COMPOSITE



EXTENDED-LIFE NUCLEAR WASTE PACKAGE UTILIZING REDUNDANT CORROSION/CONTAINMENT BARRIERS

Presenter:

Frank E. Goodwin
International Lead Zinc Research Organization, Inc.
2525 Meridian Parkway
Research Triangle Park, NC 27709
(919) 361-4647

Key Design Features:

Nickel-chromium-molybdenum alloy container; lead liner (1.25 cm thick), or lead filler.

The Physical and/or Chemical Processes Relied on for Estimated Containment Lifetimes and Degree of Isolation:

Stabilize waste form against handling stresses and lithostatic loadings. Improve heat transfer. Attenuate radiation. Additional (redundant) containment/corrosion barrier. Available corrosion data do not rule out use of lead.

Performance Considerations:

Containment -

Isolation -

Estimate of Ability to Model -

Analogs - Ancient shipwrecks provide some natural analogs information where lead usually appears to corrode uniformly in sea water.

Degree of Insensitivity to Variations in Service Environment:

Temperature -

Water Quantity -

Water Quality -

Fabrication and Emplacement Considerations:

Available Technology -

Remote Handling - The ability to simplify handling (because of self-shielding) may outweigh the 10 to 20% increase in weight due to the lead.

NDE - Non-destructive testing and void elimination are remaining issues.

Cost Estimates:

$35,000 - $50,000 per overall package. A one-inch liner would cost about $2,500, and container filler would range from $5,000 to $13,000 per package.

Summary of Weaknesses:

Lack of wetting by lead or other metals could lead to problems associated with water pathways, heat transfer, and structural integrity.

Non-destructive testing and void elimination are remaining issues.

Electrical coupling of lead filler and the container material may cause a galvanic corrosion problem involving a large cathode and a small (lead) anode. (Shoesmith)

There are uncertainties regarding crevice and pitting corrosion of lead. (Shoesmith)

Cracking of Alloys 600 and 690 can occur in solutions containing very low levels of lead in water and steam. (Miglin)

There will be mixed wastes/RCRA concerns in using lead. (Shaw)

A lot of scatter exists in the data shown. (Simons)

Long periods underground will lead to a rock creep problem because of the large weight of the emplaced materials. (Harr)

Summary of Strengths:

Stabilize waste form against handling stresses and lithostatic loadings.

Improve heat transfer.

Attenuate radiation.

Additional containment/corrosion barrier.

Radiation may affect localized corrosion, but not uniform corrosion. Also, non-passive film formation on lead may attenuate the corrosion rate and soak up carbon. (Shoesmith)

SELF-SHIELDED PACKAGE CONCEPT

Presenter:

Charles R. Bolmgren
Westinghouse Electric Corporation, Inc.
P.O. Box 598
Pittsburg, PA 15230-0598
(412) 233-6350

Key Design Features:

Heavy wall cast container of gray iron, ductile iron, or low carbon steel. Dimensions for the SSP-4, which holds four intact assemblies, are 48 cm x 48 cm x 415 cm cavity with a wall thickness of 37 cm. The SSP-9, which holds nine intact assemblies, contains a 72 cm x 72 cm x 415 cm cavity with a wall thickness of 40 cm. Total cask weight is about 85 tons for SSP-4. Intended for drift (not borehole) emplacement. Variations include: (1) use a thinner wall with an outer container for storage, transport, or disposal; and (2) replace some metal with a graphite lining. See Figure 10.

The Physical and/or Chemical Processes Relied on for Estimated Containment Lifetimes and Degree of Isolation:

Relies on mildly corrosion-resistant material, thick wall, corrosion products and backfill material. Eliminates radiation and radiolysis effects (less than 100 mrem/hour at surface). Good strength (resists hydrostatic pressure) and thermal conductivity.

Performance Considerations:

Containment - Slow corrosion of heavy wall container.

Isolation -

Estimate of Ability to Model - Corrosion model has been developed for steam (60 years) and oxic water immersion, predicting about 3 cm of uniform corrosion for first 1,000 years and an estimated pitting corrosion factor of about 2x. However, the corrosion mechanism will have to be investigated for the unsaturated zone.

Analogs -

Degree of Insensitivity to Variations in Service Environment:

Temperature - Strength insensitive to temperature.

Water Quantity - Adequate resistance.

Water Quality - Adequate resistance.

Fabrication and Emplacement Considerations:

Available Technology - Simplifies emplacement operations and retrieval. Fabrication techniques are known. Ability to perform closure weld.

Remote Handling - Eliminates remote closure welding.

NDE - Inspection capability (e.g., radiography will be difficult). NDE remains an issue.

Cost Estimates:

Reasonably inexpensive. In 1982 dollars: \$53,000 for cast steel; \$32,000 for gray cast iron; versus \$41,000 for the borehole package. Reduced costs elsewhere in the repository as a result of using this SSP design should also be considered.

Summary of Weaknesses:

Inspection capability (e.g., radiography will be difficult).

Containment lifetime in vadose zone (long-term corrosion data and model are needed).

Localized embrittlement and accelerated corrosion may occur in the heat-affected zone of welded cast ductile iron.

Backfill will get very hot and will be difficult to extract.

NDE remains an issue.

Preheating may be required for welding cast iron. (Shoesmith)

If breaching of the wall occurs by corrosion, the game is over for the container, and the mechanism for further failure will change. (Shoesmith)

In the past, it has not been established that the corrosion mechanism for these ferrous materials is general corrosion, which is the appeal of this single barrier approach. (Basham)

Brittleness may be a problem; thus, Duriron may be a better material, especially because of its better corrosion resistance compared to cast gray iron. Higher chromium steels may also improve corrosion resistance. Also, the environment could be modified (such as adding limestone) to reduce corrosion of steel. (Staehle)

Adding limestone to raise the pH to 11 may lead to complexing of radionuclides or carbonates, which may be undesirable. Also, atmospheric CO_2 will tend to drive the pH down to 8 or 9. (Langmuir)

What to surround the steel with and how long it will sustain the pH are interesting technical questions that would have to be resolved. (Staehle)

Engineering the environment is not an easier problem than engineering the waste package. You must ensure that the modified environment survives for very long times. (Halsey)

Summary of Strengths:

Potential use as storage/shipping casks (i.e., a universal cask).

Eliminates boreholes (one option).

Increased waste loading per package is possible.

Eliminates remote closure welding.

Eliminates concern about damage to corrosion barrier during handling.

Ability to perform closure weld.

Eliminates radiation and radiolysis effects.

Good strength and thermal conductivity.

Strength insensitive to temperature.

Simplifies emplacement operations and retrieval.

Fabrication techniques are known.

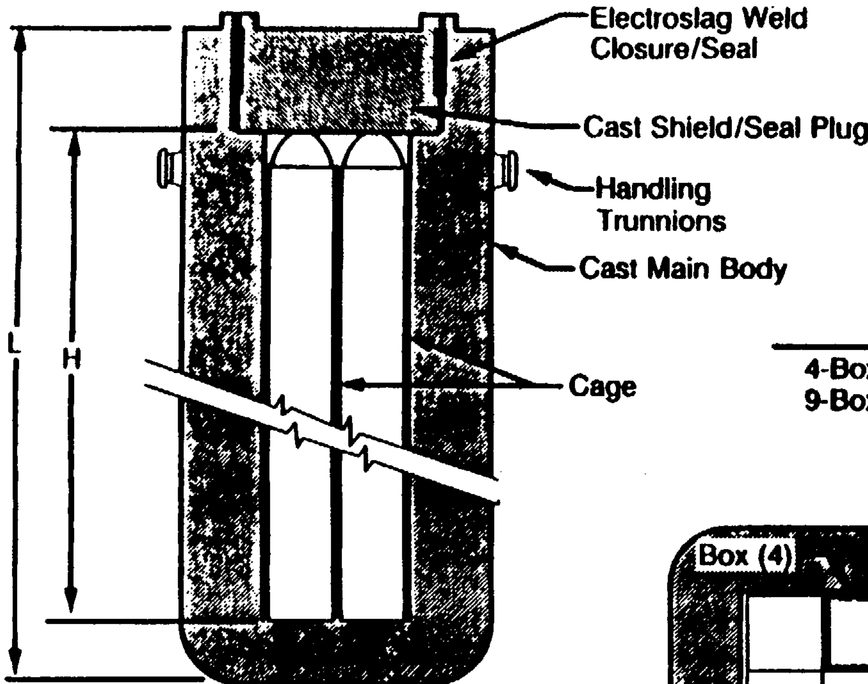
Reasonably inexpensive.

Use of large steel containers is a very attractive idea because of its simplicity. It is best to keep the outside pH around 11 to shut off pitting and stress corrosion cracking. However, we have competing issues of stabilizing the steel as opposed to increasing the transport of radionuclides once the container fails. (Staehle)

Limestone located not far from the site could be used for pH control. (Deere)

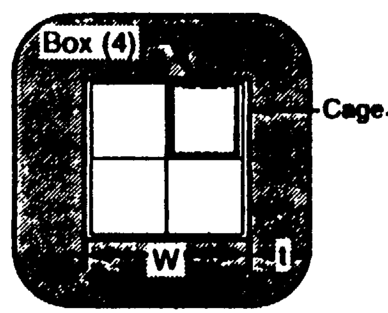
Figure 10

WESTINGHOUSE ELECTRIC CORPORATION,
ENVIRONMENTAL SYSTEMS GROUP
SELF-SHIELDED PACKAGE CONCEPT



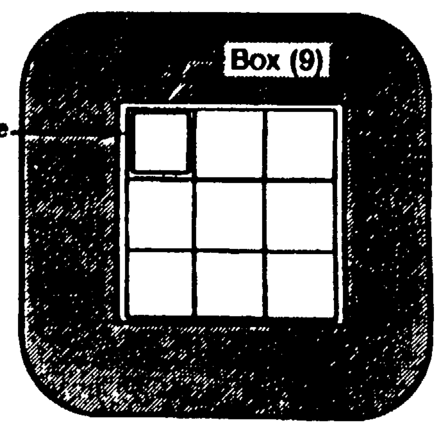
Cask Elevation - 4 Box Design

	Package Dimensions (cm) W	t	H	L	Empty Weight (Kg)
4-Box	48	37	415	502	46,000
9-Box	72	40	415	510	68,000



SSP-4 Design

Plan Views



SSP-9 Design

SUMENGP.122/9-26-91

UNIVERSAL CASK

Presenter:

Marvin L. Smith
Virginia Power Company
5000 Dominion Blvd.
Glen Allen, VA 23060
(804) 746-8231

Key Design Features:

Thick wall (about 30 cm) metal cask using carbon steel, stainless steel, cast nodular iron, lead, or a combination thereof. Dimensions are 180 cm inside diameter, 240 cm outside diameter, and 470 cm height. Bolted closure at the reactor; not welded shut until just before shipment to satisfy NRC requirements. Supplemental shielding used for storage and transport. 15 metric ton heavy metal capacity (110 metric tons loaded).

The Physical and/or Chemical Processes Relied on for Estimated Containment Lifetimes and Degree of Isolation:

Self-shielding. Radiolysis effects in repository are eliminated. Good strength and thermal conductivity.

Performance Considerations:

Containment - Long life in repository due to thick walls and materials' properties (15,000 years for nodular iron, and 50,000 years for stainless steel).

Isolation -

Estimate of Ability to Model - Radiolysis effects in repository are eliminated, improves modelability.

Analogs -

Degree of Insensitivity to Variations in Service Environment:

Temperature - Not sensitive to temperature changes.

Water Quantity -

Water Quality - Proper combinations of materials would resist changes in water quality.

Fabrication and Emplacement Considerations:

Available Technology - Stainless steel casks with 14-inch thick walls are currently being welded. (Childress)

Remote Handling - Remote handling not required.

NDE -

Cost Estimates:

Boreholes not required; simplifies repository design and reduces construction and operating costs. Enhanced retrievability. Monitored retrievable storage construction and operating costs are reduced, easy transport of packages by using an outer package if necessary. Utility storage is cheap, allows early loading. High individual waste package cost, but said to be offset by other systems savings (based on $900,000 per cask and a 3% discount rate per year). The number of casks needed would be 5,400.

Summary of Weaknesses:

Requires an early decision on the waste package.

High heat loading will likely require additional cooling time before disposal of waste compared to current waste package concept.

Requires development of small cask to large cask dry transfer facilities.

There are questions regarding the NRC position on inspection, storage, etc. (Shaw)

Not all utility sites can accommodate these large casks. (Benz)

English corrosion data indicate only 1,000-year container life for cast iron, and stress corrosion cracking can happen. (Shoesmith)

Can be designed for flooded and/or dry conditions in the repository, although corrosion rates and mechanisms must be determined. (Shoesmith)

There may be welding problems with these large casks. (Shoesmith)

The cost may be higher than that claimed, particularly for stainless steel, which may be a minimum of $1.5 million. (Childress) The response disagreed with this.

Two concerns are the temperature drop (in the packages) and criticality. (Altenhofen) The response was that pre-emplacement cooling will control the temperature drop, and filler materials and burn-up credit are possible solutions to the criticality problem.

Summary of Strengths:

Surface storage outdoors has been demonstrated.

Concept has been licensed by the NRC for storage, and storage/transport license applications have been submitted.

Horizontal transport has been demonstrated and is easily done.

Minimizes spent fuel handling (load spent fuel only once); simplifies and integrates system for utility storage, MRS transport, and disposal at repository; as low as reasonably achievable benefits (less than 1 R/hour exterior dose rate). The package provides simplicity and flexibility, and demonstrates early progress to the public on waste disposal.

High capacity cask; reduces number of rail shipments to 540 (10 casks per train). Transportation is a major public concern.

Can store above ground (until heat decays sufficiently); similar packages are already generically licensed for spent fuel storage; can store at utilities, MRS, or repository.

Boreholes not required; simplifies repository design and reduces construction and operating costs.

Enhanced retrievability.

Monitored retrievable storage construction and operating costs are reduced; easy transport of packages by using an outer package if necessary.

Utility storage is cheap; allows early loading and interim storage before repository licensing.

Self-shielding.

Radiolysis effects in repository are eliminated.

Good strength and thermal conductivity.

Without boreholes, the container can be surrounded with more buffering and environmental control material. (Kundig)

EBS WITH CONTAINER COOLING AND ROCK DRYING ENHANCEMENT

Presenter:

George Danko
University of Nevada at Reno
2785 Judit Lane
Reno, NV 89503
(702) 784-4284

Key Design Features:

Cooling enhancement techniques: heat pipes, thermal siphons, superconductor rods, and heat pumps. See Figur 11.

The Physical and/or Chemical Processes Relied on for Estimated Containment Lifetimes and Degree of Isolation:

Used to provide a "dry belt" outside the EBS for several thousand years. Decreased temperature of container. Decreased moisture content. Decreased corrosion of container. Decreased temperature variation in the rock. Develops enduring higher temperatures (> 100°C) away from the borehole (e.g., 20 to 60 meters).

Performance Considerations:

Containment -

Isolation -

Estimate of Ability to Model -

Analogs -

Degree of Insensitivity to Variations in Service Environment:

Temperature -

Water Quantity -

Water Quality -

Fabrication and Emplacement Considerations:

Available Technology - Available.

Remote Handling - Not needed because of pre-emplacement of the heat pipes.

NDE -

Cost Estimates:

$5,000 per heat pipe, including drilling (0.05-0.1 m diameter x 34 m length), emplacement, and backfilling costs. Two heat pipes per waste package are shown in the design.

Summary of Weaknesses:

Uncertain effects of cooling enhancement device emplacement boreholes on hydrology.

Further materials evaluations and device performance assessments are needed.

The life and reliability of these devices are questionable.

By creating holes for these devices, you are also producing a lot of excess holes for water to run down toward the waste package. (Simons)

Carbon steel pipes fail due to internal corrosion, with hydrogen bubble formation. (Miglin) Response was that copper, rather than steel, would be used.

What is the ability to maintain the temperature at a distance away from the package? (Basham)

Reduced capillary potential may cause higher stresses. (Harr)

Summary of Strengths:

Flexible design - both "hot" or "cool" thermal loading concepts can be achieved.

Doubling of the waste mass or reduced emplacement area are facilitated.

The technology is available, and remote handling is not needed.

Provide a "dry belt" outside the EBS.

Decreased temperature of container.

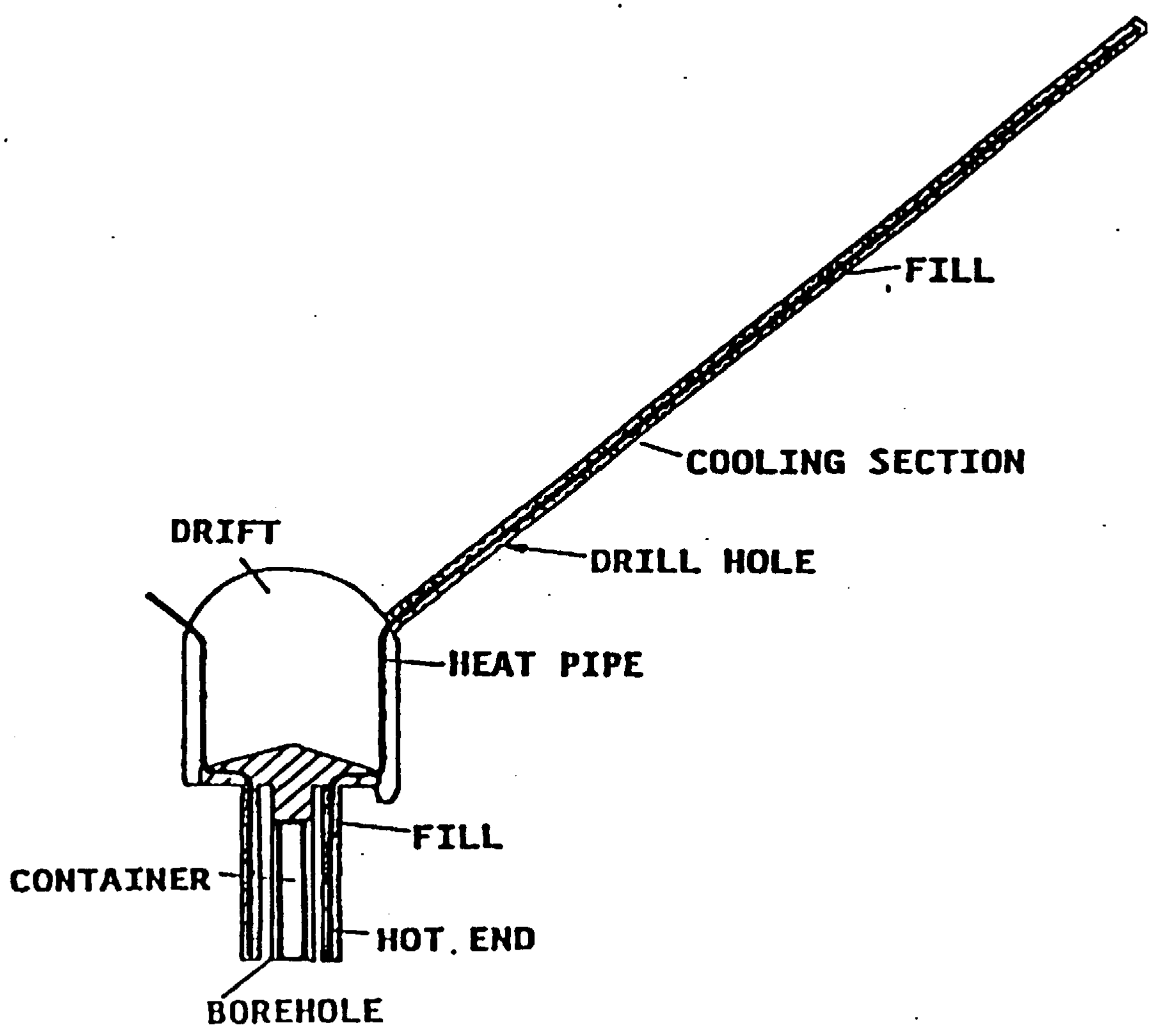
Decreased moisture content.

Decreased corrosion of container.

Develops enduring higher temperatures (> 100°C) away from the borehole.

Available technology - Available.

UNIVERSITY OF NEVADA RENO
COOLING ENHANCEMENT CONNECTION



SUMENGP.122/9-26-91

Figure 11

AUDIENCE DISCUSSION PERIOD AT THE END OF SESSION 2

Comments by audience members in this discussion period have been included in the appropriate concept headings above except for some remarks by Don Deere, NWTRB, which are included here:

> Some of the presented concepts utilize a borehole liner and some do not. For borehole stability during the thermal loading period and during any seismic ground motion, it is almost necessary to use a liner. A variety of materials can be used, and the liner can serve as a form for packing or buffer material. (Deere)
>
> Pretreatment of areas before drilling a hole is very normal civil engineering practice, and it is done by pre-grouting, which can cut off any (later) surge of water from openings for some period of time. (Deere)

SESSION 3

EXPERTS' DISCUSSION

Holmes Brown, the Workshop Facilitator, asked the experts to address three questions in this session:

1. Can a 10,000-year waste package be developed?

2. What is the applicability of the presented EBS concepts to extended life performance?

3. What is your general response to the presentations?

The experts' responses to these questions are given below, together with pertinent audience comments that were made during Session 3.

1. Can a 10,000-year waste package be developed?

   Response: "Yes" - Andresen, Basham, Shoesmith

   "Probably" - Shaw

   No response - Harr, Simons

2. What is the applicability of the presented EBS concepts to extended life performance?

   There were a number of comments that dealt with concept applicability in a general sense and were not directed to specific concepts:

   - Multi-barrier approaches were favored over monolithic barriers by Shoesmith because they spread out the failure distribution and thereby allow scientific and political fine-tuning, which are difficult to do with a single barrier. Basham and Andresen also viewed multi-barriers as promising. Audience participant Dwayne Chesnut favored a series of 200-year barriers to give the overall performance needed.

   - In the event that a materials selection decision is required within one year, Shoesmith favored a corrosion allowance material such as iron, copper, or lead (which have "public warmth," although they also have possible problems with corrosion film development) over corrosion resistant materials. However, if a few years are available, both types should be considered. If the need is open-ended, new and advanced materials could be considered as well.

   - Andresen warned against relying on galvanic interactions, which can be extremely unpredictable. He favored many of the metals discussed, including the simple iron or titanium systems, but expressed concerns about copper (localized corrosion, stress corrosion cracking, complexing) and lead (long-term toxicity). He did not favor the use of ceramics; which he said were not truly inert, could stress corrosion crack, and were brittle. Also, the labeling of systems as thermodynamically stable or reducing should be done with great caution, especially for long-term applications. The use of trapping or ion exchange materials in the multi-barriers concept appeared very attractive to Andresen. He did not favor the chemical tailoring of the drifts because of the difficulty in guaranteeing the longevity of the system within the wide range of potential environments at Yucca Mountain. Chesnut opposed the use of a high pH environment to reduce corrosion because, in the event of a waste package leak, high pH water would dissolve the glass waste form more rapidly.

- Andresen and Shoesmith strongly cautioned presenters about the use of natural analogs because of the danger that conditions in the systems being compared may not be exactly the same.

Comments that could be more clearly associated with specific EBS concepts were identified and categorized as either favorable to, or cautionary toward, one or more of the concepts. Table 1 lists the EBS concepts and the authors of the comments in the appropriate column. Both Basham and Andresen qualified their opinions in this area by saying that their opinions were really based on too little evidence.

3. What is your general response to the presentations?

- Get on with the experimental work:

  Let's get on with it and get into a concept. Program is bogged down in regulatory limits and things that are conditioning your program. (Shoesmith)

  My key message is let's get on with it. (Shaw)

  A fundamental problem is that the will to do the job is not evident. If money had been put into some experimental work ten years ago, we would have an awful lot of information to discuss today...money needs to get put in today. (Andresen)

- Probabilistic approaches should be employed:

  We need to start making comparisons on the equivalent basis. Probabilistic approaches are certainly the appropriate ones to identify these functions and to inter-compare them. We need to consider scenarios and their likelihoods. All this leads to the CCDF (complimentary cumulative distribution functions) approach that the Environmental Protection Agency uses...A probability analysis and lifetime prediction of any of the concepts could be done. (Shaw)

  We have to tolerate a probabilistic analysis and realize uncertainties exist in environment and materials performance...probability approaches ...are critical to this program. (Andresen)

You have many factors interacting in the system. How do you deal with them and account not only for the uncertainty of each variable, but their correlations, their interaction? The point estimate method has been developed -- a probabilistic method that solves the uncertainty in a closed form manner. There is something else called Baysian probability. It is an organized way of upgrading your level of knowledge. The use of these two methodologies is quantitatively robust. (Harr)

- A quantitative approach is missing:

  I found, in general, two things lacking in many of the presentations -- a clear quantifiable statement of the advantage of the concept and an analysis of the impact of applying the concept (i.e., gain and cost). (Basham)

  Something that was absolutely missing in the most, if not all presentations...was a quantitative focus. (Harr)

  The presented concepts were based on cursory information. (Andresen)

  Data, predictions, and probability approaches were missing. (I. Miller, audience member)

- The need for long-term monitoring:

  The statistical basis of our selected approach (to a robust waste package) could be improved by monitoring the EBS for one to two hundred years of the initial repository operation. This should be discussed with regulators, and I believe there is some basis for consent. That kind of verification is not out of line. (Basham)

  We have always insisted upon combining a modeling approach with monitoring approach. It is dangerous not to monitor. Very complex monitoring devices have been developed. I think monitoring the repository should be strongly considered. (Andresen)

- Avoid placing much reliance on natural analogs:

  Avoid over-reliance on the natural analog, which just shifts the burden of prediction from your system to the natural analog. These are very good to use once you are on the right track -- i.e., if you can show your conditions agree with this. Otherwise, you are in trouble. The natural analogs for longevity of material can be matched by the natural analogs for how they corrode. And for some of the systems, we are hard-pressed to guarantee that the conditions are exactly the same, both in terms of these elements in metals, as well as in the precise character of the analog system we are trying to compare to. (Andresen)

- o Need for major sustained funding:

  We need some major funding of experimental work to obtain hard data -- i.e., 20 to 40 million dollars a year for 20 years. It's not easy, cheap, or inexpensive. (Basham)

  An expenditure over a period of at least five years of something in the vicinity of 100 million dollars is needed to tackle the problem intelligently. (Andresen)

  There is the need for necessary financial support to get at the answers for these things, which are actually independent of the site at this stage. A lot of these things have to do with manipulation of the source term, and we ought to get at it. (Verink)

- o Let the mountain work for us:

  We don't need containers that will last, each one without any doubt, for 10,000 years. All we have to do is be reasonably assured that they won't leak at such a rate that allowable limits will be exceeded. (Simons)

  I would suggest that the really long-term barriers are always going to be the geosphere barriers, and it's going to be easier to quality assure them, which is not to say that I don't think we should go ahead and try to design a 10,000 year container. (Shoesmith)

- o Simplicity of concept needed:

  Simplicity should drive the program (as proposed by Staehle and others) combined with the idea of integrating the solutions to a number of problems simultaneously as represented by the Virginia Power concept. (Andresen)

  Another point of simplicity might be to use something around the container that could solve both the problem of stabilizing the container and stabilizing the radionuclides. If we could solve all these problems, the whole system begins to simplify a lot. We should at least begin to think about it at this meeting. (Staehle)

  From my thinking, the questions and remarks regarding simplicity become more and more important as you consider the variables that are involved in a long-term performance life. (Berusch)

- o Modeling:

  What controls transport is the source (rate of release), not the hydrology or system. First the basic mechanism and processes of the system must be understood, then the models can be developed, not the reverse process. I don't think we can predict anything except very short-term phenomena...because of the variability of most real systems. It's going to be impossible to validate any of these models in a way that we can be absolutely certain that our predictions for 10,000 years will occur. So we have to predict on the basis of what's occurred in the past. (Simons)

Modeling can be used to compare the various options with the base LLNL design and also to determine uncertainties. Different levels of models are needed, from very detailed ones to upper-level overview models. (Shaw)

The modeling system is an important issue. A vast number of interactive variables can be handled, for example, in stress corrosion cracking systems. I don't share David's (Shoesmith) concern that you can't design against stress corrosion cracking. It is not intimidating to design for 1,000 to 10,000 years. (Andresen)

I'm concerned about the expert's diverging opinions on how easy it is to model or prove a case. (Berusch)

Avoid conceptual complexity in the models. (Shoesmith)

- General approaches to solving the design problem

Confine and constrain assumptions by first developing the strategy, e.g., decide on a hot or cold repository before the site characterization is known. There should be a debate by experts and peers at the front end of the program on such matters. (Nair)

Corrosion at Yucca Mountain will be of a localized type, probably stress corrosion cracking. Therefore, materials susceptible to stress corrosion cracking should be ruled out. If a material is susceptible to pitting, justifying a material would be difficult, but it can be done. For crevice corrosion susceptibility, there is an experimental problem of justifying the mode of penetration. In the case of hydrogen cracking, predictions can be made...therefore, limit the scope of the problem based on susceptibility, decide what is going to happen, and look at it (experimentally). If localized corrosion is involved, assume initiation of the process occurs and experiment on propagation. Redesign the vault if the results are unacceptable, using, for example, the gravel idea presented. (Shoesmith)

A flaw in the program is the lack of data. Workshops and systems studies are not enough. We have to pick several approaches on inadequate evidence and get started. There should be some evolution in the regulations, but robust approaches backed by hard data are needed. (Basham)

We need performance assessment and system cost to get a solution to the problem, also public acceptance. Why aren't we designing the waste package for the particular issues raised by performance assessment -- such as for plutonium, which the NRC has highlighted in their performance assessment analysis? The next step is to look at the needs of the EBS in terms of radionuclide release rates, then use a simplified model to assess the concepts. Also, flexibility in thinking is needed. It's not just today's technology, it's also future technology. (Shaw)

The definitions and criteria we're going to design against are ambiguous (e.g., "substantially complete containment"). This issue is not a technical one, but how we establish regulations. Clearer goals need to be established, and experiments with benign, moderately aggressive, and very extreme conditions need to be started. We don't need site characterization to do this. This is my biggest single recommendation. (Andresen)

We can build with confidence by using the sequence: sample, test, formulation (parameters), and experience. We need inspection because the system is only good to one part in ten or twenty. (The space shuttle, our best engineered system, gave a reliability of 95 percent - i.e., a probability of failure of 5 percent). Establish a target reliability (equivalent to a probability of success). I suggest 95 percent, which is the best we can do with our knowledge base. Use the point estimate method to do this, which is a probabilistic method. Also use Baysian probability. Such systems can be used to evaluate and optimize with safety and economy. (Harr)

The use of Pourbaix diagrams with superimposed kinetics is advocated. Predictability can be worked out by knowing (degradation) modes of materials, superimposing the environmental definition, then the statistical definition or probabilistic definition of the mode multiplied by the environmental probability. This is a rational system. If you want data to make predictions, you look at some distribution function constant, as parameters, as a function of temperature, potential stress, or something. Determine these for short times (1-10 years), then you can make long-term predictions. (Staehle)

Start work on things related to the source term. You don't need site data to do this. (Verink)

On this project, a lot of our job is to build confidence in ourselves, our technical colleagues, and the general public that the system really does the job. (Chesnut)

There is a need for simplified experiments regarding the solution concentrations employed. Also radiological experiments, including the transuranics, are needed. (Reed)

- Suggested backfill concepts.

Crushed limestone is suggested as a backfill to serve as a getter for carbon-14. A possible method for encapsulating the waste is to emplace a mixture of MgO, silica, and water, which under heat will form the mineral serpentine. Also, chemical processes in the backfill may be used to limit radionuclide migration, e.g., crushed zeolitic tuffs or phosphates (uranium phosphate, Urezite), gypsum. (Langmuir)

Referring to the previous comment, the USGS reports that the exchange of carbon-14, CO_2, and bicarbonate isn't much. Therefore, carbon-14 and CO_2 will pass through the mountain in a very short time. (U Sun Park)

- Miscellaneous Comments

  It would be helpful if all the information on the DOE reference case, its component costs, materials data, corrosion rates, etc., could be put together in a better and easily digestible form. Also, DOE should make available some simple models that give temperatures, given the heat loading in the package and a surface area. Also, the utilities have experience storing and handling waste for a considerable time, and hopefully that experience could be used. (Smith)

  No progress (has been made at this meeting) as to whether the job can be done using, e.g., a metal or a composite material. I wonder if we can ever put together the necessary information to answer questions from Nevada and the intervenors. (Berusch)

  This meeting indicates that a synergism is developing which could lead to a better definition of problems and speed solutions. (Verink)

SESSION 3: CONCLUSIONS

- Development of a 10,000-year waste package is technically feasible according to four of the experts (two experts gave no opinion on this).

- The experts were highly critical of the lack of quantitative data included in the concept presentations, which made evaluation very difficult.

- Two general types of waste package design appeared to have the greatest support from the experts: the thick-walled, self-shielded/universal cask (proposed by Virginia Power and Westinghouse) and the multi-barrier designs proposed by several presenters. However, this support was qualified because of the lack of quantitative performance evidence, and only two of the experts offered assessments of specific concepts.

- Favorable comments were made on the Virginia Power idea of simplifying the program by integrating the solution to a number of problems (i.e., utility and MRS storage, transport, and disposal in the repository). The use of trapping/ion-exchange materials in the multi-barrier approach was also favored.

- The experts warned against relying on natural analogs, galvanic interactions, ceramics, and non-metals (on the outside diameter) for waste package designs.

- There appeared to be some disagreement among the experts in several areas:

  - Ability to design for stress corrosion cracking.

  - Reliance on thermodynamic stability and reducing systems.

- Chemical tailoring of the waste package environment.
- The use of copper or lead as waste package materials.
- The uses of modeling and how easy (or difficult) it is to prove a case.

o The experts offered a number of recommended approaches to future work:

  - Get on with the experimental work.
  - Probabilistic approaches (such as the point estimate method, Baysian statistics, and CCDF) should be employed.
  - Pick several approaches, even if based on inadequate evidence, and get started.
  - Since a few years of work are available to the program, probably both corrosion allowance and corrosion resistant materials should be considered.
  - Establish clearer goals and begin experiments with (1) benign, (2) moderately aggressive, and (3) very extreme conditions; do not wait for site characterization to do this.
  - Long-term monitoring of waste package in the repository should be done.
  - Let the mountain work for us as a long-term barrier.
  - Sustained major funding of the EBS program is needed (at least $20 million/year for five to twenty years).

Table 1. Experts' Comments on the EBS Concepts

		Comments	
		Favorable	Cautionary
1.	SiC/Al matrix composite (ACS)		Andresen
2.	Filament-wound ceramic matrix (TA&T)		Andresen
3.	Metal/non-metal multi-barrier (ENA)	Basham	Andresen
4.	Thin metal with environmental modification (ANL)		Andresen (outside diameter non-metal, backfill)
5.	Gravel backfill (INTERA)		
6.	Spent fuel stabilizers (INTERA)	Basham	
7.	Graphite design (NAMC)		Andresen
8.	Multi-barrier container concept (B&W)	Basham Andresen	
9.	Copper composite container (CDA)		Andresen
10.	Redundant corrosion/containment barriers (ILZRO)	Basham	Andresen (lead)
11.	Self-shielded package concept (W)	Andresen Basham Douglas* Niedzielski-Eichner*	
12.	Universal cask (VP)	Andresen Basham Douglas* Niedzielski-Eichner*	
13.	Cooling and drying enhancements (UNR)	Basham Niedzielski-Eichner*	Andresen (not a simplifying approach)

*Audience member

3.0 CONCLUSIONS AND RECOMMENDATIONS

Having completed the EBS Concepts Workshop and reflected on the presentations and discussions which took place, the YMP can make the following general conclusions and recommendations, while recommendations regarding specific EBS concepts will require further detailed evaluations.

CONCLUSIONS

The objectives of the workshop were successfully achieved.

A broad range of concepts and approaches was presented and discussed.

Development of a 10,000-year EBS is technically feasible.

No changes in the Waste Package Plan, resulting from the workshop, are apparent at this time, but this will be evaluated further during the next revision of the plan.

Decisions by the DOE to pursue a more redundant and extended-life EBS would be reflected in waste package design requirements (WPDRs) to be issued for the next design phase.

Most conclusions made by the participants at the workshop appear reasonable. Any conflicting statements made during the discussions will require further consideration.

Disagreement among experts will make consensus difficult, and this suggests that the YMP select well-understood and simple approaches to its EBS design.

Major sustained funding is needed if the EBS program is to be successful and timely.

RECOMMENDATIONS

Most recommendations made by the participants at the workshop appear reasonable and will be considered by the DOE.

All the concepts presented deserve further consideration; however, evaluating specific concepts may be difficult without more quantitative data.

Attractive features of different concepts should be considered in developing alternative concepts for the next design phase. Both corrosion allowance and corrosion resistant materials should be considered. Probabilistic methods should be used to evaluate these alternatives.

At least one EBS approach should be selected now, and the data necessary for its evaluation should be developed. The approach should be simple, but robust, with potential for extended life well beyond 1,000 years.

Another EBS Concepts Workshop should be scheduled during 1993. The 1993 workshop would focus on those concepts selected by the DOE for Advanced Conceptual Design.

EXTENDED SUMMARY REPORT ON ENGINEERED BARRIER SYSTEM CONCEPTS WORKSHOP

JUNE 18-20, 1991
DENVER COLORADO

APPENDICES

PREPARED BY

SCIENCE APPLICATIONS INTERNATIONAL CORPORATION
and
WESTON TECHNICAL SUPPORT TEAM
for
YUCCA MOUNTAIN SITE CHARACTERIZATION PROJECT
U.S. DEPARTMENT OF ENERGY
LAS VEGAS, NEVADA

OCTOBER 1991

APPENDIX A

WORKSHOP ANNOUNCEMENT

DOE NEWS

NEWS MEDIA CONTACT:
Stephanie Hanna, 202/586/5806

FOR IMMEDIATE RELEASE
February 27, 1991

DOE ANNOUNCES DENVER WORKSHOP ON YUCCA MOUNTAIN ENGINEERED BARRIER SYSTEM CONCEPTS

The Office of Civilian Radioactive Waste Management of the U.S. Department of Energy (DOE) is pleased to announce the Yucca Mountain Engineered Barrier System Concepts Workshop to be held June 18-20, 1991, in Denver, Colorado. The DOE is seeking participants who may be interested in presenting Engineered Barrier System (EBS) concepts at this Workshop.

The focus of the workshop will be EBS concepts for extended-life performance in a potential high-level radioactive waste repository at Yucca Mountain. The EBS is defined in NUREG 10 CFR 60.2 as the waste packages and the underground facility including openings and backfill materials, but excluding shafts, boreholes, and their seals. Extended-life refers to exceeding the regulatory performance standards imposed on the engineered barrier system and its components in NUREG 10 CFR 60.113. The objectives of the Workshop are to provide a forum for the discussion of EBS concepts and their applicability to extended-life performance.

(MORE)

R-91-041

Participants for the workshop will be selected in a two-step process based on the evaluation of their personal qualifications and of their technical analysis of the proposed concept. First, interested participants must submit a qualification statement which should include a one page discussion on why the individual believes he/she is qualified to address the subject. Second, after determining who is qualified to participate, DOE will ask qualified participants to submit a technical analysis which should include a description of the concept, physical and/or chemical processes relied on for containment and isolation, predicted performance, degree of insensitivity to variations in service environment, fabrication and emplacement aspects, and rough cost estimates. At the same time DOE requests technical analyses of qualified participants, it will send an information package about requirements imposed on design. This invitation for participation in the Workshop should not be construed as a request for proposal for future work in this area or as a commitment to compensate participants in any manner.

Individuals interested in participating in the Workshop should submit their qualifications by March 15, 1991, for consideration by DOE. Requested technical submittal will be due to DOE by April 19, 1991. Send qualification statement to: Diane J. Harrison-Giesler, U.S. Department of Energy, Yucca Mountain Site Characterization Project Office, M/S 523,
P.O. Box 98608, Las Vegas, NV, 89193-8608.

(DOE)

R-91-041

necessary in order for the terms of Western's tariff to conform with the Order.

In addition, Western moved to place the foregoing tariff sheets and those previously filed in this proceeding into effect on March 1, 1991.

Finally, Western requested waiver of the 30 day notice period, thereby allowing the tariff sheets to be effective on March 1, 1991.

Any person desiring to protest said filing should file a protest with the Federal Energy Regulatory Commission, 825 North Capitol Street, NE., Washington, DC 20426, in accordance with Rules 214 and 211 of the Commission's Rules of Practice and Procedure (18 CFR 385.214, 385.211 (1990)). All such protests should be filed on or before February 25, 1991. Protests will be considered by the Commission in determining the appropriate action to be taken, but will not serve to make protestants parties to the proceeding. Persons that are already parties to this proceeding need not file a motion to intervene in this matter. Copies of this filing are on file with the Commission and are available for public inspection.

Lois D. Cashell,

Secretary.

[FR Doc. 91-4308 Filed 2-22-91; 8:45 am]

BILLING CODE 6717-01-M

Office of Civilian Radioactive Waste Management

Announcement of Yucca Mountain Engineered Barrier System Concepts Workshop

AGENCY: Office of Civilian Radioactive Waste Management, Department of Energy.

ACTION: Notice.

SUMMARY: In this notice, the Department of Energy announces the Yucca Mountain Engineered Barrier System Concept Workshop. The Department is seeking participants who may be interested in presenting Engineered Barrier System (EBS) concepts at this Workshop.

EFFECTIVE DATE: The Workshop will be held June 18–20, 1991, in Denver, Colorado.

FOR FURTHER INFORMATION CONTACT: Diane J. Harrison-Giesler, U.S. Department of Energy, Yucca Mountain Site Characterization Project Office, M/S 523, P.O. Box 98608, Las Vegas, NV 89193-8608.

SUPPLEMENTARY INFORMATION: The focus of the Workshop will be EBS concepts for extended-life performance in a potential high-level radioactive waste repository at Yucca Mountain. The EBS is defined in NUREG 10 CFR 60.2 as the waste packages and the underground facility including openings and backfill materials, but excluding shafts, boreholes, and their seals. Extended-life refers to exceeding the regulatory performance standards imposed on the engineered barrier system and its components in NUREG 10 CFR 60.113. The objectives of the workshop are: (a) To provide a forum for the discussion of engineered barrier system concepts and their applicability to extended-life performance, and (b) to solicit the opinions of experts regarding extended-life engineered barrier system concepts.

Participants for the Workshop will be selected based on their personal qualifications and their technical submittal of the proposed concept. The qualifications submission should include a one page discussion on why the individuals believe they are qualified to address this subject. The technical submittal should include a description of the concept, physical and/or chemical processes relied on for containment and isolation, predicted performances, degree of insensitivity to variations in service environment, fabrication and emplacement aspects, and rough cost estimates. DOE will request the technical submittal from interested qualified participants and an information package will be sent with this request. This invitation for participation in the Workshop should not be construed as a request for proposal for future work in this area or as a commitment to compensate participants in any manner.

Individuals interested in participating in the Workshop should submit their qualifications by March 15, 1991 for consideration by DOE. Requested technical submittals will be due to DOE by April 19, 1991.

Franklin Peters,

Acting Director, Office of Civilian Radioactive Waste Management.

[FR Doc. 91-4394 Filed 2-22-91; 8:45 am]

BILLING CODE 6450-01-M

Office of Fossil Energy

[FE Docket No. 90-112-NG]

Transco Energy Marketing Company; Order Granting Blanket Authorization to Import Natural Gas

AGENCY: Department of Energy, Office of Fossil Energy.

ACTION: Notice of an order granting blanket authorization to import natural gas.

SUMMARY: The Office of Fossil Energy of the Department of Energy gives notice that it has issued an order granting Transco Energy Marketing Company blanket authorization to import up to 730 Bcf of Canadian natural gas over a two-year period beginning on the date of issuance of this order.

A copy of this order is available for inspection and copying in the Office of Fuels Programs Docket Room, 3F-056, Forrestal Building, U.S. Department of Energy, 1000 Independence Avenue, SW., Washington, DC 20585, (202) 586-9478. The docket room is open between the hours of 8 a.m. and 4:30 p.m., Monday through Friday, except Federal holidays.

Issued in Washington, DC, February 7, 1991.

Clifford P. Tomaszewski,

Acting Deputy Assistant Secretary for Fuels Programs, Office of Fossil Energy.

[FR Doc. 91-4386 Filed 2-22-91; 8:45 am]

BILLING CODE 6450-01-M

ENVIRONMENTAL PROTECTION AGENCY

[FRL-3907-8]

Prevention of Significant Deterioration of Air Quality (PSD); Final Determination

AGENCY: United States Environmental Protection Agency.

ACTION: Notice of final action.

SUMMARY: The purpose of this Notice is to announce that the Administrator of the United States Environmental Protection Agency issued a final decision pursuant to the Prevention of Significant Deterioration of Air Quality (PSD) regulations codified at 40 CFR 52.21 and the Procedures for Decisionmaking codified at 40 CFR part 124 regarding Mecklenburg Cogeneration Limited Partnership, Inc. in Mecklenburg County, Virginia.

DATES: The effective date of the Administrator's decision is December 21, 1990.

FOR FURTHER INFORMATION CONTACT: Mr. Denis Lohman, Chief, New Source Review Section, Air Enforcement Branch, Air, Radiation and Toxics Division, U. S. Environmental Protection Agency, Region III, Mail Code 3AT22, 841 Chestnut Building, Philadelphia, Pennsylvania, 19107, (215) 597-3024.

SUPPLEMENTARY INFORMATION: In a petition dated June 15, 1990, the Southside Concerned Citizens, Inc. of Halifax, Virginia requested review of a Prevention of Significant Deterioration

Enclosure 1
Attachment

APPENDIX B

INFORMATION PACKAGE

TECHNICAL INFORMATION PACKAGE

for
Engineered Barrier System Concepts Workshop Participants

Contents:

ENCLOSURE

<u>10 CFR 60.113</u> Performance of particular barriers after permanent closure.

(a) *General provisions.* (1) *Engineered barrier system.* (i) The engineered barrier system shall be designed so that assuming anticipated processes and events: (A) Containment of HLW will be substantially complete during the period when radiation and thermal conditions in the engineered barrier system are dominated by fission product decay; and (B) any release of radionuclides from the engineered barrier system shall be a gradual process which results in small fractional releases to the geologic setting over long times. For disposal in the saturated zone, both the partial and complete filling with groundwater of available void spaces in the underground facility shall be appropriately considered and analysed among the anticipated processes and events in designing the engineered barrier system.

(ii) In satisfying the preceding requirement, the engineered barrier system shall be designed, assuming anticipated processes and events, so that:

(A) Containment of HLW within the waste packages will be substantially complete for a period to be determined by the Commission taking into account the factors specified in § 60.113(b) provided, that such period shall be not less than 300 years nor more than 1,000 years after permanent closure of the geologic repository; and

(B) The release rate of any radionuclide from the engineered barrier system following the containment period shall not exceed one part in 100,000 per year of the inventory of that radionuclide calculated to be present at 1,000 years following permanent closure, or such other fraction of the inventory as may be approved or specified by the Commission; provided, that this requirement does not apply to any radionuclide which is released at a rate less than 0.1% of the calculated total release rate limit. The calculated total release rate limit shall be taken to be one part in 100,000 per year of the inventory of radioactive waste, originally emplaced in the underground facility, that remains after 1,000 years of radioactive decay.

(2) *Geologic setting.* The geologic repository shall be located so that pre-waste-emplacement groundwater travel time along the fastest path of likely radionuclide travel from the disturbed zone to the accessible environment shall be at least 1,000 years or such other travel time as may be approved or specified by the Commission.

(b) On a case-by-case basis, the Commission may approve or specify some other radionuclide release rate, designed containment period or pre-waste-emplacement groundwater travel time, provided that the overall system performance objective, as it relates to anticipated processes and events, is satisfied. Among the factors that the Commission may take into account are —

(1) Any generally applicable environmental standard for radioactivity established by the Environmental Protection Agency;

(2) The age and nature of the waste, and the design of the underground facility, particularly as these factors bear upon the time during which the thermal pulse is dominated by the decay heat from the fission products;

(3) The geochemical characteristics of the host rock, surrounding strata and ground water; and

(4) Particular sources of uncertainty in predicting the performance of the geologic repository.

(c) Additional requirements may be found to be necessary to satisfy the overall system performance objective as it relates to unanticipated processes and events.

YUCCA MOUNTAIN ENGINEERED BARRIER SYSTEM CONCEPTS WORKSHOP

June 18, 19, and 20, 1991
Denver, Colorado

Tuesday, June 18, 1991

8:00 am Introduction

- Purpose
- Introduce Facilitator and Experts
- Review Agenda

9:00 am - 12:00 pm Session 1: Background

- Summary of Systems Engineering Approach for Developing EBS Design Concepts
- Approach for Establishing Design Basis
- Extended Life Performance

12:00 pm - 1:00 pm Lunch

1:00 pm - 5:00 pm Session 2: Concepts

- Invited Presentations and Discussion

Wednesday, June 19, 1991

8:00 am - 12:00 pm Session 2: Concepts (continued)

- Invited Presentations and Discussion

12:00 pm - 1:00 pm Lunch

1:00 pm - 5:00 pm Session 2: Concepts (continued)

- Invited Presentations and Discussion

Thursday, June 20, 1991

8:00 am - 11:00 am Session 3: Experts Discussion

11:00 am - 12:00 pm Closing Remarks

EBS/WP DESIGN CONCEPTS PRESENTATION CHECKLIST

- Drawing or sketch
  - Include approximate dimensions
  - Include list of materials considered
- The Physical and/or Chemical Processes Relied on for Estimated Containment Lifetimes and Degree of Isolation
- Performance Considerations
  - Containment
  - Isolation
  - Estimate of ability to model
  - Analogs
- Degree of Insensitivity to Variations in Service Environment (i.e. Robustness)
  - Temperature
  - Water Quantity
  - Water Quality
- Fabrication and Emplacement Considerations
  - Available technology
  - Remote handling
  - NDE
- Cost Estimates
- Summary of strengths/weaknesses

Near Field Environmental Information

The Waste Package (WP) is a major component of the EBS and is defined as the waste form (i.e., any radioactive waste materials and encapsulating or stabilizing matrix), and any containers, shielding, packing, and other absorbent materials immediately surrounding an individual waste container emplaced at a repository. Radioactive waste materials include irradiated reactor fuel and a borosilicate glass which incorporates reprocessing wastes, as well as the non-fuel bearing components of spent fuel assemblies.

The primary performance requirement for the waste package is stated in the Nuclear Regulatory Commission (NRC) regulation 10 CFR Part 60 (see Appendix A) as "substantially complete containment" for a prescribed period (300 to 1000 years). Further, following the containment period, 10 CFR Part 60 specifies a controlled release rate limit for radionuclides from the EBS (see Appendix A). Other requirements on the container include retrievability, compatibility with the waste forms and other repository components, provision for transportation and handling, reasonable cost and readily available technology.

It is expected that 25,000 to 35,000 spent fuel containers and about 14,000 high-level waste (HLW) containers will be needed to contain the 63,000 metric tons uranium (MTU) of spent fuel and 7,000 MTU of HLW which sum to the mandated 70,000 MTU limit imposed by the Nuclear Waste Policy Act. Approximately 25 to 30 years would be required to fill the potential repository.

ENVIRONMENT DESCRIPTION

The potential repository would be mined in a series of volcanic tuffs at Yucca Mountain in southern Nevada. It would be located about 300 meters above the water table and about 200 meters below the mountain surface. No significant hydrostatic or lithostatic loads on the WP containers are expected. Although the potential repository horizon is in a densely welded tuff unit, core analyses indicate a fracture density range from 20-42 fractures/m^3. Based on samples taken from surface cores, the tuff is expected to have 65% saturation (± 19%) and a porosity of 12% (± 3%). Air in the unfilled voids is expected to be moist (100% humidity). Average flux estimates within the repository horizon range from 0 to 1.0 mm/yr downward; a very small upward flux due to vapor transport from the underlying saturated zone is possible. The atmosphere is expected to be oxidizing.

Interaction between the EBS components and the near field environment is to a large extent dominated by the possible presence of liquid water. Although it is not expected that pore water would contact WPs, any concept design should consider pore water as a bounding case. The composition of pore fluids from the vadose zone is not known. Water from well J-13 has been used as a reference groundwater because it is produced from the Topopah Spring tuff at a location where the tuff occurs below the water table. The composition of J-13 water is that of a dilute bicarbonate water, with chloride ion concentration less than 10 mg/l (Table 1). Also shown in Table

1 are values for pore water composition from a non-welded tuff. The composition of the water may change after emplacement of the WPs depending on any temperature rise that may be associated with waste emplacement in the mountain. Although it is not presently possible to determine the composition of surface water in contact with the tuff during fracture flow, the use of the J-13 well water composition is considered a good estimate. The components of the EBS must be able to withstand potentially aggressive environments. Such environments might result from radiation effects on the air or water, refluxing of water on the container surface leaving a salt residue that may later give rise to a concentrated salt solution, or a high-humidity environment resulting in condensed water reaching the containers.

Changes in the environment surrounding the containers can occur due to the radiation emitted by the HLW and the spent fuel. The radiation that is able to penetrate the container wall will be primarily neutrons and gamma radiation. Maximum neutron fluxes are of the order of 10^4 neutrons/cm^2/sec. This flux is unable to cause any significant damage to materials or radiation-chemical changes. Gamma radiation dose rates may initially be as high as 10^5 rads/hr, and therefore gamma radiation is of primary concern. Radiolytic effects will decrease in the later years as the waste ages. Concomitantly with the decrease of the radiolytic effects there will be a decrease in the waste package temperature (after the initial rise), because of their common source. The effects of radiation on the chemical environment surrounding the WP containers are given in Table 2.

The decay heat of the waste will cause the container temperatures to initially rise. The temperature reached will depend on the WP design and emplacement configurations. For design purposes, thermal output values of 0.3 KW and 0.75 KW at time of emplacement should be used for each BWR and PWR assembly, respectively. The reference design sets and average power density of 57 KW/acre. However, this may be increased. Temperature limits include 350°C for spent fuel and 225°C for the rock mass adjacent to the WP.

The physical, mechanical, and thermal properties of the rock mass and of intact rock which forms the potential near field environment are given in Tables 3-4.[1] The physical properties including porosity, grain density, bulk density and in-situ saturation, and dry bulk density determined from core samples are given in Table 3. Thermal properties of the repository horizon are presented in Table 4, while the mechanical properties are given in Table 5.

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[1] Yucca Mountain Project Reference Information Base Version 4 - Revision 3 (Jan. 91)

Table 1. Chemical composition of water extracted from pores of non-welded unsaturated tuff at Yucca Mountain and of water obtained from a well near Yucca Mountain.

Species	Concentration (mg/l) Extracted Pore Water	Well (J-13)
Li	*	0.04-0.17
Na	26-65	42-50
K	5-15	3.7-6.6
Mg	5-21	1.7-2.5
Ca	27-127	11.5-15
Sr	0.55-1.5	0.02-0.1
Fe	<0.003-0.118	<0.01-0.16
Al	*	0.008-0.11
Si	72-100	26.6-31.9
NO_3	*	6.8-10.1
F	*	1.7-2.7
Cl	34-105	6.3-8.4
HCO_3	*	118-143
SO_4	37-174	17-21
pH	*	6.8-8.3

* not measured

Table 2. Radiation-chemical effects on selected environments.

1. Water Vapor

   a. Small steady-state concentrations of H_2, O_2, and H_2O_2 are produced
   b. If catalytic materials such as Cu or MnO_2 are present, H_2O_2 decomposes to H_2O and O_2.

2. Dry Air

   a. N_2O, O_3, and N_2O_5 are produced
   b. O_3 decomposes and converts N_2O_5 to NO_5.
   c. Long-term products are N_2O and NO_2.
   d. N_2O is chemically stable, but NO_2 is reactive (with Cu, for example).

3. Moist Air

   a. At room temperature and low humidity, products are N_2O, O_3, and HNO_3.
   b. At high humidity, ammonia is observed.

4. Liquid Water

   a. For pure water in a closed system, small steady state concentrations of H_2, O_2, and H_2O_2 are produced.
   b. If solutes are present or system is open, net radiolysis to H_2 and O_2 occurs.

5. Two-phase (Moist Air and Liquid Water)

   a. Nitrogen from air is fixed and NO_2^- and NO_3^- ions appear in the water.
   b. H ions are produced in equivalent amounts.
   c. pH drops unless buffer is present, for example HCO_3^-.
   d. Radiolysis of water to H_2 and O_2 occurs, particularly if solutes are present.

Table 3. Anticipated Physical Properties of Potential Repository Horizon

Porosity (%)	Grain Density (g/cm^3)	Bulk Density at In situ Saturation (g/cm^3)	Dry Bulk Density (g/cm^3)
12 ± 3	2.55 ± 0.03	2.297 ± .088	2.219 ± .104

Table 4. Anticipated Thermal Properties of Potential Repository Horizon

	Matrix Thermal Conductivity (W/m - K)	In situ Thermal Conductivity (W/m - K)	Thermal Capacitance (J/cm^3 - K)
Dry	2.51 ± 0.17	2.1 ± 0.2	2.17
Saturated	—	2.1 ± 0.2[a]	2.16

Coefficient of Thermal Expansion x 10^{-6} $(K^{\circ})^{-1}$:

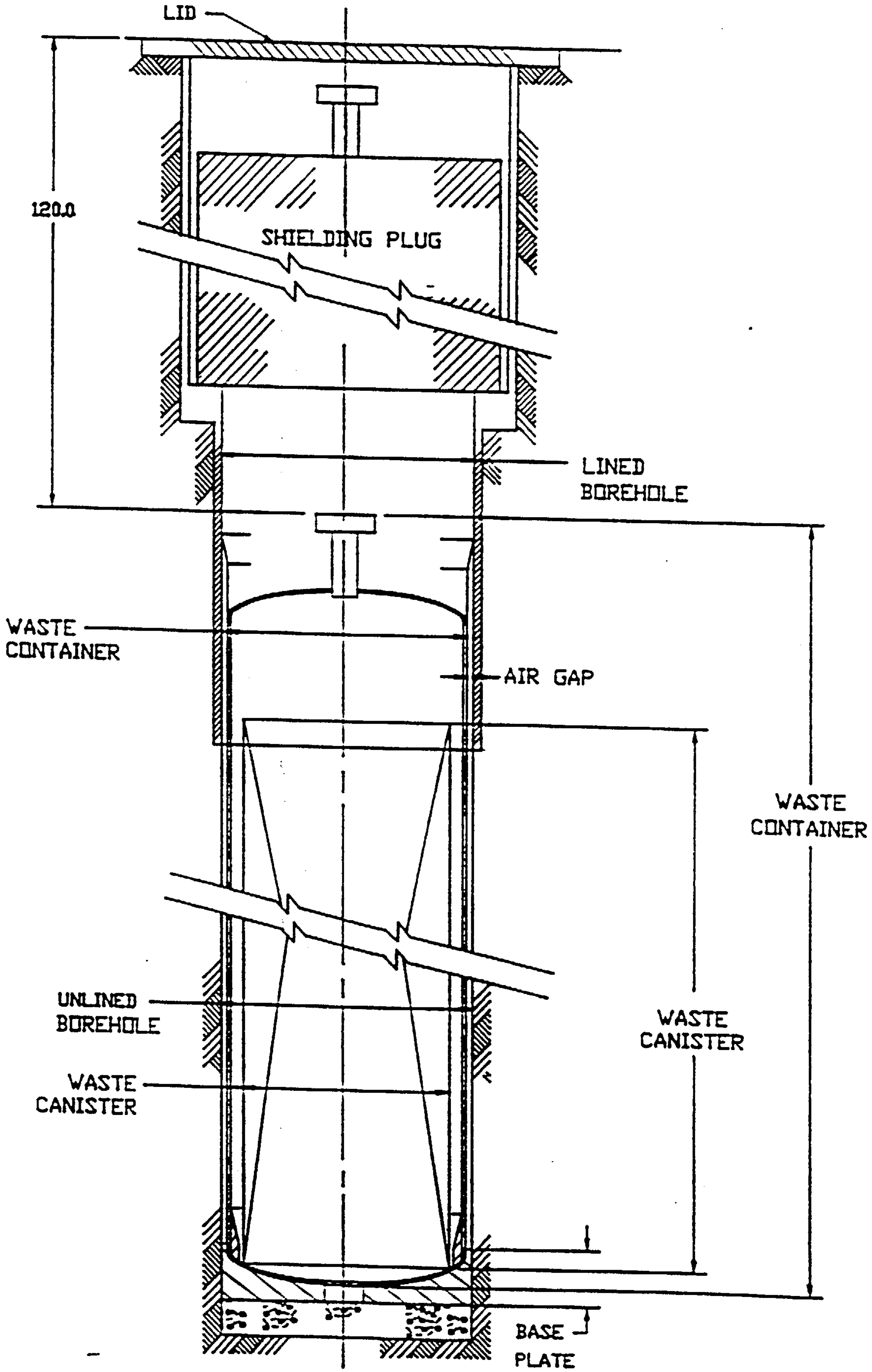
Temperature Range (°C)	Mean	Comment
25 - 200	8.8	Pre-transition
200 - 350	24.0	Transition

a - at in-situ saturation of 0.65 ± 0.19 with lithophysal cavities and fractures assumed dry.

Table 5. Anticipated Mechanical Properties for Intact Rock and Rock Mass for Potential Repository Horizon

Property	Intact Rock	Rock Mass
Deformation Modulus (GPa)	32.7 ± 4.6[a]	15.2 ± 4.2
Poisson's Ratio	22 ± .03/.30 ± .05	0.22 ± 0.05
Unconfined Compressive Strength (MPa)	155± 59	83.3 ± 33.30
Cohesion (MPa)	18.3 ± 5.2/37.8 ± 12.4	17.8 ± 5.7
Angle of Internal Friction (°)	19.7 ± 5.2/36.5 ± 9.0	23.5 ± 0.2
Tensile Strength (MPa)	15.2 ± NA	9.00

NA = Not Available
a = Elastic Modulus



WASTE PACKAGE DIMENSIONS			
WASTE FORM TYPE			
	BWR	PWR	GLASS
WT. LBS. MAX.	13,210	11,640	9,017
DIA. IN. MAX.	26.0	26.0	26.0
LENGTH IN. MAX	187.5	187.5	126.0
WALL THICK'S	.39 TO 1.2 INCH	.39 TO 1.2 INCH	.39 TO 1.2 INCH

SI APERTURE CARD

Also Available On Aperture Card

WASTE PACKAGE FEATURES						
RADIOACTIVE WASTE	ENCAPSULATING/ STABILIZING MATRIX	CONTAINER		ABSORBENTS	SHIELDING	PACKING
SPENT FUEL PWR/BWR	NONE	YES	(METAL — SELECTION IN PROGRESS USING DOE APPROVED CRITERIA)	YES (AIR)	YES (SHIELDING PLUG)	NONE
REPROCESSING WASTE	BOROSILICATE GLASS (INSIDE 304L STL'S ST'L CANISTER)	YES	(METAL — SELECTION IN PROGRESS USING DOE APPROVED CRITERIA)	YES (AIR)	YES (SHIELDING PLUG)	NONE

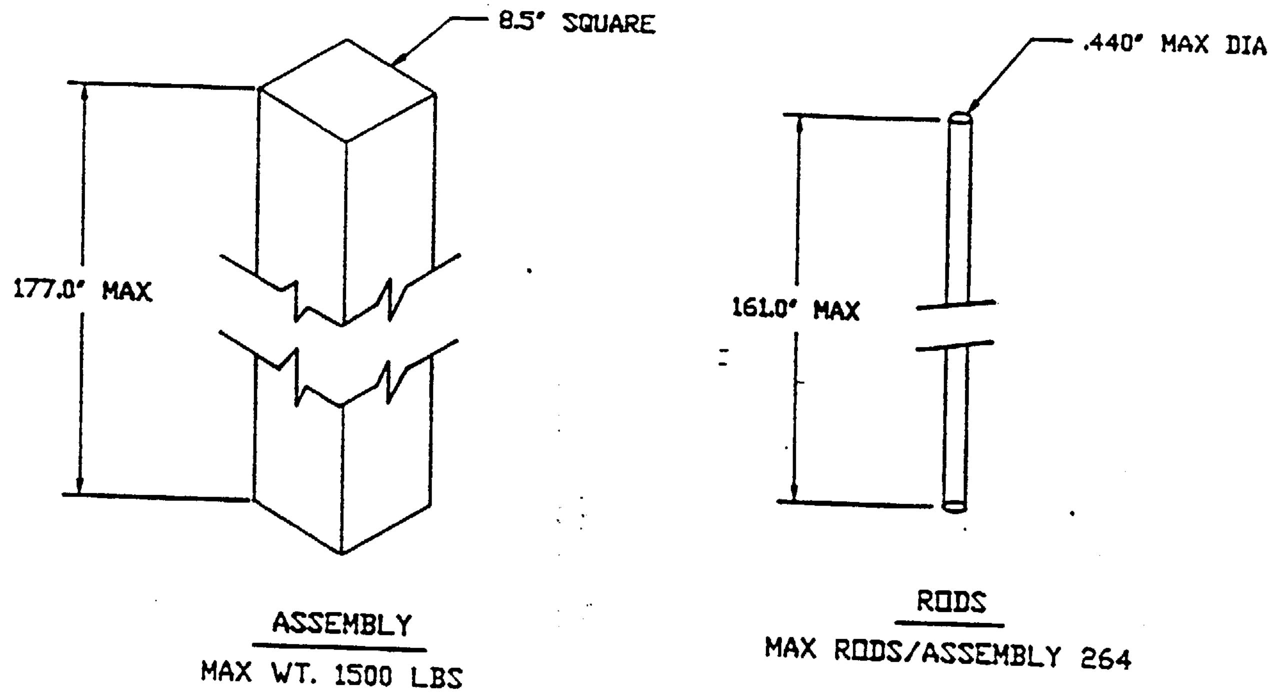
REFERENCE CONCEPTUAL DESIGN

SINGLE WALL CONTAINER

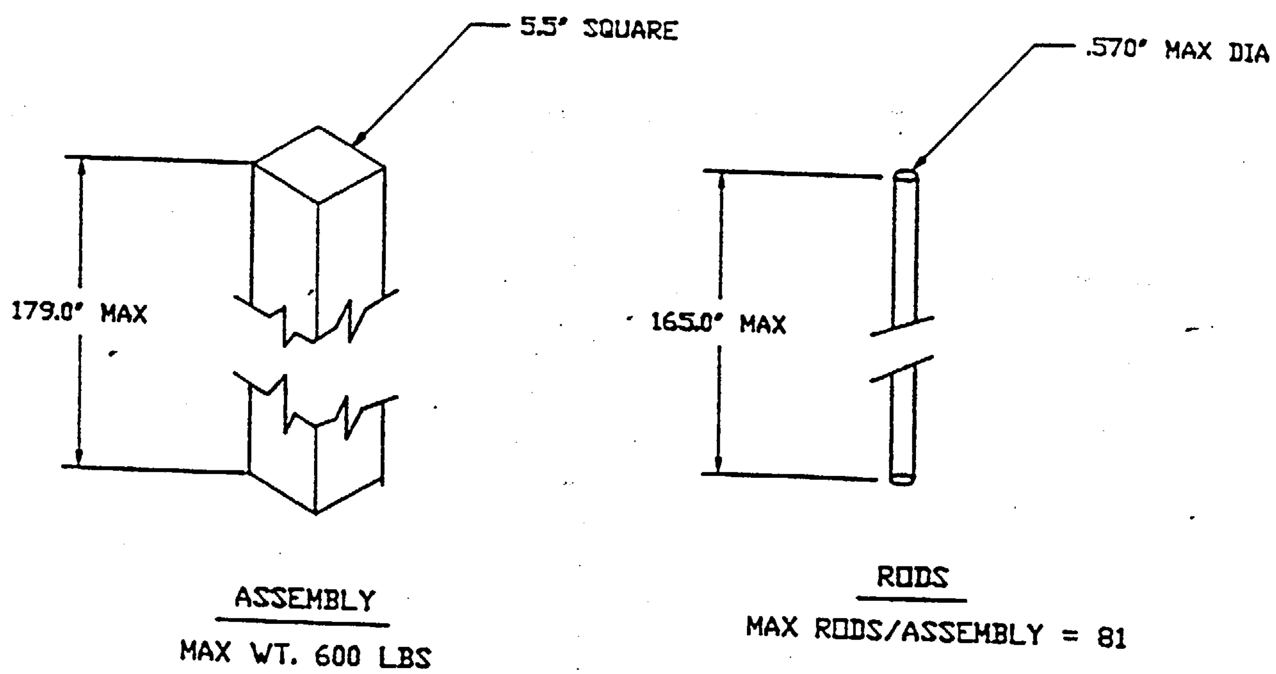
WLCWPC-1

9201060338-01

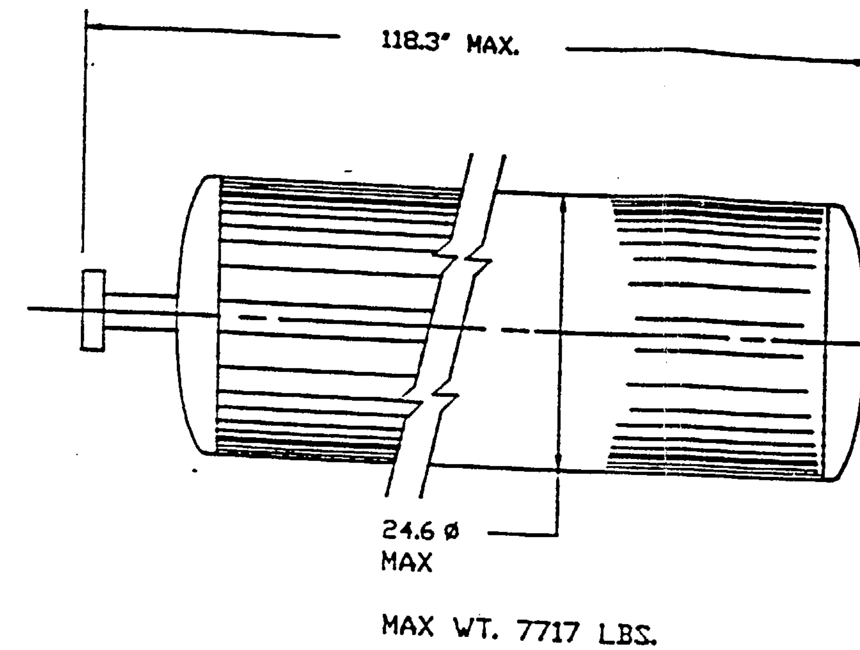
ATTACHMENT 5



PWR



BWR



GLASS WASTE CANISTER

PRELIMINARY INPUT			
WASTE FORM TYPE			
	BWR	PWR	GLASS
GAMMA REM/HR	5×10^4	5×10^4	1×10^5
NEUTRONS REM/HR	1	1	10
HEAT KW/ASS'Y	0.78	0.30	0.2 TO 0.7
WT. LBS. MAX.	SEE DETAIL	SEE DETAIL	SEE DETAIL
CROSS SECT.	SEE DETAIL	SEE DETAIL	SEE DETAIL
LENGTH IN. MAX	SEE DETAIL	SEE DETAIL	SEE DETAIL

WLCWF

APPENDIX C

LIST OF EXPERTS

ENGINEERED BARRIER SYSTEM CONCEPTS WORKSHOP

JUNE 18-20, 1991

DENVER, CO

LIST OF EXPERTS

EXPERT	AFFILIATION	TECHNICAL AREA
Sam Basham	Battelle	Codes, Licensing
Peter Andresen	General Electric Company	Corrosion, Life Prediction
Milton Harr	Purdue University	Geotechnical
Steve Simons	Pacific Northwest Laboratory	Geohydrology
Robert A. Shaw	Electric Power Research Institute	Performance Assessment
David Shoesmith	AECL Research	Canadian EBS Design

APPENDIX D

WORKSHOP AGENDA

AGENDA

YUCCA MOUNTAIN ENGINEERED BARRIER SYSTEM CONCEPTS WORKSHOP
JUNE 18, 19, and 20, 1991
Denver, Colorado

Tuesday, June 18, 1991

8:00 am INTRODUCTION

- Opening Remarks & Objective of Workshop — Carl P. Gertz, DOE
- Introduce Experts and Review Agenda — Holmes Brown, Afton Assoc.

8:30 am - 12:00 pm Session 1: Background

8:30 - 8:45	o Role of Engineered System, M. O. Cloninger, DOE
8:45 - 10:15	o Summary of Systems Engineering Approach for Developing EBS Design Concepts, Lawrence Livermore National Laboratory
10:15 - 10:30	BREAK
10:30 - 11:00	o NWTRB Perspective on Extended Life Performance, NWTRB
11:00 - 11:30	o "Considerations for Extended Life Performance", Dr. T. H. Pigford, U. C. Berkeley
11:30 - 12:00	o DISCUSSION

12:00 - 1:00 LUNCH

1:00 pm - 5:15 pm Session 2A: Concepts

1:00 - 1:45	o "Sic/Aluminum Metal Matrix Container", Advanced Composite Systems
1:45 - 2:30	o "Filament Wound Ceramic Matrix Composite Radioactive Waste Containment Structures", Technology Assessment & Transfer, Inc.
2:30 - 2:45	BREAK
2:45 - 3:30	o "Hazardous Waste Encapsulment Technology", Entrepreneurs Nuclear de las Americas
3:30 - 4:15	o "EBS Concept for Extended Life Performance in a Potential Repository at Yucca Mountain", Argonne National Laboratory
4:15 - 5:15	o DISCUSSION

AGENDA

YUCCA MOUNTAIN ENGINEERED BARRIER SYSTEM
CONCEPTS WORKSHOP
JUNE 18, 19, and 20, 1991
Denver, Colorado

Wednesday, June 19, 1991

8:00 am - 12:00 pm	Session 2B: Concepts (continued)
8:00 - 8:15	o Introduction
8:15 - 9:00	o "Use of a Gravel Backfill as a Hydraulic and Diffusion Barrier", Intera Sciences, Inc.
	o "Use of Spent Fuel Stabilizers in Waste Package Design", Intera Sciences, Inc.
9:00 - 9:45	o "Surfaced Sealed Commercial Graphite Design Concept", Nuclear and Aerospace Materials Corporation
9:45 - 10:00	BREAK
10:00 - 10:45	o "Multi-Barrier Container Concept", Babcock & Wilcox
10:45 - 11:30	o "The Natural Analogue Copper Composite Container for HLW Disposal", Copper Development Association Inc.
11:30 - 12:00	DISCUSSION
12:00 pm - 1:00pm	LUNCH
1:00 PM - 5:15 PM	Session 2C: Concepts (continued)
1:00 - 1:45	o "Extended-Life Nuclear Waste Package Utilizing Redundant Corrosion/Containment Barriers", International Lead Zinc Research Organization, Inc.
1:45 - 2:30	o "Self-Shielded Package Concept", Westinghouse Electric Corporation, Environmental Systems Group
2:30 - 2:45	BREAK
2:45 - 3:30	o "Universal Cask", Virginia Power Company
3:30 - 4:15	o "EBS with Container Cooling and Rock Drying Enhancement", University of Nevada, Reno, Department of Mining Engineering
4:15 - 5:15	DISCUSSION

AGENDA

YUCCA MOUNTAIN ENGINEERED BARRIER SYSTEM
CONCEPTS WORKSHOP
JUNE 18, 19, and 20, 1991
Denver, Colorado

Thursday, June 20, 1991

8:00 am - 12:00 pm		Session 3: Experts Discussion
8:00 - 8:15	o	Introduction & "Overview of EBS Concepts", D. J. Harrison-Giesler, DOE
8:15 - 9:45	o	Applicability of EBS Concepts to Extend-Life Performance
9:45 - 10:00		BREAK
10:00 - 11:00	o	Can a Waste Package Be Developed to Last 10,000 Years?
11:00 - 12:00	o	DISCUSSION
12:00 - 12:15	o	Closing Remarks, M. O. Cloninger, DOE

APPENDIX E

ATTENDEE LIST

YUCCA MOUNTAIN
ENGINEERED BARRIER SYSTEM
CONCEPTS WORKSHOP

JUNE 18, 19, AND 20, 1991
DENVER, COLORADO

United States Department of Energy
Office of Civilian Radioactive
Waste Management
Yucca Mountain Site Characterization
Project

June 20, 1991

YUCCA MOUNTAIN ENGINEERED BARRIER SYSTEM
CONCEPTS WORKSHOP
JUNE 18, 19, AND 20, 1991

ATTENDEES
ALPHABETICAL/ADDRESS-PHONE LISTING

Mark Abhold, Ph.D
TRW Environmental Safety
Systems, Inc.
101 Convention Center Drive
Las Vegas, NV 89109
Phone: 702-794-1846
FAX : 702-794-1844

Martin K. Altenhofen
Consultant
2000 Logston Blvd.
Richland, WA 99352
Phone: 509-375-3268
FAX : 509-375-4838

Dr. Peter L. Andresen
General Electric Company
Bldg. K-1, Room 3A43
Post Office Box 8,
Schenectady, NY 12301
Phone: 518-387-5929

Ronald L. Ballard
Nuclear Regulatory Commission
1515 H Street N.W.
Washington, DC
Phone: 301-492-3462

William D. Barnard, Ph.D.
Nuclear Waste Technical
Review Board (Staff)
1100 Wilson Boulevard
Suite 910
Arlington, VA 22209
Phone: 703-235-4473
FAX : 703-235-4495

Dr. Eric A. Barringer
Babcock & Wilcox
Post Office Box 1165
Lynchburg, VA 24506-1165

Phone: 804-522-6191
FAX : 804-522-6196

Sam J. Basham
Battelle
106 West Allegan, Suite 520
Lansing, MI 48933

Phone: 517-335-4491
FAX : 517-373-0578

John K. Bates
Argonne National Laboratory
9700 S. Cass Avenue
Argonne, IL 60544

Phone: 708-972-4385

Edward F. Benz
Weston
CRWM Tech.Support Team
955 L'Enfant Plaza, S.W.
Eighth Floor
Washington, DC 20024

Phone: 202-646-6600

Lester Berkowitz
TRW
600 Maryland Avenue SW
Washington, DC 20024

Phone: 202-488-2300
FAX : 202-488-2323

Alan Berusch
United States Department
of Energy
Office of Geologic Disposal
Washington, DC 20024

Stephen Blair
Lawrence Livermore
National Laboratory
LLNL L-201
Livermore, CA 94550

Phone:415-422-6467

Charles R. Bolmgren
Westinghouse Electric Corp.
Post Office Box 598
Pittsburgh, PA 15230

Phone: 412-733-6350
FAX : 412-733-6279

Holmes Brown
Afton Associates
403 East Capitol St. SE
Washington, DC 20003
Phone: 202-547-2620
FAX : 202-547-1668

Ann Cavazos
T&MSS/ Science Applications
International Corp.
101 Convention Center Drive
Las Vegas, NV 89019
Phone: 702-794-7000

Dwayne Chestnut
Lawrence Livermore
National Laboratory
Post Office Box 808, L-202
Livermore, CA 94550
Phone: 415-423-5053

Paul Childress
Babcock & Wilcox
101 Convention Center Drive
Las Vegas, NV 89109
Phone: 702-794-1846
FAX : 704-794-1844

Nathan A. Chipman
Westinghouse Idaho
Nuclear Company, Inc.
Box 4000
Idaho Falls, ID 83403-3205
Phone: 208-526-1424
FAX : 208-583-1424

Donald E. Clark
Westinghouse Hanford Co.
G6-08
Post Office Box 1970
Richland, WA 99352
Phone: 509-376-8730
FTS : 444-8730

W. L. Clarke
Lawrence Livermore
National Laboratory
Post Office Box 808, L352
Livermore, CA 94550
Phone: 415-423-4803
FAX : 415-828-3719

Hal Cleary
Weston/Jacobs
955 L'Enfant Plaza
Eighth Floor
Washington, DC 20024
Phone: 202-646-6728

Michael O. Cloninger
United States Department of Energy
Yucca Mountain Project Office
101 Convention Center Drive
Las Vegas, NV 89109
Phone: 702-794-7847

Jim Conca
WSU Tri-Cities
100 Sprout Road
Richland, WA 99352
Phone: 509-375-3268

Dr. Gustavo Cragnolino
Southwest Research Institute
6220 Culebra Road
San Antonio, Texas 78228-0510
Phone: 512-522-5539
FAX : 512-522-5155

William G. Culbreth, Ph.D.
University of Nevada, Las Vegas
4505 Maryland Parkway
Las Vegas, NV 89154
Phone: 702-739-3426
Phone: 702-597-4153

James C. Cunnane, Ph.D.
Argonne National Laboratory
9700 South Cass Avenue
Argonne, IL 60439-4837
Phone: 708-972-4541
FAX : 708-972-4176

Michael J. Danielson, Ph.D.
Babcock & Wilcox
1562 Beeson Street
Alliance, OH 44601
Phone: 216-829-7630
FAX : 216-823-0639

George Danko, Ph.D
University of Nevada, Reno
2785 Judit Lane
Reno, NV 89503
Phone: 702-784-4284
FAX : 702-784-1766

Don U. Deere, Ph.D.
Nuclear Waste Technical
Review Board
1100 Wilson Blvd., Suite 910
Arlington, VA 22209
Phone: 703-235-4473
FAX : 703-235-4495

Thomas W. Doering
B&W Space and Defense Systems
3315 Old Forest Road
Post Office Box 10935
Lynchburg, VA 24506-0935
Phone: 804-385-2789
FAX : 804-385-3755

A. C. Douglas
Senior Geologist
City of Las Vegas
400 East Stewart
Las Vegas, NV 89101
Phone: 702-799-6469
FAX : 702-385-3128

Carl W. Dralle
Consultant
CDA & Wiscednt
12975 Continental Drive
Brookfield, WI 53045
Phone: 414-781-1042

Robert Einziger, Ph.D.
Pacific Northwest Laboratories
Battelle Boulevard
Richland, WA 99352
FTS : 444-3453
Phone: 509-376-3453
FAX : 509-376-9781

Glen B. Engle
Nuclear & Aerospace
Materials Corporation
16716 Martincoit Road
Poway, CA 92064
Phone: 619-487-0325
FAX : 619-487-0566

Robert L. Fish
Babcock & Wilcox
101 Convention Center Drive
Suite 113
Las Vegas, NV 89109
Phone: 702-794-1805

Gregory E. Gdowski
KMI/Lawrence Livermore
National Laboratory
Post Office Box 808, L-352
Livermore, CA 94550
Phone: 415-423-3486

Carl Gertz
United States Department
of Energy
Yucca Mountain Project Office
101 Convention Center Drive
Las Vegas, NV 89109
Phone: 702-794-7847

Raymond W. Godman
TRW
10306 Eaton Place
Fairfax, VA 22030
Phone: 703-934-7620
FAX : 703-934-7622

Rick Gonzales
Advance Composite Systems
13825 B Alton
Irvine, CA 921718
Phone: 719-859-0662

Frank Goodwin
1LZRO
2525 Meridian Pkway., Suite 100
Durham, NC 27713
Phone: 919-361-4647

William Halsey
Lawrence Livermore
National Laboratory
Post Office Box 808, L-202
Livermore, CA 94550
Phone: 415-423-5053

Milton E. Harr
Purdue University
Lafayette, IN 47907
Phone: 317-404-5029

Diane Harrison-Giesler
United States Department
of Energy
Yucca Mountain Site
Characterization Project Office
101 Convention Center Drive
Las Vegas, NV 89109
Phone: 702-794-7900

M. Elise Hyland
Aluminum Company of America
Alcoa Technical Center
Alcoa Center, PA 15069
Phone: 412-337-2054
FAX : 412-337-2005

Leslie J. Jardine, Ph.D
Lawrence Livermore
National Laboratory
Post Office Box 808 M.S. L-204
7000 East Avenue
Livermore, CA 94550
Phone: 415-423-5032
FTS : 543-5032

Andrea R. Jennetta
T&MSS/Science Applications
International Corp.
101 Convention Center Drive
Las Vegas, NV 89109
Phone: 702-794-7895

Konrad J.A. Kundig, Ph.D.
Metallurgical Consultant
Two School House Road
Randolph, NJ 07869
Phone: 201-361-8789
FAX : 201-361-5760

Dale F. LaCount
Babcock & Wilcox
1562 Beeson Street
Alliance, OH 44601
Phone: 216-829-7527
FAX : 810-433-9151

Dr. Samaan G. Ladkany
University of Nevada,
Las Vegas
4451 E. Rochelle
Las Vegas, NV 89121
Phone: 702-435-8901
Phone: 702-597-4328

Donald Langmuir
Nuclear Waste Technical
Review Board
1100 Wilson Blvd., Suite 910
Arlington, VA 22209
Phone: 703-235-4473

David C. Langstaff
United States Department
of Energy/ RL
403 W. 26th Place
Kennewick, WA 99337
Phone: 619-487-0325

W. Stuart Lyman
Copper Development Assoc.,Inc.
2 Greenwich Office Park
Greenwich, CT 06836
Phone: 203-625-8230

Corinne Macaluso
Department of Energy/RW
1000 Independence Ave. SW
Washington, DC 20585
Phone: 202-586-2837

Ezra B. Mann
Intera
6850 Austin Center Blvd.
Suite 300
Austin, TX 78731
Phone: 512-346-2000

Steve Marschman
Pacific Northwest Laboratory
Post Office Box 999
MSIN P7-18
Richland, WA 99352
Phone: 509-376-3569

David F. Medley
Wisconsin Centrifugal
905 E. St. Paul Avenue
Waukesha, WI 53188-3898
Phone: 414-544-7700
FAX : 414-544-7843

Bruce Miglin
Babcock & Wilcox
1562 Beeson Street
Alliance, OH 44601
Phone: 21 29-7220

Ian Miller, P.E.
Golder Associates, Inc.
4104 148th Avenue NE
Redmond (Seattle), WA 98052
Phone: 206-883-0777
FAX : 206-882-5498

Homi Minwalla
Roy F. Weston, Inc.
CRWM Tech.Support Team
955 L'Enfant Plaza, S.W.
Eighth Floor
Washington, DC 20024
Phone: 202-646-6710
FAX : 202-863-2220

Richard Morissette
T&MSS/Science Application
International Corp.
101 Convention Center Dr.
Las Vegas, NV 89109
Phone: 702-794-7783
FAX : 702-794-7009

Dr. Eng. Hiroo Nagano
Visiting Senior Researcher
University of Minnesota
Dept. of Chemical Engineering
and Materials Science
Amundson Hall
421 Washington Avenue
Minneapolis, MN 55455
or
Sumitomo Metal Industries, Ltd.
1-8, Fusoh-Cho,
Amagasaki, 660, Japan
Phone: (06) 401-6201
FAX : (06) 489-5790

Prasad K. Nair, Ph.D., P.E.
Center for Nuclear Waste
Regulatory Analyses
6220 Culebra Road
San Antonio, TX 78284
Phone: 512-522-5150

Phillip A. Niedzielski-Eichner
Technical Advisor
Nye County Board of
Commissioners
Post Office Box 221274
Fairfax, VA 22022-1274
Phone: 703-818-2434
FAX : 703-818-2437

Donald A. Nitti
B&W Nuclear Service Co
3315 Old Forest Road
Post Office Box 10935
Lynchburg, VA 24506-0935
Phone: 804-385-2514
FAX : 804-385-3663

D. Warner North, Ph.D.
Nuclear Waste Technical
Review Board
40 Decision Focus Inc.
4984 El Camino Real
Los Altos, CA 94022
Phone: 415-960-3923

Bonnie Packer, Ph.D.
TRW
10306 Eaton Place
Fairfax, VA 22030
Phone: 703-934-2435
FAX : 703-934-7622

E. L. "Ted" Paquette
Technology Assessment and
Transfer, Inc.
133 Defense Highway, Suite 212
Annapolis, MD 21401
Phone: 301-224-3170
FAX : 301-224-4678

U Sun Park
T&MSS/Science Applications
International Corp.
101 Convention Center Dr.
Las Vegas, NV 89109
Phone: 702-794-7000
FAX : 702-794-7009

Dr. Sidney J.S. Parry, Ph.D.
Nuclear Waste Technical
Review Board (Staff)
1100 Wilson Blvd., Suite 910
Arlington, VA 22209
Phone: 703-235-4473
FAX : 703-235-4495

Pamela Patrick
Alcoa
1615 M Street, NW #500
Washington, DC 20036
Phone: 202-956-5322

Dale T. Peters, Ph.D.
Copper Development Assoc., Inc.
Greenwich Office Park 2
Box 1840
Greenwich, CT 06836
Phone: 203-625-8234
FAX : 203-625-0174

W. H. Pheifer
NAMCO/BFGoodrich
16716 Martincoit Rd.
Poway, CA 92064
Phone: 619-487-0325
FAX : 619-487-0566

Thomas H. Pigford
Lawrence Berkeley Laboratory
University of California
Berkeley
1 Cyclotron Road/ MS Campus
Berkeley, CA 94720
Phone: 415-642-6469

Dennis L. Price, Ph.D.
Nuclear Waste Technical
Review Board
1100 Wilson Blvd., Suite 910
Arlington, VA 22209
Phone: 703-235-4473
FAX : 703-235-4495

Joe Randazzo
Advance Composite Systems
13825B Alton
Irvine, CA 92718
Phone: 719-859-0662

Donald Reed
Argonne National Laboratory
9700 S. Cass Avenue
Argonne, IL 60439
Phone: 708-972-7964

Phillip R. Reed
Unite States Nuclear
Regulatory Commission
Office of Nuclear Regulatory
Research
MS: 260 NL/S
Washington, DC 20555
Phone: 301-492-3879

Don Reuscher
Texas A&M
Nuclear Science Center
College Station, TX 77843

Rey Rodriguez
Brunswick Corporation
Defense Division
150 Johnston Road
Marion, VA 24354

Phone: 703-783-9618
FAX : 703-783-9665

Roberta Romero
Nuclear Regulatory Commission, M/S P315
Washington, DC 20555

Phone: 301-492-7672

Charles Russomanno
United States Department
of Energy
M & O, Management Division
Forrestal Building
1000 Independence Avenue
Washington, DC 20585

Phone: 202-586-4347
FAX : 202-586-4959

Don Ruffner
Lawrence Livermore
National Laboratory
Post Office Box 808, L-202
Livermore, CA 94550

Phone: 415-423-5053

Ed Russell
Lawrence Livermore
National Laboratory
Post Office Box 808, L-197
Livermore, CA 94550

Phone: 415-422-6398

Eric Ryder
Sandia National Laboratories
Albuquerque, NM 87185

Phone: 846-9644

Patricia Salter
Intera Sciences
3609 South Wadsworth Blvd. #550
Denver, CO 80127

Phone: 303-985-0005
Ext. 106

Robert A. Shaw
Electric Power Research Institute
High-Level Waste and Spent
Fuel Storage
3412 Hillview Ave.
Post Office Box 10412
Palo Alto, CA 94303
Phone: 415-855-2774
FAX : 415-855-2774

David Shoesmith
AECL
WNRE, Pinawa
Manitoba, Canada ROE1LO
Phone: 204-753-2311

David Short
Lawrence Livermore
National Laboratory
Post Office Box 808, L-202
Livermore, CA 94550
Phone: 415-423-5053

Steve Simons
Pacific Northwest Laboratory
Post Office Box 999
Richland, WA 99352
Phone: 509-376-3569

Marvin L. Smith
Virginia Power
5000 Dominion Blvd.
Glen Allen, VA 23060
Phone: 804-746-8231

Peter Spiegler
State of Nevada
Nuclear Waste Project Office
Capitol Complex
Carson City, NV 89710
Phone: 702-687-3744

Roger W. Staehle
22 Red Fox Road
North Oaks, Minnsota 55127
Phone: 612-482-9493
FAX : 612-484-5735

David Stahl, Ph.D.
Science Applications
International Corporation
101 Convention Center Drive
Las Vegas, NV 89109
FTS : 544-7778
Phone: 702-794-7778
FAX : 702-794-7009

Ray B. Stout
Lawrence Livermore
National Laboratory
Post Office Box 808, L-201
Livermore, CA 94551
Phone: 415-422-3965

Jim Teak
Science Applications
International Corporation
101 Convention Center Drive
Las Vegas, NV 89109
or
Albuquerque, NM
Phone: 702-794-7000
Phone: 505-844-3132

John Therien
T&MSS/Science Applications
International Corporation
101 Convention Center Drive
Las Vegas, NV 89109
Phone: 702-794-7000

Thomas A. Thornton
Babcock and Wilcox
Old Forest Road
Lynchburg, PA 24503
Phone: 804-385-3255

Dr. William C. Triplett
ENA/Triad Research and Development
Associates, Inc.
Box 517
Campwood, Texas 78833
Phone: 512-854-1095
Ext. 30

Richard A. VanKonynenburg
Lawrence Livermore
National Laboratory
Post Office Box 808, L-352
Livermore, CA 94550
Phone: 415-422-0456

Ellis D. Verink, Jr., Ph.D., P.E.
Nuclear Waste Technical
Review Board
1100 Wilson Boulevard
Arlington, VA 22209
Phone: 703-235-4473
FAX : 703-235-4495

Arun Wagh
Argonne National Laboratory
9700 S. Cass Avenue
Argonne, IL 60635
Phone: 708-972-6295

Rick Weller
Nuclear Regulatory Commission
Office Nuclear Regulatory Research
Washington, DC 20555
Phone: 301-492-3879

Dale Wilder
Lawrence Livermore
National Laboratory
Post Office Box 808-L204
Livermore, CA 94550
Phone: 415-422-6908

David Worth
ENA/ Core Ceramics
Box 517
Campwood, TX 78833
Phone: 512-854-1095

William E. Wowak
Roy F. Weston, Inc.
955 L'Enfant Plaza, S.W.
Eighth Floor
Washington, DC 20024
Phone: 202-646-6600
Phone: 202-646-6617

APPENDIX F

PRESENTER'S STATEMENTS AND OTHER CONTRIBUTIONS

ACS / Advanced Composite Systems

Soft Tooling / Composites / Material Design

I-317215

July 31, 1991

Department of Energy
Yucca Mountain Site Characterization
Project Office
P.O. Box 98608
Las Vegas, NV 89193-8608
Attn: Diane J. Harrison-Geisler

Re: Engineered Barrier System Overview

Dear Diane:

Enclosed you will find my statement concerning my proposal for a high level nuclear waste container for the Yucca Mountain Site Project.

Please submit this with your final recommendations for the DOE report which will be released in October.

Joe and I look forward in seeing you at the end of September for the waste package workshop.

Best regards,

Rick Gonzales
Planning / Research & Design

enclosures/rdg

13825-B Alton Parkway • Irvine, CA 92716 • 714-859-0662 • Fax 714-859-0671

Overnight Mail

The Environmental Solution
A Sensible Approach for High Level Nuclear Waste

The EBS performance is essential to avoid catastrophic failures for both the storage systems and the natural environment we are protecting. Our Al-SiC Compound of 20% Silicon Carbide particulate reinforcement is the only solution.

The Al-SiC compound will outlast ceramic matrix compounds in the areas of thermal shock, corosion resistance and load-to-stress failure. Examining Al-SiC to conventional metals, Al-SiC outperforms copper, aluminum, brass, lead, etc. because of our material's flexibilty to meet specific mechanical / physical properties. Al-SiC is no match for polymers: it has higher elevated temperature properties, no moisture absorption or desorption, superior radiation resistance and metalurgical container sealment.

With present day technology, the EBS production cost is estimated at $ 275,000.00 each.

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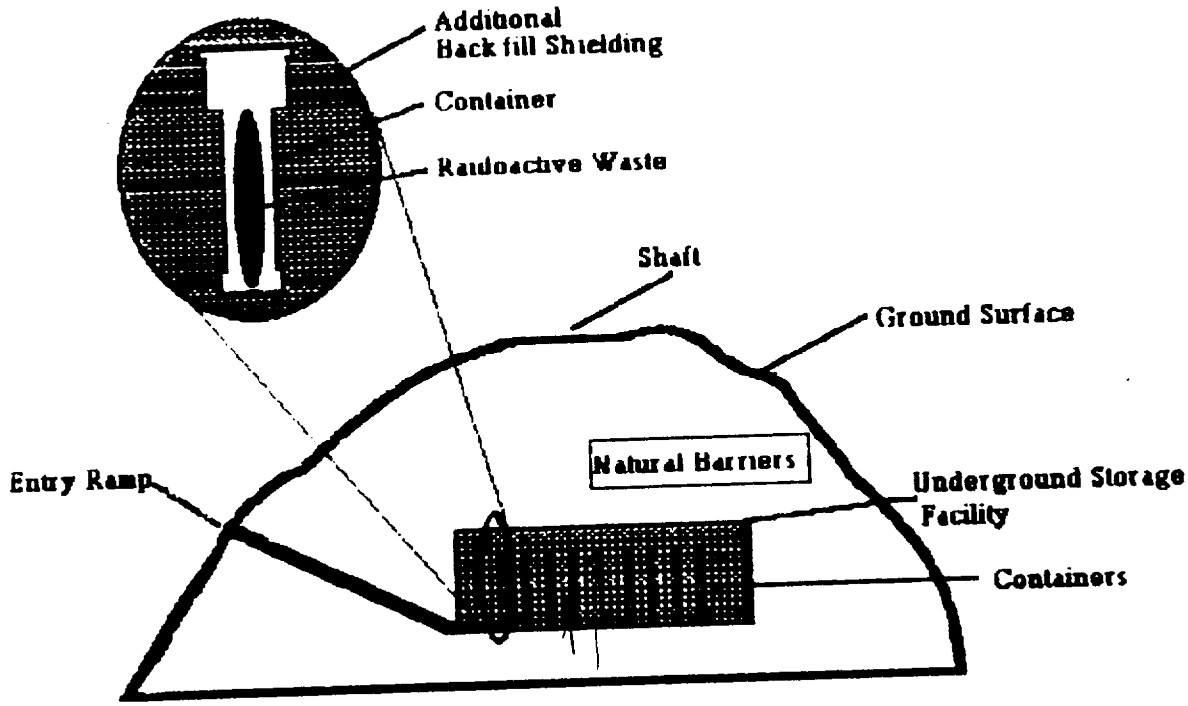

Engineered Barrier System Concept
Underground System and Waste Containers

13825-B Alton Parkway • Irvine, CA 92716 • 714-859-0662 • Fax 714-859-0671

T A & T *Technology Assessment and Transfer, Inc.*

133 Defense Hwy.
Suite 212
Annapolis, Maryland 21401

August 5, 1991

Ms. Diane J. Harrison-Giesler
Dept. of Energy
Yucca Mountain Site Characterization
Project Office
P.O.Box 98608
Las Vegas, NV 89193-8608

Re: EBS Workshop Responce

Dear Ms. Harrison-Geisler:

Thank you for your letter dated 7/17/91. I found the Workshop to be extremely informative and I left with a much deeper understanding of the issues and concerns that the EB system haces as an integrated portion of the repository system. I would like to take advantage of your invitation to state the benefits of the specific concept I proposed at the Workshop:

Benefits of Ceramic Matrix Composites
as a Containment System Component.

Corrosion Resistance

Wet Oxidizing Conditions appear to be the dominant worst case long term environmental condition. While oxide matrix composites can be coroded under some relatively unique conditions in comparison to metallic systems the corrosion/oxidation failure modes are extremely limited. In short ceramics in general get the highest marks in this category.

Fabrication Feasibility and Costs

A generally true observation is that monolithic ceramics are less expensive than ceramic matrix composites. However, in the case of

WASHINGTON (301) 261-8373 ANNAPOLIS (301) 224-

these very large vessels, a thin wall monolithic ceramic container is beyond the state of the art and may not be feasible. A 26" diameter by 12 to 15 feet length container with a 1-2" wall thickness is not only feasible but relatively economical in comparison to other advanced materials such as bulk graphite. Fire resistance, moderate thermal conductivity and toughness of CMC's suggest that a CMC container is more likely survive moderate geological disturbance without failure than any other non-metallic candidate.

Porosity, Sealing and Joining

Effective sealing of large CMC containers has to be demonstrated and a preliminary plan to address open technical issues was presented at the Workshop. Sealing and Joining concerns are shared by both advanced material candidates and metallic systems. These issues can be the Achilles Heel of any container structure. Any proposed solution short of welding the parent material will work for CMC's.

Thank you for the invitation to join this technical community. I look forward to future discussion and collaboration.

Yours truly,

E.L."Ted" Paquette
General Manager, Ceramic Composites

ENTREPRENEURS NUCLEAR
de las AMERICAS

WASHINGTON, D.C.
CORPUS CHRISTI, TEXAS
MEXICO CITY, D.F

P. O. Box 517
Camp Wood, Texas 78833
(512) 597-5294

CABLE "ENA

I-317859 37

August 5, 1991

Department of Energy
Yucca Mountain Site Characterization Project Office
P. O. Box 98608
Las Vegas, Nevada 89193-8608

Attention: Diane Harrison-Geisler

Good day Diane

Regarding Gertz letter of July 17, 1991 suggesting a benefit summary of each presenters' technology; I am enclosing a short statement which summarizes our conclusions.

Thank you.

Sincerely ~~yours~~

William C. Triplett, M.D.

ENTREPRENEURS NUCLEAR
de las AMERICAS

WASHINGTON, D.C.
CORPUS CHRISTI, TEXAS
MEXICO CITY, D.F.

CABLE "I

P. O. Box 517
Camp Wood, TX 78833
(512) 597-5294

"TRICAP"

Hazardous Waste Encapsulment Technology

Summary of the benefits:

1. Based on current technology, which has previously been modeled (SIREN, of Sanders Nuclear Corp)

2. Ease of fabrication.

3. Redundency of safety factors.

4. Geopolitical acceptable.

5. Ease of emplacement and retrieval.

6. Considering the vital needs, the technology is economically acceptable.

7. Refer to our presentation "Performance Considerations," "Fabrication and Emplacement" and estimated costs (in 1991 $s). See attached.

8 – May be used in any environmental parameter

William C. Triplett, M.D.
CEO - ENA s.a.

TRICAP ENCAPSULATION

Fabrication & Emplacement

Available Technology ....Based on current technology

Remote handling ....Top has lifting slot for using current remote handling devices
Hastelloy C labels for individual ID attached to each unit

Fabrication ....Recommended encapsulation on site of creation of waste

Advantage ....Redundancy of encapsulation results in added safety and greater ability to reassure public of safety during transportation and placement

Title 10, Chapter, Code of Federal Regs-Energy ....Meets or exceeds regulations

Estimated Costs (in 1991 $s)

Hastelloy C and Nextel™ ....$213k per unit

Hastelloy C and Graphite ....$199k per unit

Stainless Steel and Nextel™ ....$122K per unit

Stainless Steel and Graphite ....$105k per unit

TRICAP ENCAPSULATION

	Hastelloy C Alternative 1	Stainless Steel Alternative 2
Performance Considerations		
Containment	10k years*	10k years*
	*if no catastrophic environmental event (meteor)	
Withstands water, heat and shearing forces	yes	yes
Isolation	10% stonger overall	
Ability to withstand radiation	more	less
Model Est.		
Future demonstration project	yes	yes
Analogs		
Previous SIREN technology	yes	yes
Degree of Insensitivity to Variations in the Environment		
Temperature	10% higher overall	
Prolonged radiation exposure	no effect	tendency to embrittlement
Water Quantity	no effect	no effect
Water Quality	inert*	inert*

*Some shielding, but still radioactive, effect dependent on age of materials encapsulated

TRICAP ENCAPSULATION
Safety Parameters

Crush Resistant
Test Modules (1969) survived 500 Ft/sec/sec impact with no loss of integrity.

Thermal Resistant
Test Modules (1969) survived 5000°F direct flame, for 30 min. burn time, with no loss of integrity.

Fluid Imperviousness
Because of its coating of ceramic cement overlaid with pyrolytic graphite, the external cover is fluid proof.

Chemical Inertness
Inert, coating, filament, winding, ceramic capsule. Chemical intertness of the 1st (metallic) encapsulation depends on the specifics of the metal.

Radiation
Resistant, with no structural failure.

Addenda
(Psycho-socio Geo-political) Because of the redundancy of the multiple encapsulation, ENA s.a. believes the technology will answer any adverse criticism.

ARGONNE NATIONAL LABORATORY
9700 South Cass Avenue, Argonne, Illinois 60439

TELEPHONE: FTS 972-4541

July 1, 1991

Dr. Diane J. Harrison-Giesler
U.S. Department of Energy
Yucca Mountain Site Characterization
Project Office, M/S 523
P. O. Box 98608
Las Vegas, NV 89193-8608

Dear Diane:

To follow up on a recommendation that was made by Sam Basham at the Engineered Barrier System (EBS) workshop in Denver, I have attached a short summary of the advantages and disadvantages of the concept that was presented by Argonne. Hopefully, this will be helpful in your consideration and evaluation of our concept.

As illustrated in the concept that I presented, chemically bonded ceramic (CBC) materials could be used to perform several important engineered barrier functions. In particular, the phosphate-bonded CBCs appear to be attractive. If you concur, Argonne would welcome an opportunity to pursue investigation of these materials for possible EBS applications.

I enjoyed the opportunity to participate in what I believe was a very useful workshop.

Sincerely,

James C. Cunnane
Chemical Technology Division

JCC:rr

Attachment: "Summary of Advantages and Disadvantages of EBS Concept Presented by ANL at the EBS Concepts Workshop"

cc: (w/attachment)
M. Cloninger, YMPO
[redacted]

SUMMARY OF ADVANTAGES AND DISADVANTAGES OF EBS CONCEPT PRESENTED BY ANL AT THE EBS CONCEPTS WORKSHOP

The advantages and disadvantages of the concept are discussed below using the current reference design as a basis for comparison.

Advantages

- It proposes use of a chemically bonded ceramic material (CBC) (e.g., phosphate-bonded magnesium oxide) to achieve the following functions:

    1. Divert water flow around the emplaced container. This will prevent the potentially aggressive salt solutions, that result from groundwater evaporation, from contacting the metallic container. The concept that was presented suggests that this function could be achieved by fabricating the shield plug and borehole liner from a suitable CBC material; a coarse aggregate material (e.g., crushed tuff) emplaced in the annulus around the liner would provide the hydraulic bypass path.

    2. Encapsulate/stabilize the waste inside the container. Although we suggested that the waste be encapsulated/ stabilized by setting the waste in a hardened CBC matrix, the option of incorporating the CBC as dry powders, which would harden upon water contact, is an option that may be attractive. Encapsulation would provide containment redundancy and would inhibit radionuclide release. Phosphate-based materials appear particularly attractive for inhibiting the release of rare-earth and actinide radionuclides. The known capacity of phosphates (e.g., monazite) to incorporate these radionuclides as solid solutions is supported by observations in waste glass testing at ANL, under simulated Yucca Mountain conditions, which shows that actinides are often associated with secondary glass alteration phases that contain phosphate.

- It provides for attenuating the release of any radionuclides that escape from the waste package by directing the effluent groundwater flow through a tailored backfill before release from the EBS.

- The proposed CBC materials could be utilized to achieve the functions of groundwater flow diversion, and encapsulation for a variety of waste package configurations that would be suitable for horizontal or drift/tunnel emplacement.

<u>Disadvantages</u>

- Optimization of CBC properties and establishment of long-term chemical and mechanical durability must be completed.
- Although the cost of suitable CBC materials is expected to be reasonable, it is not possible to give a credible cost estimate this point.

YUCCA MT. ENGINEERED BARRIER SYSTEM CONCEPTS

Martin K. Altenhofen

July 3, 1991

The Yucca Mountain Engineered Barrier System Concepts Workshop on June 18-20, 1991 focused on the critical issues of the need for and technical feasibility of alternative conceptual designs for long-lived containment and controlled isolation performance. This paper is intended to express my views on the four major design alternatives being proposed and further recommend that the multi-barrier design concept be adopted for the candidate Yucca Mountain repository system.

THIN-WALLED CONTAINER CONCEPT

The SCP conceptual reference and alternative designs are characterized by a thin-walled, corrosion-resistant container and borehole emplacement. The reference stainless steel container material concept is based primarily on cost considerations and relies mainly on the site partially-saturated conditions for containment time and spent-fuel dissolution rate for controlled release from the waste package. The alternative container materials may also be susceptible to a localized failure mechanism and potentially hold ingressing groundwater as described in the wet-drip type release scenario. As a result, the predictability of the thin-walled container concepts depends greatly on our ability to characterize in-situ host rock conditions and long-term spent fuel behavior.

It may be difficult to demonstrate compliance with the waste package performance requirements prior to completion of the NRC's Performance Confirmation period (50 years) following initial waste emplacement. The recent reviews by the Ad-Hoc Corrosion Panel and the Nuclear Waste Technical Review Board tend confirm this position. In response to these reviews and waste package performance assessments, the YMP has proposed several interpretations and revisions for the NRC's regulatory guidelines (10CFR60), instead of incorporating these important concerns into a more robust design strategy.

THICK-WALLED CONTAINER CONCEPT

The proposed thick-walled container concepts are characterized by very large capacity, low-carbon steel containers and tunnel emplacement. The self-shielded container and universal cask concepts are based primarily on cost considerations due to their large-capacity (up to 15 MTU) and potential system trade-offs. It was suggested that further savings would result from reduced rock excavation requirements and a more focused site characterization program. The universal concept is also attractive because of the repository schedule constraints and could be utilized early in spent-fuel storage and transportation programs. A very large corrosion allowance is used to achieve the long-lived containment objective. Like the SCP conceptual design, the isolation performance of the container based concept depends greatly on our ability to characterize in-situ tuff conditions and long-term spent fuel dissolution behavior. The thick-walled container concept has several other disadvantages related to geologic isolation performance. Most importantly, this concept does little to promote spent-fuel cladding integrity or control release rates from the engineered barrier system. The large capacity containers are likely to be constrained by spent-fuel temperature limits which could, in the long term, stress rupture the cladding. Repository area thermal loads may have to be reduced substantially (increasing rock excavation) to accommodate the increase in container thermal loads relative to the SCP conceptual design.

Following loss of containment, the buildup of clay-like corrosion products in the waste emplacement tunnels could accelerate spent-fuel matrix dissolution due to groundwater retention. Without a repository seal system, the tunnels themselves could provide a potential fast pathway for ingressing groundwater and radionuclide release from the package. Furthermore, the potential for nuclear criticality may be increased during a disruptive flood type scenario, due to large near-field pore volume relative to the emplacement hole configuration. And following loss of institutional control, there is a long-term proliferation risks imposed by the concepts relative ease of retrieval and handling operations.

MULTI-BARRIER CONTAINMENT CONCEPT

The multi-barrier containment concepts are characterized by a solid spent-fuel stabilizer, thin-walled container and particulate packing components of a engineered system in a borehole emplacement configuration. The stabilizer was defined as a solid matrix material used to fill the volume remaining inside the spent-fuel containers. The potential advantages and disadvantages of metallic, ceramic, and composite materials have been identified on a preliminary basis for material selection (see attachment). The metal-matrix composite materials are judged to be best materials based on their reported physical properties and chemical stability. A specific material was not recommended for the stabilizer concept because the material costs and methods of emplacement were identified as important considerations and the stabilizer material properties need to be further evaluated.

The stabilizer is designed to promote cladding and container integrity by improving heat transfer and providing internal structural support. Reducing the temperature drop across the spent-fuel waste form would allow for increased container temperatures which are favorable for maintaining dry container surface conditions in a partially-saturated tuff environment. The internal structural support function would increase the external container load bearing capacity and allow for a thinner-wall, more corrosion resistant container material. In terms of extended containment time performance, the solid stabilizer could provide galvanic protection for the spent-fuel cladding or effectively distribute the cladding failures over time based on the stabilizer dissolution (i.e. corrosion) rate. In terms of controlled isolation performance, the solid stabilizer could provide an effectively low porosity diffusion barrier for solubility limited releases or limit releases by the stabilizer matrix dissolution rate.

The packing was defined as a layer of crushed tuff gravel surrounded by thinner layer of coarse sand material in the emplacement hole. In this case, the packing is designed to promote borehole wall and container integrity by restricting heat transfer and providing internal structural support. Increasing the temperature drop across the packing would allow for increasing container temperatures without increasing the borehole wall temperature and near-field rock stresses. The internal structural support function would help prevent rock decrepitation (i.e. sloughing) at the borehole surface and mitigate the impact of rock joint displacement caused by potential seismic events. In terms of extended containment time and controlled isolation performance, the sand and tuff gravel packing provides an effective capillary barrier for ingressing groundwater and effective diffusion barrier for aqueous radionuclide transport.

HEAT-PIPE CONTAINMENT CONCEPT

The heat-pipe concept is characterized by a engineered heat-removal system of conduits emplaced in the near-field host rock. This concept is based on the objective of maintaining dry near-field conditions to control waste package container corrosion. The heat pipes are designed to improve waste package thermal performance by lowering waste package peak temperatures and maintaining longer-term borehole surface temperatures above the boiling point. The reduction of waste package maximum temperatures allows for an increase in the repository area thermal load which, in turn, increases the near-field rock temperatures. The major disadvantage of this concept is that it does not promote the integrity of the near-field host rock. The conduits drilled vertically up and away from the waste packages may provide a fast pathway for ingressing groundwater and radionuclide releases from the waste package. The accelerated boiling of groundwater in the near-field of the waste package could introduce a less favorable chemical environment for corrosion and spent-fuel dissolution.

An alternative approach to improve thermal performance is simply to reduce the waste package thermal output which allows for a higher repository area thermal loading. This would be accomplished by using a smaller container diameter and/or aging the spent fuel prior to waste emplacement. Studies have indicated the potential system cost and performance benefits of "heat management" strategies by tailoring the burnup and age characteristics prior to waste packaging and emplacement. Further improvements are realized with extended spent-fuel aging strategies considering the trend toward higher spent-fuel burnup levels. However, the political climate may have to change before the technical merits of these proposals are given proper consideration.

CONCLUSION AND RECOMMENDATION

In conclusion, the multi-barrier concept is recommended because it promotes the integrity of the spent-fuel waste form and near-field host rock. The waste package container remains as the primary containment barrier, but its performance is functionally enhanced by the solid stabilizer and particulate packing components. The multi-barrier concept takes full advantage of the spent-fuel decay heat characteristics and the partially-saturated near-field conditions. The multi-barrier concept is very robust in that it provides two additional containment barriers (e.g. stabilizer matrix dissolution and packing breakthrough times) once the container has been breached. Furthermore, the multi-barrier concept provides an engineered system with controlled release performance which is independent of the spent-fuel dissolution rate and in-situ rock porosity. The multi-barrier design concept is more reliable than the alternative concepts being considered because the performance can be allocated to the engineered materials, which are potentially much more readily characterized than long-term spent fuel behavior and in-situ host rock properties. Because of the potential impacts on waste package performance and reliability, the multi-barrier concept is recommended until a final decision is made on waste package advanced conceptual design.

I-316968

NAMCO

NUCLEAR AND AEROSPACE MATERIALS CORPORATION

16716 Martincoit Rd
Poway, CA 92064
Phone: 619-487-0325

Consulting and Research Studies

July 23, 1991

Diane J. Harrison-Giesler
US Department of Energy
Yucca Mountain Site
Characterization Project Office, M/S 523
PO Box 98608
Las Vegas, NV 89193-8608

Subject: Statement of Benefits of Graphite for waste Burial

Dear Ms. Harrison-Giesler:

Enclosed is a brief statement of the benefits of developing a sealed graphite overpack for protecting the metal canisters in the Yucca Mountain waste burial program.

Thank you for your consideration in this matter.

Sincerely,

Glen B. Engle
President

Enclosure: Statement

7-25-91

BENEFITS OF GRAPHITE FOR WASTE BURIAL

A sealed-graphite overpack may be used to protect the metal canisters containing high energy nuclear waste. Graphite is extremely inert to all types of environmental conditions and has existed in nature unchanged for millions of years. Graphite has a large capacity to absorb fission products, if they leak out of the metal canisters, which will keep the fission products from entering the surrounding environment. The technology and commercial equipment to develop and manufacture full size sealed-graphite overpack containers is available. Graphite is compatible with other materials in the system, temperatures and the Yucca Mountain environment.

I-317002

INTERNATIONAL LEAD ZINC RESEARCH ORGANIZATION, INC.

2525 Meridian Parkway
Post Office Box 12036
Research Triangle Park, NC 27709-2036 U. S. A.

FACSIMILE MESSAGE COVER

To	FROM:
Diane Harrison-Giesler Yucca Mt. Project Office Department of Energy Las Vegas, NV	Dr. Frank E. Goodwin Vice President, Materials Sciences
Fax #: (702) 794-7907/7908	Telephone No. (919) 361-4647 Facsimile No. (919) 361-1957 Telex No. 261533
Subject: LM-337 EBS Workshop Summary	
Date: 26 July 1991	Number of Pages (This cover included): 2

Following is the summary of benefits of the concept I presented in Denver, as suggested by Sam Basham. Please include this in the summary record of the meeting.

Best Regards,
F.E. Goodwin

Benefits of Redundant-Barrier EBS Concept Made From Ni-Cr-Mo Alloy/Lead

by Frank E. Goodwin
International Lead Zinc Research Organization, Inc.

Submission to Summary Report
EBS Concepts Workshop
Denver, CO

June 18-20, 1991

Use of a redundant barrier waste package incorporating a high quality Ni Cr Mo alloy outer container wall and a Pb filler material, each with the capability of performing as independent barriers for times greater than 1000 years, should greatly reduce the requirements for exhaustive modelling of the many different potential metal failure modes. This EBS design should result in a much greater system longevity (much lower failure rate) than a single-barrier waste EBS.

UNIVERSITY OF NEVADA, RENO

Department of Mining Engineering

September 9, 1991

Ms. Diane J. Harrison-Giesler
U.S. Department of Energy
Yucca Mountain Site Characterization Project Office, M/S 523
P.O.Box 98608
Las Vegas, NV 89193-8608

Dear Ms. Harrison-Giesler:

Please find attached a statement of the benefits concerning the concept entitled "EBS with Cooling and Drying Enhancement."

I would appreciate if you would include the material in the summary report. I would like to apologize for the delay of this submission; the letter of notification from DOE was delayed by a delivery error, and I received it only two days ago.

Sincerely,

George Danko
Associate Professor

EBS WITH CONTAINER COOLING AND ROCK DRYING ENHANCEMENT

The technique is aimed to (a) mitigate negative effects relative to the high heat load, (b) realize positive effects due to increased rock drying, and (c) improve system predictability and container life expectancy. The concept is applicable to both cavity or drift emplacement, and to cool or hot storage concepts. For cavity emplacement, long heat pipes, or thermal syphons provide the best results: e.g. a 40% decrease in the emplacement borehole temperature, and an increase in rock heating and drying in the pillar area. Alternatively, in the hot storage concept, either (a) 100% more waste can be stored in the same area, or (b) the currently considered emplacement area can be reduced by two thirds. For drift emplacement, short heat pipes or heat conductors can be used, with the advantage that they can be integrated into a rock bolt support system.

ROGER W. STAEHLE

22 RED FOX ROAD

NORTH OAKS, MINNESOTA 55127

(612) 482-9493

TELECOPIER: (612) 484-5735

June 25, 1991

Dr. Michael O. Cloninger
United States Department of Energy
Yucca Mountain Project Office
101 Convention Center Drive
Las Vegas, NV 89109

Dear Mike:

At the recent meeting in Denver to consider containers, a number of themes seemed to develop as well as some sentiment for using these themes as a part of an approach to licensing.

I have tried to summarize these themes and an approach to considering them.

I would be interested in your comments and any suggestions for any action which should be considered.

I would be pleased to work with whomever, in a more official capacity than mine, thinks that these ideas and their pursuit would be useful.

Best,

Roger

Attachment

Simplicity, Probability, Data--

Outline of the Ideas and An Approach to Licensing of Containers for Radioactive Waste

Roger W. Staehle
University of Minnesota

June 25, 1991

THE THREE IDEAS

At the meeting to review canister approaches in Denver 18-20 June 1991, several themes evolved during the various presentations, discussions and coffee break sessions. These were:

Simplicity: Simple designs are easier to manufacture, inspect, protect, and predict. Simple designs may also be easier to describe to the public and should be lower cost. Simple designs may be multi-purpose.

Probability: No deterministic approach is possible for predicting life. Whatever is done needs to be done in a probabilistic sense. Probability is needed to describe the occurrence of both failure by the various modes of corrosion and various environments.

Data: Data from accelerated testing are desirable to provide a credible basis for prediction based on models. Models and analysis alone are not adequate. There are no data available which provide any bases for long term prediction. Data need to fit into the probabilistic framework.

These ideas might be a good place to start for a constructive approach to "what next."

To suggest some implications of these ideas the following might apply:

1. Simplicity:

Simplicity implies two themes:

a. Simplicity in concept most likely includes the following:

- "Big dumb" construction with no high tech stuff.
- Self shielding.
- Thick wall for corrosion as well as shielding.
- Fewest movements (*a la* Virginia proposition).
- Simple, well known, cheap alloy.
- No modification of the exterior environment.
- No relief of residual stresses.

b. Simplicity in assuring predicted life most likely includes the following:

- Multiple barriers for the container with at least two barriers each with long life and chemical compatibility, e.g. thick steel and thinner titanium. This gives multiplication of two low probabilities for containers as well as low probabilities associated with the waste form.
- Adjusting chemistry of surroundings to maximize the insolubility of the container materials.
- Minimizing residual stress.
- Minimizing dripping water.

Ideally, both simplicities could be integrated

2. Probability

Probabilities are associated with the following:

a. Failure over time by any single mode or submode over time.

b. Failure by one of several modes.

c. Occurrence of definable environments.

d. Occurrence of non-defined environments.

e. Fault movement which stresses the container

f. Defects in container weld or body.

g. Failure related to a-f of successive container walls

h. Loss of intended outside environment (e.g. pH buffer control)

i. Failure of zirconium or glass.

The objective here is to assure long life by arranging for failure to require a sequence of low probability events.

3. Data

The essential reason for obtaining data is to provide adequate (licensing) credibility that the container will last for its desired life. Analyses alone are inadequate. The question, then, is what kind of data and for how long.

Data need to be obtained for:

a. Failure of container materials by the various modes and submodes that fit probabilistic formulations.

To obtain confidence that a long life can be assured, some kind of testing needs to be conducted which is indicative of much longer life than a few years. Such testing is accelerated testing. There are obvious problems with such testing such as whether the mechanism studied at the accelerated condition is the same as that for the long time. However, such potential difficulties can be solved once they are identified.

It is possible to achieve accelerations along several routes, e.g. temperature, stress, pH, concentration, potential.

It is possible to validate accelerations by achieving accelerations of several orders of magnitude along different coordinates. Also, accelerations can evaluated by conducted accelerated tests for shorter durations and predicting successively longer durations.

Further, the various parameters of distribution functions can be modeled according to temperature, stress, pH, potential, and concentration.

b. Properties of environments to which the materials of construction are exposed over life.

The environments to which materials may be exposed need to be identified. These include, for Yucca Mountain, water layers in equilibrium with various relative humidities, wet drip, wet drip with oxygen cell, immersed and immersed with crevice, microbial and radiolytic.

Each of these environments has certain characteristics of pH, potential, and concentration (of species which do not relate to pH or potential). These need to be characterized in such a way that the range of parameters which need to be tested is defined.

These environments also need to be characterized relative to the probability with which they occur. This environmental probability, then, modifies the distribution function which applies to the respective modes and submodes of corrosion.

AN APPROACH

The ideas which underlie licensing the container will be based on the results of some serious discussions among people of different backgrounds, each of whom knows a part of the story. To facilitate the development of an approach the following ideas might be subjects for a Gordon Conference type of program where discussions are more or less open ended.

The topics which might be considered are:

1. Quantitative bases for the desired performance of the EBS and the site as a linked system.

   - Desired life of EBS and confidence level

   - Confidence level of the site

2. The design concept of *simplicity* and its implications for concept and assuring predictions.

3. Multiple use of containers.

4. Accelerated testing required to obtain data.

    - Types of accelerated testing
    - Limitations
    - Focus on limited number of materials
    - Validation of accelerated testing

5. Possible utility of "site independence" for a design criterion for the container.

6. Definition of failure.

7. Environmental definition.

    - Specific environments which can be defined
    - Probability of occurrence of environments

8. Probabilistic approach.

    - Multiple barriers
    - Relationship to accelerated testing
    - Environmental probabilities

Out of such a set of discussions might come a strategy document upon which broad agreement could be reached.

NEAR-FIELD GEOCHEMISTRY AND SOME IDEAS
FOR A GEOCHEMICALLY ENGINEERED BACKFILL

DONALD LANGMUIR -NWTRB

It is useful to conjecture as to the nature of the water-rock environment at Yucca Mountain following the possible emplacement of high level radioactive wastes, and how that enviroment might affect waste containment. At initial waste temperatures above about 90°C, the boiling temperature at Yucca Mountain, all moisture in the unsaturated rock near the waste will be evaporated and the steam moved by diffusion and perhaps convection for distances necessary to find rock at a lower temperature where condensation can occur. As the waste cools, this condensation will gradually percolate downward, redissolving salts which have accumulated earlier by reaction with the tuff and by evaporation. The first water to reach the waste once it has cooled below 90°C will thus be saline, and have as its major components, Na, Ca, Cl and SO_4, with smaller but important amounts of Si and HCO_3. It will be saturated with respect to calcite ($CaCO_3$), anhydrite ($CaSO_4$), possibly halite (NaCl), and with a SiO_2 phase such as cristobalite. Metal cannnister corrosion could clearly be a problem in such a water. However, only gaseous radionuclides such as ^{14}C could move significant distances from the waste under these unsaturated conditions.

What would happen if groundwater levels rose and saturated the repository?. If the waste was still hotter than the country rock, a convective cell would develop. If groundwater moved from the hot waste to cooler surrounding rocks, mineral precipitates would result. These would include precipitated calcite and gypsum near the waste, and silicate precipitates further away. Silicate precipitates alone, have been shown to reduce the permeability of granites in thermal gradients by from 3 to 70 times (cf. Langmuir, 1987). Similar reductions in the permeability of fractures and matrix are likely in the tuff.

Given these effects and possible conditions after waste emplacement, how might we design a backfill to optimize containment of radionuclide releases?

During the thermal stage with unsaturated rock surrounding the waste, the radionuclide of most concern is perhaps ^{14}C, which could escape to the assessible environment as gaseous CO_2. A possible getter to prevent such releases might be crushed limestone ($CaCO_3$) in the backfill. At high backfill temperatures the $^{14}CO_2$ would perhaps be retained in the backfill by isotopic exchange according to the reaction

$$Ca^{12}CO_3 + {}^{14}CO_2(g) = Ca^{14}CO_3 + {}^{12}CO_2$$

I am unaware of any published information on this exchange rate or its temperature dependence in dry systems, but the rate could be determined experimentally.

If we were designing a backfill to prevent or limit radionuclide releases should the waste be submerged in groundwater, we could use substances in the backfill to provide containment by both physical and chemical means. As mentioned above, physical containment could be affected by reducing rock permeability with mineral precipitates. Such precipitation will probably occur in any case, but can be enhanced if we mix silica glass, and calcite and/or gypsum-anhydrite in the backfill.

Another idea, which I suggested in a 1987 paper, is to let the heat of the waste create its own encapusulation by precipitation of the mineral serpentine throughout the backfill. This might be accomplished by mixing water, MgO and silica glass in the backfill in proportions to give the reaction

$$3MgO + 2SiO_2 + 2H_2O = Mg_3Si_2O_5(OH)_4 \text{ (serpentine)}$$

Such a crystalline precipitate might form a practically impermeable barrier to fluid or gaseous transport to or from the waste package.

How about designing a backfill to chemically limit the release of radionuclides should groundwater levels rise into the waste? A variety of possibilities come to mind, some of which have already been suggested at this workshop. Radionuclide retardation can be by adsorption, or by precipitation in minerals. In selecting the rocks and minerals for such a purpose I have chosen materials which are both cheap and readily available. It should be noted, however, that retardation reactions are reversible, and that with time the same radionuclides can escape from the backfill as conditions change. What retardation in the backfill beneficially does is to dampen and stretch out in time any elevated radionuclide releases from the waste package.

An obvious selection to retard Cs, Sr and Ra, and any other uncomplexed, cationic radionuclides by adsorption, is zeolitic tuff from the vicinity of Yucca Mountain. Crushed apatite ($Ca_5(PO_4)_3(OH,F,)$) or phosphate rock is probably the best material as a precipitant for U, Th, Pu and Np, and perhaps also Am and Cm. The logic of such a choice is supported by the fact that the autunite group of minerals, which are phosphates, are among the least soluble phases of uranyl found in ore deposits (cf. Langmuir, 1978).

Goethite (alpha-FeOOH) might be useful as a sorbent for I. How to retard ^{99}Tc is more problematic. As pertechnetate ion, TcO_4^- it may substitute for sulfate in some minerals. Such substitution might be optimized if gypsum/anhydrite were mixed in the backfill.

These are just a few of the possibilities that might be considered and tested in designing a backfill so that it functions as an important barrier to the release of radionuclides from the waste. A well-conceived and designed backfill with a major potential role in waste containment could greatly increase the confidence of both experts and the public in the long-term safety of a high-level waste repository. Developing such a backfill could be cheap, and should be a high priority in the DOE program.

Reference:

Langmuir, D., 1987, Overview of coupled processes with emphasis in geochemistry. Chap. 8 in Coupled Processes Associated with Nuclear Waste Repositories. Editor, C-F. Tsang. Academic Press, Inc. 67-101.

NEAR-FIELD GEOCHEMISTRY AND SOME IDEAS FOR A GEOCHEMICALLY ENGINEERED BACKFILL

DON LANGMUIR -NWTRB

-INITIAL WASTE AT TEMPERATURES ABOVE BOILING

FORMATION OF SALINE CONDENSATES AT A DISTANCE, BELOW 90°C

-UNSATURATED CONDITIONS WITH WASTE TEMPERATURES BELOW 90°C

1. PERCOLATION OF SALINE CONDENSATES TOWARDS THE WASTE
2. CONDENSATES SATURATED WITH CALCITE, ANHYDRITE AND SILICATES AND PERHAPS HALITE
3. CLOGGING OF ROCK PERMEABILITY WITH MINERAL PRECIPITATES
4. POSSIBLE CORROSION OF METAL CANNISTERS AND $^{14}CO_2$ RELEASE

-DESIGN OF A BACKFILL TO LIMIT RADIONUCLIDE RELEASES

1. WASTE TEMPERATURES ABOVE 90°C, UNSATURATED ROCK
   - $^{14}CO_2$ RELEASES: POSSIBLE ISOTOPIC EXCHANGE WITH $Ca^{12}CO_3$
2. WASTE TEMPERATURES BELOW BOILING, SATURATED ROCK
   a. PHYSICAL CONTAINMENT BY MINERAL PRECIPITATION REDUCING ROCK PERMEABILITY

      -RETROGRADE SOLUBILITIES OF CALCITE AND ANHYDRITE

      -PROGRADE SOLUBILITIES OF SILICATES SUCH AS CRISTOBALITE

      -SERPENTINE ENCAPSULATION OF THE WASTE

$$3MgO + 2SiO_2 + 2H_2O = \underset{\text{(Serpentine)}}{Mg_3Si_2O_5(OH)_4}$$

b. CHEMICAL/GEOCHEMICAL CONTAINMENT BY ADSORPTION AND PRECIPITATION

ZEOLITIC TUFFS

-ADSORPTION OF UNCOMPLEXED CATIONIC RADIONUCLIDES SUCH AS Cs, Sr, Ra, Am, & Cm

APATITE OR PHOSPHATE ROCK $(Ca_5(PO_4)_3(OH,F)$

-PRECIPITATION/COPRECIPITATION OF U, Th, Pu, Np, Am, & Cm

GOETHITE (alpha-FeOOH)

-ADSORPTION OF IODINE

GYPSUM/ANHYDRITE

-SUBSTITUTION OF PERTECHNETATE FOR SULFATE

CONCLUSIONS

1. A WELL-CONCEIVED AND DESIGNED BACKFILL WITH A MAJOR POTENTIAL ROLE IN WASTE CONTAINMENT COULD GREATLY INCREASE THE CONFIDENCE OF BOTH EXPERTS AND THE PUBLIC IN THE LONG-TERM SAFETY OF A HIGH LEVEL WASTE REPOSITORY.

2. DEVELOPING SUCH A BACKFILL COULD BE CHEAP, AND SHOULD BE A HIGH PRIORITY IN THE DOE PROGRAM.

APPENDIX G

EXPERT PRESENTATIONS

YUCCA MOUNTAIN SITE CHARACTERIZATION
ENGINEERED BARRIER SYSTEM
CONCEPTS WORKSHOP
JUNE 18, 19, AND 20, 1991

PRESENTATION BY: PETER ANDRESEN
TAKEN FROM TRANSCRIPT OF SESSION 3: JUNE 20, 1991

Identified as the time when we get to earn our keep and speaking for myself anyway, I'm getting either no direct or indirect compensation for this, so perhaps I should be confident that you'll get your money's worth.

(Laughter)

But I'm afraid that after perhaps some of my questions and indeed my review comments now, that perhaps you would have paid me to stay away.

I am the odd man out in some ways in the group of experts that, at least to my awareness or perception. I have no historical involvement with this, and so I bring at the same time a sense of naivete to this, but also I think a sense of independence. I'm going to try to exceed the bounds of the question a little bit, because I think the technical feasibility issues are perhaps some of the least intimidating ones.

In terms of the meeting in general, I guess I was disappointed in some ways in terms of the structure of the meeting, because I think it's size and diffuseness made it a little bit difficult, at least as from someone who deals technically in very specific areas with very specific problems. Getting my hands around some of these issues in any kind of detailed way is almost impossible.

The flip side of that is that I appreciated very much the presentations and Holmes way of running the meeting, and the kind of interaction in general that we've had. That has led, I think, to very good character of the meeting, in particular very good technical interaction, at least to the depth we are able to have that. And, my experience is, and I'll relate this a little bit later, with organizations that have functioned very, very powerfully in addressing technical issues, is that character and interaction has been a critical ingredient.

If I had to identify a fundamental problem with the problem, I guess I would call it the will to do the job. It seems to me that the issue of the general will to get this job done, to start it and to do it, is not that evident to me. And, I think that really relates to the issue of leadership and a champion for this idea. And, I don't know whether that is a political or legislative, executive issue, whether it is a regulatory issue, whether it is a technical or DOE issue, whether it is indeed a utility participation issue. I don't know where this specific advocacy should come from. I think all corners. But, as I look at the nature of the history of this from my simplistic perception, I think the single biggest problem we face is the will to do the job.

In terms of the technical issue of, do I think it is feasible to design for a thousand years or ten thousand years. I think within the context of realizing that we have to tolerate a probabilistic analysis for these things, and that there are uncertainties in what we have to analyze in terms of the environment and how some of the materials will perform given that specific environment, I think the answer is yes. I am not intimidated by the prospect as someone who has really been involved, although at arm's length being at the research center at G.E., with nuclear issues. We're concerned more, you know, with one to a hundred year kind of time scale. We're now heavily involved in life extension issues. But, a lot of these things happen on a long rhythmic time scale, and so extending out to a thousand years or ten thousand years, despite the fact that exceeds the time period of certainly our engineering experience if not indeed the base of science on which we need to rely, it's still not an intimidating issue to design something that is going to last for a thousand to ten thousand years.

And, so I think the question which we were asked to address in a very simple and generic form, can this be done? And, I think the answer is yes. And, again I'll reiterate, I'm sure the technical issues are the limiting factors right now.

Within that context, there's a whole bunch of questions, including ten to the fourth years. I enjoyed seeing summaries of the Swedish program and other programs where they are estimating ten to the fifth, ten to the sixth and ten to the eighth years. Again, on a logarhythmic time scale, why not?

And I think the other problem is what are the definitions and criteria against what we're going to design. And, I certainly have not heard any definitive explanation of the regulations as they exist, but it seems to me that there is a vast ambiguity in terms of the vernacular that's used. One of them is substantially complete containment. And, I'm not sure that some of these terminologies are assisting the technical community in addressing the issues. And, I get the impression that some of the other international programs have much more helpful, specific goals against which they're designing. And, so again in a sense this is not a technical issue. It is a much more involved issue of how we establish regulations. And, indeed one would like to believe, and I think this is true based on David's comments referring to Canada, who said there needs to be some light in evolution to the nature of the regulations. And, it's not clear to me that that process of interaction and evolution is occurring at all. And, indeed, if there's a will or a vision for that happening, and then I think that's a major problem.

I want to layer down as I talk to more specific issues. Clearly, a modeling system is an important issue. My own background for the last ten or fifteen years has been largely in energy systems and largely, although not completely, on stress corrosion cracking and corrosion fatigue. And, our evolution of that, which I think has been a meaningful and useful evolution in a very complex system where there's a vast number of interactive variables, is that you can get your arms around the important parameters. You can have a fundamental understanding of what's driving cracks in this case. You can establish with reasonable accuracy how fast cracks will grow. I guess I don't share David's concern that you can't design again stress corrosion cracking. We have looked not only at chemical issues and really the micro-structural issues that are more critical to pitting and general corrosion, but throwing into that pot mechanical variables is not an intimidating addition. And I think these things can be handled, certainly up to the twenty, or ten, to hundred year lifetime. I think there's a recognition that these things are being handled with a great degree of success.

I think one of the big difficulties I have is that despite the vast effort that has been done not only by us but by many others on environmental cracking, we are not inclined to try and convince either utilities or regulatory people or indeed the scientists, our own business people, or the scientific community, that our theories are that airtight or that flawless. And, we have always insisted upon combining a modeling approach with a monitoring approach. And, while people felt ten years ago that was a very intimidating problem in the nuclear situation, nuclear environment, to put useful monitors in a reactor, we have been able to develop high-temperature PH electrodes which are very complex, high-temperature seals where you can put, you know, coupons or whatever materials to measure their corrosion potentials. In the last five years there has been a lot of development by us on taking actual fracture mechanics, crack growth samples, instrumented, putting them in situ, not only in pipes, but there are several operating, commercial reactors, including Nine Mile Point and others, Dwayne Arnold, Pilgrim, that have these devices in the core of the reactor while it operates getting continuous crack growth measurements. And, I think if you can accomplish those kinds of things, it's not clear to me why it is that we should preclude monitoring the situation of a waste repository.

I think the other benefit that we have seen from the approach that we've taken, which includes modeling and monitoring, is the primary issue we handled which is the cracking in sensitized stainless steel pipe issue. We have evolved that with a common kernel of probably 75 or 80 percent of commonality to extend that to non-sensitized steels, to nickel based alloys, to pressure vessel steels which is a big issue, to irradiation effects, radiation and stress corrosion cracking to turbine steel which is reappearing as a problem. And, I think there are a variety of things that come out of monitoring and modeling programs that permit you to get beyond where you thought you were going to get in terms of being able to understand and quantify and monitor your system.

And, so I'm not sure I understand enough about the details of this system to know why it could or could not or should or should not be monitored. But my experience and background tells me that being able to accomplish that is not that intimidating, certainly compared to some of the situations we have monitored, and I think it should be very strongly considered.

I had a whole list of comments about some of the waste package concepts that were discussed. And, I guess my biggest concern about relaying some of those is that it really is based on an awful lot of cursory information that was presented without an awful lot of detailed interaction to permit me to really make these comments with much intelligence, I guess is my feeling.

A lot of the concepts I found very interesting, and I think that the concept which was presented by Roger Staehle and many other people is that I think we should be driven insofar as possible by simplicity. But not only simplicity, but I think the idea of integrating the solution to a number of problems simultaneously as represented by Virginia Power, by Mark Smith is it, I think is a superb example of how to tackle problems like this. Again, I'm not sure that part of the problem isn't thrown back into a will to resolve the regulatory and other issues that permit these problems to be solved simultaneously in a way that is very symbiotic and very powerful.

Again, let me go through some of the comments in simplified form. I think some of the ideas of self-shielding are very interesting, particularly since I'm inclined to be an advocate of being able to model and monitor which implies retrievability I think in some sense. People are, again, very concerned about the concept of if you monitor it then you might have to retrieve it. It seems to me the alternative is a blinder approach when we say we don't really want to know what happens, and that's a much more dangerous approach in my opinion.

The flip side of that is I don't think that simplicity precludes multi-barrier approaches, and I think that the ones presented were very good. Let me mention a couple of biases I have. It seems to me that trying to rely on galvanic interactions, particularly sacrificial galvanic interactions can be a very chancy situation -- not unworkable, but chancy, because the galvanic series of response relied upon can be very dependent on whether the material is passive or active. I mean materials like stainless whip from the bottom to the top of the galvanic series as do other materials -- quite shifty with temperature and pH and other effects, and I think that can be very complex to handle without a great deal of care.

As I think I made clear in a number of my comments, I have some bias against non-metallic materials on the OD of the container because they are largely low-fracture toughness, and I think that whatever benefit they might have accrued for you, could easily be destroyed very early on either by handling or by shifting of rock.

I liked very much the idea in the multi-barrier concept of using materials that would provide some sort of trapping or ion exchange capability. I think that's an excellent thing that needs to be pursued.

In terms of metals, I guess I'm inclined to have some bias against some of the concepts, such as copper. It probably is workable and I'm not saying I'm completely against it. I think compared to other materials I guess my concerns about copper are that I think you certainly can undergo localized corrosion. You certainly can undergo cracking, and some of the stress relaxation phenomena which rely upon the creep of the material, which is ongoing, can be very disadvantageous. In most of the materials it's not the stress per se which is damaging, but it's the creep rates which really can drive stress corrosion cracking. So, I'm not sure that the creepy nature of copper should be looked upon as beneficial. And of course the whole issue of the complexing chemistry, or chemical complex of copper, I think is also a real problem.

I guess I have the same tendency toward a bias against lead. I'm not sure what it brings to the ball game. And, I think the issue of it's toxicity, not only after the ten to the fourth years, but after the ten to the twentieth years is something that makes it unpleasant.

The selection of metals, I think, has a whole variety of criteria, and I don't want to go into those in any detail because I know they've been analyzed by many people that have worked on this program. I think that many of the ones that were discussed including some of the simple iron systems as well as titanium are excellent, and let me make no more comments beyond that.

A number of people have commented about ceramics. The implication having been that there is some level of inertness, both chemically and from an environmental cracking perspective, and that really does need to be dispelled. Other people have also dispelled that. These materials do stress corrosion crack. They do dissolve, and of course, they do mechanically crack.

BY HOLMES BROWN:

Five minutes.

BY PETER ANDRESEN:

I think we need to be very careful about labeling systems as thermodynamically stable or as reducing because for long-term conditions whenever you're dealing with an electro-chemical system, the only reason you're at or near equilibrium is because you have some ionic content and equilibrium with the stable metal form. And, the question is whether the solubility and other cations are adequate to maintain that in the long-term without an unpleasant corrosion rate. But, I think that it's easy to hear the word reducing and thermodynamic, and come to the conclusion that the system is fully stable and that is often not the case, particularly as we look to very long term.

I have a little bit of bias against the chemical tailoring of some of the drifts for the same reason I guess that people have historically been worried about adding inhibitors to systems. For one reason, if we aren't concerned about wet environments, as you look at the massive scope of conditions, with very dry to some moisture present, where these tailored systems would work to lots of water present, where you would again be able to extract some of the beneficial species, it's not clear to me that you want to get in the position of guaranteeing the longevity of this tailored system. Again, I'm not against it. I just have some concern for that approach.

And let me just again mention several other simple issues to get on. One is the issue of some of these ion exchange fillers. I think these are excellent examples. The backfills are excellent approaches. I'm more concerned about some of the backfills because of in terms of keeping water out, and because if they pack around the canister, I think you end up with problems, not only from corrosion product release and pressure on the canister from that, but also if water does drift you get dissolved solid buildup and you could get pressure from that as well.

I'm far more interested in the heat pipe approach than

I was when it was presented, having talked extensively afterwards. But, again there's this tradeoff of whether it is a simplifying approach or not, and I think that does need to be considered.

Finally, I share someone's earlier comment about natural analogues, because as I perhaps unpleasantly made clear in one of my questions, the analogues for longevity of material can also be matched by the natural analogues for how they corrode. And, some of the systems for which we want to make analogues, we are hard pressed to guarantee that the conditions are really exactly the same, both in terms of trace elements in metals, as well as the precise character of the analog system that we're trying to compare to.

Let me close by sort of summarizing, I guess, my recommendations. I think that the biggest issue again is a will to get on with the job. I think the job is doable. It's clear to me that since this program has apparently been running in some form or another for the better part of ten years, that if money had been put in to some experimental work ten years ago, we would have an awful lot of information to discuss today. And, I think that the only thing that is clear is that money needs to get put in today so that in a few years we will have something to work off of in terms of data.

I've been involved in a couple of organizations that have really handled more narrow technical issues than this. One has been pressure vessel, cycle crack growth in pressure vessels. Another international cooperative group on irradiation system cracking, which has only been around for three or four years. The pressure vessel cracking group has been around for eleven to twelve years. But if you look at the kind of money involved, in this case on an international scale, to tackle these problems intelligently, you're looking at an expenditure over the period of at least five years of something in the vicinity of a hundred million dollars. And, it seems to me that kind of dollar value is the kind of expenditure you're asking me to make a broad brush estimate for what it takes to get something underway, can begin to resolve the fundamental technical issues, then that's the number I pull out with my experience with those other groups.

It would be awfully nice in conjunction with that to establish some clearer goals, part of which is design from a regulatory issue, part of which, in terms of the barrier system, is related to defining and site characterizing -- I'm not sure that's that critical. Today we can do experiments on both the fairly benign conditions, on moderately aggressive conditions, which you might call wet as opposed to dry, and on scenarios which you consider very extreme, which might be very highly concentrated ionic solutions near or above the boiling point. We don't need to characterize the site any further to get on with some of the fundamental experiments which gives us preliminary data on how to handle this. And, I think that's my single biggest recommendation. And, I think it's the single biggest problem with the program as I see it as an outsider, having extended for ten years and not having applied resources in that area.

Finally, I guess that it's clear that a few years or ten years of data will not tell us everything we need to know. And, rather than my fumbling around with the description of the probability approaches, I think I'll use that as a lead in to Milt Harr who I think is going to emphasize some of those issues. Clearly, those approaches are critical to this program.

YUCCA MOUNTAIN SITE CHARACTERIZATION
ENGINEERED BARRIER SYSTEM
CONCEPTS WORKSHOP
JUNE 18, 19, AND 20, 1991

PRESENTATION BY: SAM BASHAM
TAKEN FROM TRANSCRIPT OF SESSION 3: JUNE 20, 1991

My name is Sam Basham with Battelle. We've been asked to address can a waste package be developed to have reasonable assurance of lasting ten thousand years. If yes, how? If no, why not? I'll return to this question a little later on.

We've heard a programmatic approach and then we have heard thirteen ideas, I counted them, presented by twelve organizations. And, they range from broad, generic approaches, to very specific topics. I found seven of these to be of questionable value, primarily for the lack of a clear advantage and application. That is, what is gained by the use of this particular concept, or I found that the material choice wasn't based on a supportive, theoretical, experimental basis.

The six have appeared to offer some promise, including the use of stabilizers both to control the environment, or to protect some component of the waste package, and this is what I'll call the engineered barrier system for want of a general term. I thought the multi-barrier approach has merit. I think that heavy wall containers and the concept of cooling and drying enhancement are good.

Now, having said that, do my opinions as stated bear on the basic question. No they really don't. Because they're opinions and they're based on too little evidence. So, I'd like you to ignore what I've just said because I wanted to make a point, and I'll return to that later.

By the way, I was not asked to do what I just did and there was good reason for them asking me not to do that for the points that I just made. Now, I have to do just like all the others have done. As being called an expert and surrounded by people with impressive credentials of training and professional experience, this has resulted in a number of jokes in the halls during this meeting. Several of those were mine.

On a serious note, I've devoted a large part of my career to this program in an area that failed. I've had time to think long and hard about my part, the part of my company, the approach that was being taken during that time period, the total system in which we were all working, so any claim to expertise on my part comes from that sobering experience. I hope I will bring that to bear today.

Now, let's return to the concepts and take a look at it from an entirely different point of view. I found in general two things lacking in many of the presentations.

One, I would like to have seen a clear quantifiable statement of the advantage of the concept, right up front. Then I would like to have seen each of these people give an analysis of the impact of applying the concept. That is, what is the effect from the total disposal system if I use this concept. Another way of expressing this is what is the gain and what is the cost of the concept. And when I say cost, I mean far more than the cost of the materials. I want to know what does it do to the system? What do I have to pay to put that in my system? How do I have to change it?

Now, much of the discussion and a lot of the uncertainty about these concepts could be eliminated even if we had a modest data base on them. A basic program flaw appears to be the lack of data which are areas of strong need to select some concepts and test them, both in the laboratory and by building prototypes and trying them out. What I'm talking about here ranges from rigorous scientific experiments to the heat and beat engineering applications. I think we need both of these. We definitely need the data, and we need the data to toss out weak concepts. It's time we got rid of some of those, and right now we don't know what they are. We also need to show those that tend to be workable.

This is not inexpensive and it requires a continuing commitment of managing and budgeting support for time periods like five to ten years. In some cases, maybe even more. We can never drive to closure with workshops and system's studies alone. Planning is very necessary, but execution is essential. We simply have to get about it.

Now, I personally give high marks to any concept that was backed by hard data derived from rigorous analyses and experiments. And, a number of them brought some real data in here, and I think you should look at every one of those. Also, I prefer those where a quantifiable benefit can be stated. And, a number of those came in and said, this is the benefit of my approach.

I recommend to DOE that each presenter go home and make a fifty or hundred word statement of the specific benefit of their concept approach. And, then I would add these statements to the record of this meeting.

Now, let's return to the original question and let me frame it in a way to make a point. I do not think we can provide rigorous proof that 99.99 percent of a specific number of waste packages will retain 99.99 percent of their contents for 9,999 years. This is the old four-nine statement that we have all hear in this program many times. I quickly go on to note that the board didn't pose the question that way. They asked -- let me go back and read it again. Can a waste package be developed that can be demonstrated to have reasonable assurance of lasting for ten thousand years? That was the way they posed it.

Now, I'm going to define reasonable assurance, because they didn't. I'm going to say I consider reasonable assurance to be able to convince a majority of trained people, and I didn't say technical people, I said trained people, with credentials for treating major problems and questions with a perspective beyond their specific area of expertise. That is what I'm talking about are the knowledged synthesis of our society. Those people who are viewed as being able to look beyond their own specific expertise and deal with problems.

Given this approach, convincing these people, I believe in time and step by step that we can obtain regulatory and public and political acceptance. First, we've got to start with these knowledgeable people, those people who are viewed by our society as knowledgeable. You've got to convince them that where you're going has some merit and, I think, given that, you can go on to the rest.

Now, if you'll give me my definition of reasonable assurance, then I think I can make a statement about the question. I believe that, given a reasonable data base, that a majority of a given number of waste packages can hold most of the radioisotopes in close proximity to the emplaced location for several thousand years. I think we can provide a robust approach that has a high level of confidence of the proper function.

Let me define robust. I'm a mechanical engineer, so my analogies are mechanical. The Briggs and Stratton lawn mower engine is an example of a robust design. You buy that for a modest amount of money. You throw it in the corner of your garage. You pull it out every spring. You yank on the cord, and it runs. You kick it. You don't put oil in it. Some people don't know where the oil plug is. It works year after year, after year. It doesn't work great, but it works.

Now another kind of mechanic device is an F-15 airplane. This is a high-performance system. It does wonderful things. We've seen examples in the past year. But you've got to bring that sucker in every hundred hours, pull the engine and put a new one in it. You've got to replace most of the major systems. You've got to constantly maintain it. This is not what I call a robust system. I think many of us would agree that what we mean by robust is something that has some self-evident elements, as well as our ability to model it, analyze it, and predict it.

Now, how can we do this? How can we get on with the job? I take it as a given that certain decisions have to be made. We have to pick several approaches and get started.

We're going to have to pick these approaches on inadequate evidence. We're not going to have enough knowledge to know whether they're right ones or not, and how can we do it. Well, that's where managers are under-paid. They have to make decisions with inadequate information. We have to get started on the job of doing it.

Then, number one, after that we need some major funding of experimental work. We need to obtain hard data. And, what I mean by major funding, I mean we've got to have budgets like twenty to forty million dollars a year for twenty years. It's not easy, cheap or inexpensive.

I think the statistical basis of our selected approach has got to be considerably improved by this hard data, by developing theories, and testing them until we have predicted models we have some confidence in. I think we could also improve this statistical basis by monitoring in some fashion the engineered barrier from one to two hundred years of initial repository operation. I believe this is something to be discussed with regulators and I believe that there's some basis for consent. Considering the time and effort in time frames we're discussing here, that kind of experimental verification is not completely out of line.

Third, I think there should be some evolution, and I think there will be, in the regulations or in the guidance that's developed on how to apply, as well as evolution in our understanding in competence in the behavior of the disposal system. Now, I believe this will happen because it has happened over the history of the Nuclear Regulatory Commission, which in it's earlier incarnation was part of the AEC. They're an entirely different operation. They have entirely different regulations than they had thirty years ago. We're not going to finish this job in five or ten years. You must consider the fact that the regulations are not going to get easier, but they might well be tougher, and I think they will be more applicable to the real systems as we bring these real systems to the table. When the program comes in with some robust approaches, backed by hard data, lays them on the table, I think we can settle our regulatory problems. I don't think we should view those as impossible.

Now, in closing -- I know Holmes thought I'd never get there. I appreciate DOE asking me to participate. There are good people working on this program. There is sufficient time and there is sufficient money, and as Herman Kahn of the Hudson Institute said in one of his books, with some good luck and good management, we, and by we in this particular book he meant the entire human race, can solve our problems. I see no reason why we can't solve this one. Thank you.

YUCCA MOUNTAIN SITE CHARACTERIZATION
ENGINEERED BARRIER SYSTEM
CONCEPTS WORKSHOP
JUNE 18, 19, AND 20, 1991

PRESENTATION BY: MILTON HARR
TAKEN FROM TRANSCRIPT OF SESSION 3: JUNE 20, 1991

Can you hear me? I hate devices like this. I'm a lecturing, chalk throwing professor, but they wouldn't let me carry the board on the plane. So, I'm going to try and use this infernal gadget devised by the devil, if I may.

It's very nice to see old friends, new friends, new old friends, old new friends, participating in a program such as this. As I was sitting here listening to my colleagues, I wondered about how did I join an illustrious group like this. And, really it is because I'm a survivor. An expert has to be somebody who sticks out their neck and has survived.

In the scientific field survival means you've published papers that were critiqued by your colleagues and you can answer their statements. In engineering you survive by designing and building things that pass the test of time. I'm an engineer. All my degrees are in engineering. I teach engineers. About ten years or so ago I was privileged to lecture at Moscow University on the subject of reliability based design in engineering. And after my lecture, Gorbudanov Pasadov (sp) came over to me and he said, "Professor Harr, are you the son of M.E. Harr who wrote Ground Water and Seepage?" And, I was taken back. I am M.E. Harr who wrote Ground Water and Seepage.

(Laughter)

He couldn't believe it, because Ground Water and Seepage deals with conformal mapping, elliptic integrals, elliptic functions. I found it necessary to learn these things to be able to predict the performance of carefully constructed earth dams that retain water.

When I was approached by Bendix Corporation of South Bend, Indiana, the home of Notre Dame, to help them design the pads of the lunar module, upon which rested the prestige of our country and also two Purdue Alumni --

(Laughter)

--I realized that a deterministic approach had it's limits. I am very fortunate never to have had a course in statistics or probability, so I did not have to forget anything to learn new things.

What I'd like to share with you in the time allotted to me this morning is something that was absolutely missing in most, if not all, the presentations. And, that was a quantitative focus. And the quantitative focus must be directed at uncertainty. I did not choose to go into probability and statistics. I got my feet wet in Ground Water and Seepage, and it was a marvelous field. It supported my wife, my children, my grandchildren and all, but it's necessary as an engineer to do this. Unlike the scientist who can test something for thirty or forty years and lying on his death bed watching flies fornicating on the ceiling --

(Laughter)

-- he can say, maybe it can't be done. In engineering it is often more important to get the concrete out of the mixer, even if you put it in the wrong driveway, than to let it harden inside the mixer.

(Laughter)

(Referring to the microphone) God I hate these things. I once saw this done, and I thought well maybe I'll do the same thing.

We're talking about an engineered barrier system, not a scientific system. And, we're talking about the feasibility of something lasting ten thousand years. And, this is what I'd like to address and point out to you first of all, what is the engineering system? Now I chose as an example of the engineering system the system that I grew up in. I'm a geotechnical engineer and civil engineer, and this is the system. Let me point out what it is. The system is like links in a chain. And, the function of the system is to be able to build with competence. It is this system that spanned the continent that provided this room, that provided the air fields, the airplanes, all of this that we call the glory and wonder of the twentieth century. But let's look at that a little bit in detail.

First of all, we sample something. And, what do you think the level of sampling is? The best level of sampling that I know of is one part of half a million. That's it. In highway work it's often one part of ten million. And, what do we do? We take the samples out and test them. What is testing? Testing is quantifying a theory. Quantifying a hypothesis. If you did not have a hypothesis, what would you test? How would you know what to test? The thing that generally governs testing in the hypothesis is a very interesting concept. That which is simple is important. The testing quantifies the parameters that exist within our formulas. We often, more than not, test cylinders because we sample cylinders. We seldom build cylindrical soil samples, but we always test cylindrical soil samples.

Where did the formulations come from that gave us the insight into the testing process? They were developed a hundred, to two hundred years ago, before the age of computers and graduate students. Do you realize how many parameters we have? There is no such thing as a property. A property is an invariant, and everything changes. They are parameters and they are subject to all types of changes and degrees of uncertainty. There are so many parameters identified in my field that we have exhausted the English alphabet, the Greek alphabet, subscript and now we're using super script. Such is the degree of uncertainty in things we know how to do well.

However, like links in a chain, we test. We test these formulations. And, by the way these formulations always use a differential element, and always only use two laws. It doesn't matter what field of energy you deal with. There are only two laws. One says the change in the number of people in this room over a given period of time is the difference between those that come in and those that go out, the conservation of people in meetings.

(Laughter)

The second law is called entropy. It says water will flow down hill. It says, you will leave from here and go home because there is an emotional gradient.

(Laughter)

BY HOLMES BROWN:

Downhill?

BY MILTON HARR:

Okay. Why did the system work. The system worked because of this last link in the chain called experience. In civil engineering, every single structure, every design is different. What did this mean? How did we gain this experience? Well, there were a few people, a few organizations who observed a number of like circumstances and they said, "if you sample a certain way, run these tests, have these formulations, and use a certain factor of safety, you can build with confidence". However, I know of no structure or no system where you can build with confidence without inspection because our system is only good, let's say, one part in ten, one part in twenty. The space shuttle, the thing that perhaps was the best engineered system that we will ever see in our lifetime, even if we live those ten thousand years, it failed the twenty-fourth or the twenty-fifth passage. We had such security in the system, we even put a kindergarten teacher in there and had her children in the class down below watching. That was it. That's a reliability of 95 percent. That's a probability of failure of 5 percent of the best engineered system we know of. Anything beyond that is speculative.

What do you do if you don't have the last link, and that's the name of the game. It has nothing to do with New York. It's how to predict the performance of things not yet done. You cannot use this system. You don't have the experience, and besides this was very simplistic. And, you don't have the fifty factorial experiment around which you can build your system.

How am I doing in time.

BY HOLMES BROWN:

Ten minutes.

BY MILTON HARR:

Ten minutes? Good. I'm all set and half way through. Okay.

One of the things that needs to be done in my opinion is to establish a target reliability. What is reliability?

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MILTON HARR

Reliability is the probability of success. What is probability? Probability has nothing to do with chance. Statistics is chance. It's very simple. Probability is like geometry. Statistics is like astronomy, like surveying. It's an application of probability, adding other things. I suggest a target reliability of 95 percent, and I'll elaborate. That's the best we can do. Our knowledge base is no better.

How do we do it? Well, it is unfortunate that the people who teach us probability, the probabilists are not interested and were not interested in the problems we are interested in. They were interested in saving widgets. Probability was not developed to deal with functions of many variables that have uncertainties. I'll state it in another way, functions of random variables. When you see a probability distribution, it has meaning. It just doesn't have significance in the engineering sense. We are interested in functions of many variables. You have many factors interacting in the system. How do you deal with them? How do you account not only for the uncertainty of each variable, but their correlations, their interaction?

This is precisely the problem that I began addressing a few years ago. I had great guidance. One of the top engineers in the world is a fellow named Emilio Rosenblueth. I don't know if you ever heard of him. He was offered the post of Minister of Education in Mexico. He's one of the people who escaped from Germany just in time, went to Mexico. There weren't many places that would accept him. And, he is a structural engineer, a graduate from the University of Illinois, marvelous man, soft-spoken man. As a structural engineer faced with the problems of dealing with functions with many variables, he said, "look, the way it's done in probability theory .n't right. Let's do it from an engineering point of view." And, he developed something called the point estimate method.

I have been in fortunate in years of having a number of graduate students who have helped me develop this method. Let me tell you what it is. It is a probabilistic method that solves for uncertainty in a closed form manner. It is not a Monte Carlo simulation. Monte Carlo simulations can do you very little good, because you don't know enough to choose the proper initial distributions and you cannot handle their correlations. This method does. And, the extension of this method is such that we can handle uncertainty, correlated variables, skewed variables. Now, having this, we have a definition whereby we can communicate.

If you use methods such as this and you have a target of, let's say, a reliability of 95 percent, then you can change the various elements and see where the degree of sensitivity could improve your analysis. Whether it's right or wrong, I believe it's right, and I don't know how we're going to improve upon it greatly, but this system has worked in the geotechnical vein and many others.

There's something else called baysian probability. It is an organized way of upgrading your level of knowledge. This means, using these two systems it is possible to do the following: Giving each and every individual knowledgeable in this system, in these two methodologies, the same information and they would come up with the same number. It is quantitatively, if you will, robust.

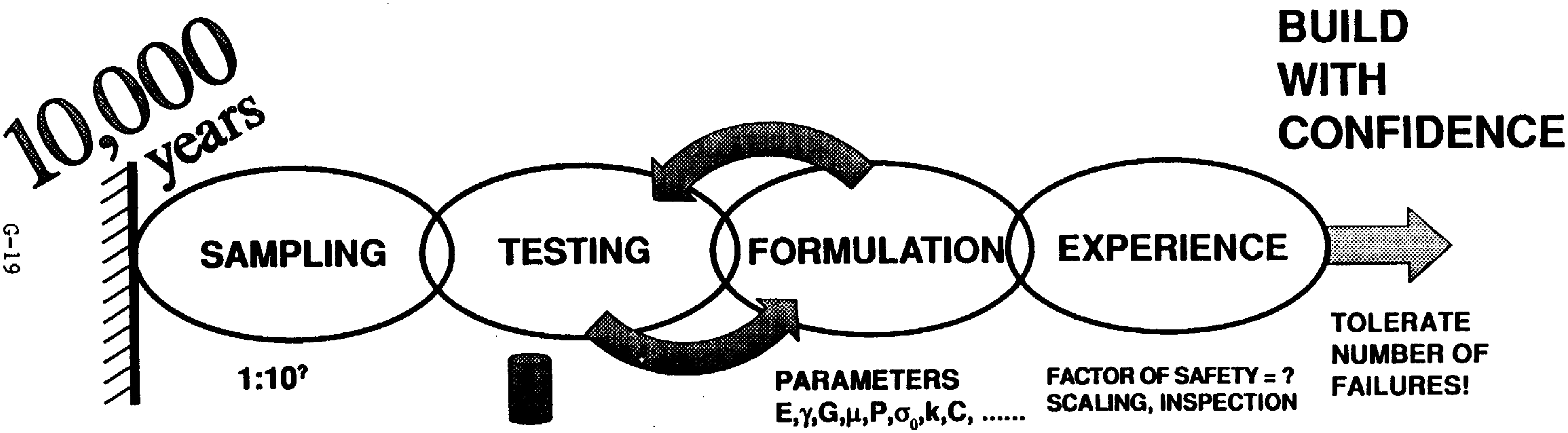
This is the subject that I tried to address, quantitative versus qualitative. We cannot be qualitative. It does little good to say you're good. It does little more to say you're really good. And, it does even less to say you're pretty damn good, but it means something when you put numbers around it.

With such systems we have been able to -- and very complicated system in geo-technical engineering such as movement of contaminants, and hazardous waste and things that have held up in court -- been able to evaluate and optimize. And, I do that, but recognize the great flag, the pennant of engineering to do this both with safety and to honor the almighty dollar.

The great sage, Chinese sage Confucius, said, "if you plan for one year, you grow rice. If you plan for ten years, you grow fruit trees. You plant fruit trees. If you plan for a hundred years, you educate people." It may even hold true for ten thousand years. Thank you.

(Applause)

"ENGINEERED" BARRIER SYSTEM



HTPTPOTNYD ?

(HOW TO PREDICT THE PERFORMANCE OF THINGS NOT YET DONE)

1) NEED TO ESTABLISH TARGET RELIABILITY
$R \simeq 95\%$

2) $f(x_1, x_2, \ldots x_n)$ PEM/BETA DISTRIBUTION

3) BAYSIAN PROBABILITY

4) QUANTITATIVE vs QUALITATIVE

5) EVALUATE/OPTIMIZE = $AFETY

WKSHPEBS.122/8-1-91

YUCCA MOUNTAIN SITE CHARACTERIZATION
ENGINEERED BARRIER SYSTEM
CONCEPTS WORKSHOP
JUNE 18, 19, AND 20, 1991

PRESENTATION BY: ROBERT SHAW
TAKEN FROM TRANSCRIPT OF SESSION 3: JUNE 20, 1991

I echo some of the words that other people have said that it's been a real pleasure to be here. I think the presentations have been very good and very stimulating. There have been quite a few creative ideas that have come forth as a result of the presentations that we've had here. We've heard a wide range of concepts. It's a real challenge to evaluate the various concepts that we've heard. I'm going to choose to do some generalization and some categorization of some of the concepts that we have heard.

I'll start off by starting right near the fuel rods within the waste package and say, first of all that we had some presentations on canister fill materials where a number of different options were presented for ways in which to fill that canister. The purposes there varied, but in general were either to prevent water access to the fuel rods with a subsequent degradation and transport that would take place, or it was to reduce radionuclide transport including, on some occasions, gaseous transport. We had a few occasions where people talked about gaseous transport, but for the most part it was not discussed.

In addition, people will mention, or did mention, that the canister fill material can serve the purpose of strengthening structurally the canister itself.

Secondly, we heard a number of presentations about the canister wall itself. We heard about thick canister walls, multiple walls, and in some cases multiple metals, other cases multiple in ceramics. We heard about composite materials. And, again the purposes of these were, in many cases, very similar, to prevent water access to the fuel rods, to reduce or prevent radionuclide transport and in some cases, to strengthen structurally. And, one additional feature that came through here, which was the reduction of radiation fields, which for the most part is the pre-closure handling of the waste package. But in some cases it also influences the near-field chemistry post-closure.

Then there were a number of things that we heard that I would refer to as system considerations, backfill materials that go outside the canister, which were to reduce corrosion by controlling the chemistry, or to reduce the radionuclide transport, or to reduce the access of water to the waste package itself. Bore hole liners, another topic, part of what I call system considerations, to prevent bore hole spalling and the effects that it can have on the waste package, to channel flow, or in some cases to contain the buffer material or the backfill material that would be present there.

We heard also of overpacks, systems that can be used on top of the waste package to further prevent the access and ingress of water to the waste package. We heard of gravel diversion of water transport away from the waste package to keep it dry. Similarly all of these are under system considerations. There were heat pipes to take the heat away from the waste package and create an area of hotter temperature for a longer time. Again, the ultimate aim is to prevent the access of water to the waste package.

And, a number of people raised questions, do we use bore holes or don't we? The mine drift itself might be the appropriate location in which to put these waste packages rather than continuing to consider bore holes. It brings you to the point of saying, okay we've got this large collection of features, how do we evaluate them. Do we evaluate them individually, case by case? Of course, that was the process that we undertook here, which was to discuss each and every one individually, and yet it's very difficult to do that. In many cases, one could consider that a number of these could be used in conjunction with each other; and therefore, in combination one could consider putting in gravel drains, having two or three walls and putting a filler in, etc.

So, the question of how do you do this, how does one come to some approach or solution, I think is a very important element of what we need to go away from here with. I will put forth what I think are just two issues that need to be considered in order to make these kinds of evaluations.

The first one is to evaluate performance, and you do this by performance assessments. And, I'll talk a little bit more about how that might be carried out. But, basically you're constructing a performance assessment in order to develop a license application. There are a number of other reasons for that performance assessment, but that's the eventual goal.

Second feature that I would put alongside that is system cost. And I underline the word system. In many instances we heard what the cost might be for a particular canister or a particular waste package. In some specific presentations we heard a little bit more about system cost, but system cost becomes a vital feature just as Sam emphasized in his presentation. Perturbations or changes in the system in one aspect can cause significant changes in another aspect. George Danko (Marvin Smith) did that in his presentation, where he talked about the self-shielded container, or self-shielded canister system, and he said, I don't want to put this in a bore hole. I want to put this in the drift. And, as a result of that I have a cost change because I don't have to drill bore holes now. I only have to drill drifts, and not only that, my drifts don't have to be as large because I don't have to put this in the vertical role in order to get it into the bore hole. That's the system kinds of costs that need to be analyzed.

There are other aspects that I would call secondary that are still important parts of how you would evaluate these various techniques that have been suggested to us. Public acceptance is one that has been bandied about in a variety of ways. There is the public that lives in Nevada, that includes the Governor and a few other people. And we have seen that that's a very effective public. The Governor and his troops have been very, very effective in causing work not to occur. I think the Governor and his troops can be and will be influenced by public attitude. We've seen some changes in the public attitude in Nevada, which tends to be in the right direction for those of us who are in favor of a repository, and I think they will influence politically what happens. So it's important for us not to isolate ourselves from that, but to be very involved in that whole prospect of how do we influence the local public.

The second public that Sam also alluded to is the general technical public, not just those of us who are in this room, but the general technical public who will, at times, say "ten thousand years, you've got to be kidding." And, you know, I think a lot of us in this room would echo that, ten thousand years, you've got to be kidding. And yet that's a part of what we have to consider when we consider radioactivity that's going to last for ten and more thousands of years. So, public acceptance is an important integral part of what we have to do, but I still would put that secondary.

Another secondary important part of all of this is the R & D needs. We heard a variety of levels of presentations, some with a fair amount of data to back them up, particularly data that would be applicable to the site at Yucca Mountain. Others in which there was essentially no data that would be applicable, and yet some very creative ideas about modern materials and other things that still might have a glimmer of hope. I like the way that David Shoesmith classified those various aspects of lots of data applicable and new materials, the sort of space age materials. It's important for us as we look at these to determine what are the R & D needs. Is it possible that we could take these new materials and make them applicable? What kind of data would we have to collect together in order to do that?

So, at this stage we really need to start making comparisons on the equivalent basis. Probabilistic approaches are certainly the appropriate ones in my mind to identify these functions and to inter-compare them. We need to consider scenarios and their likelihoods. And, all of this leads us to the CCDF approach, the Complimentary Cumulative Distribution Function that has been the EPA approach. And, that certainly would be the one that I would advocate in taking any one of these. It's very easy for us to talk about the corrosion allowances in this particular package and in another particular package. Yet from a systems point of view, that doesn't do it. We can't just talk about the chemistry. We can't just talk about the corrosion allowance. Eventually, we have to get to the whole point of what allows this site to be licensable. And, what allows this site to be licensable fundamentally is the release of radioisotopes that control release.

And it's important to remember when we talk about a thousand year package, a ten thousand year package, whatever you talk about, the rules for the Nuclear Regulatory Commission do not say total containment. It's really controlled release. That is permitted appropriately by the law. This is different than hazardous waste, and we need to take advantage of that to whatever extent we can. It's controlled release. It doesn't say put this stuff in a box so it will never come out.

So, to echo a little of what Ian Miller said earlier in his comments with regard to modeling, that's where I would start in making an evaluation, and my charge to DOE is just that. We need to take these various proposed ideas, many of which have creative elements and consider them. First of all there is a basic design that Lawrence Livermore has presented to us, and now look at the effects of these various other options. How do they compare with the basic design. And you use modeling as a basis for this.

We've heard, all of us, about the various limitations of modeling. We're never going to get an accurate model. Of course not. Modeling to me is a lot like corporations which have strategic plans. Any wise person in a corporation doesn't believe his strategic plan. His strategic plan is not there to chart the future. His strategic plan is there to go through the exercise of charting the future so that when something happens, which isn't in your strategic plan, you know how to respond to it. I consider modeling in the same way. We're not going to be able to model all the aspects of everything that goes on, but it gives us a common base to say, here's where we are, here's where sit, here's where we think the important scenarios are, the important interactions, the important mechanisms that cause this system to degrade. Now, we do our best to model those and we use that model for a couple of purposes. Right here, we can use that as a purpose for inter-comparing the various techniques that we've heard here. Otherwise, I find it extremely difficult to compare.

Secondly, we use them for determining uncertainties. Uncertainty is a vital part of what we do. Everything we do will have uncertainties and we need to quantify it. And, that to me is one of the things that you need to do. You need to make use of experts for it. Experts don't so much know about what's going to happen in the future, but experts do have a sense of uncertainty. And, when you get a group of experts together in the room, my perspective is that the attempt is not to drive them to consensus, but it's to get a sense of what's the difference of opinion, because there will be a difference of opinions.

There are a variety of models that are presently being used to predict how this system is going to perform. Those varieties of models are advantageous to have. I think we're not at a point where we should be driving towards a single model. By having a number of different models, this gives us a sense of the uncertainty in the kind of calculations. They use different mechanisms. They use different sub-models and so on.

It's also important that we have different levels of models. There are very detailed models that have been developed very capably by people in the various national laboratories under contract to DOE. There also needs to be upper level overview type models, ones that do quick and dirty calculations. It's very difficult to take some of these creative applications that were recommended to us and say, okay we're going to do a very detailed analysis of this. We've got to get the corrosion allowance. We have to understand the chemistry, etc. There have to be opportunities to doing quick, overview models so that you say, okay I've got thirteen, fourteen new techniques here. Hey there's three that look pretty darn good. I plug them in my model. I run them out, and boy it's reduced. There's something very significant out here.

That brings me to my next point. We were asked to evaluate whether we think we can have a system that lasts ten thousand years. I happen to think that's the wrong question. It's not clear to me why we want a system to last ten thousand years. I haven't seen a performance assessment that suggests to me that we have a radioisotope that's going to be released at ten thousand years that needs to be contained. That's my way of saying let's look at performance assessments and look at radioisotope releases. When do they come out? Do they exceed the EPA standards? Yes they come out at eight thousand years and it exceeds the

EPA standards. Then we have a strong basis of saying we need a long-lived package, because we have to assist the geology and they need to work together. Just to say we want more confidence to me is not a sufficiently strong basis. If a thousand year package, together with the near field and the far field geochemistry, do the job of containing the radioisotopes so that the release satisfies standard, why go any farther? Why spend anymore money, etc.? So, I think that, to me, is the very first question. Can we do it? Probably. It's all in a probabilistic sense. One could take any of these packages and do probabilistic analysis on them and predict what the lifetime is going to be.

It's important through all of this to have a very flexible kind of approach to this. People built nuclear reactors starting thirty, forty years ago. One of the questions that was raised with us is how robust is this system going to be. I don't think there were too many people who thirty, forty years ago thought that the nuclear reactor system was not going to be sufficiently robust, that the steam generators wouldn't last for the entire lifetime of the reactors. Some of those steam generators go through the hatch with only like a half an inch clearance. Nobody thought we were going to have to take them out. People early on would have said, you've got to be kidding, if that doesn't work shut the plant down and we'll build a new one. What happened? We take them out. We replace steam generators. Nobody would have thought twenty years ago we were going to do that.

I think the same kind of flexibility has to be a part of our thinking now. It's not just today's technology. It's the future technology. So, I'll take it one step further. Pressure vessels in nuclear reactors have come under fire recently because of the neutron degradation that takes place in the system and the potential for cracking. The Russians have a much more serious problem with that than we do because their core is closer to the wall. The Russians have now annealed the pressure vessel in ten reactors. In one reactor they've done it three times, and they do it in a very brief short period of time. When the need is there -- we would never have thought we were going to take everything out of the core and we're going to get in there and with the high radiation fields we are going to be able to anneal the vessels. We've done it.

I think a lot of consideration has to go into the designing of these waste packages as well. When I say we've done it, I recognize the U.S. has not yet annealed a pressure vessel, but others have. Certainly we in the U.S. are considering it. But there are going to be new technologies and we have to have designs, and just our general thinking that allows us to consider the new technologies and the other options. It's been mentioned that the NRC rules, be they what they may, and the EPA rules, be they what they may, are inevitably going to change. Most people say it will probably get stricter.

But as we've gone through this whole analysis, the presentations we've heard over the last few days, for the most part I've only heard one radioisotope mentioned, Carbon 14, gaseous transfer. Nobody talked about plutonium. Yet the NRC analysis, they did one performance assessment. They highlighted plutonium and it's transport by colloidal mechanisms as one of the key ingredients. Well, if we're designing a waste package, why aren't we designing it for the particular issues that are being raised by performance assessment. That's, I think, the direction that we should be taking.

It doesn't need sophisticated and detailed analysis in order to carry out these kinds of, at least, preliminary assessments. The EBS is part of the entire system and must be properly included in an entire systematic analysis, and that would be my primary emphasis.

Again, I do want to compliment the presenters. I think we had an excellent set of presentations, and you can just see the stimulation. Yesterday afternoon I was amazed to look out in the crowd. Here at 4:30 or quarter to five people were still hopping up to the microphone. Hardly anybody had left. The evidence is there that so many of you who came are still here, still involved in the discussions, and I think this shows where we should be.

Where do we go from here? In my mind what we do is take a simplified model and we analyze what are the needs of the engineered barrier system. What are the radioisotopes that are being released. When are they being released? Are they above the EPA standard? Are they going to give us problems when we get to licensing. Then, looking at those needs for this system, we can then take the various techniques that have been proposed here and say, in a simplified model which of those begin to address the particular needs that performance assessment shows are important ones.

My key message is, let's get on with it. It's time to go. Thank you.

YUCCA MOUNTAIN SITE CHARACTERIZATION
ENGINEERED BARRIER SYSTEM
CONCEPT WORKSHOP
JUNE 18, 19 AND 20, 1991

PRESENTATION BY: DAVID SHOESMITH
TAKEN FROM TRANSCRIPT OF SESSION 3: JUNE 20, 1991

Being of English descent, I --

(Laughter)

I'd like to thank Bill Clarke for inviting me to take part in this particular workshop. It is indeed an honor to be classed as an expert. When I look around the room at all the people present, I realize that I'm the only expert here that I've never heard of. So, let's hope that's a compliment to one.

There's been a lot of complimentary comment given to me about the Canadian program, and I just wanted to address, before I get into a few specifics, a couple of points.

Yes, we have decided on two concepts. We had a nice easy situation, and I recognize where people like Marvin Smith came from yesterday. We're actually in bed with the one utility that has nuclear power or that has many reactors. So, we have a program which is jointly funded to start with, which means it's very easy to focus on because if you get too far off line, guys came at you from left field and tell you what the problem is and they keep you on line. So, it's a lot easier for us to concentrate our efforts.

Like any couples in bed together, there are magic moments, but there is also a big potential for argument. In our case we didn't have a lot of money under the mattress anyway. So, we made decisions eleven years ago, which are reflected in the models that we've developed and which we're going to try and put forth to a government review in the next couple of years. The government review is slipping a little bit as they always do in Canada. If in doubt, start a royal commission and blame it on the Queen.

(Laughter)

But whatever, we do have two concepts, and -- to concentrate that has helped us, and I would suggest, given the number of concepts that I've seen here, that a similar kind of concentration could prove a large number of the concepts. As the past speaker just said, there's a warm feeling about a lot of the concepts, and it's my opinion that a lot of them would actually work if you ever got the time to spend the ten or eleven years on it, or if you work harder and do it shorter and use the past experience from the Swiss and ourselves, it would take you a lot shorter than that. The problem is, are you going to concentrate on it, and it's not clear to me that you are.

Just to -- now to address the questions. The question posed was, "do I think or do we think that a barrier potential of ten to the fourth years is possible", and I would say, yes it is. If you were to ask me do I think that any scientific or government review group would accept what we say about whether it is possible, I would say probably yes. If you were to ask me, do I think we need it, I would say probably not. And, the reason for saying that is because when you get to the final assurance you have two things to assure here. You have an engineered barrier, or you can knock it down to many little barriers, but you have an engineered barrier system and you have a geosphere. And to those of us that talk engineering, we talk tens to hundreds of years or hundreds of years to hundreds of years, but to those people that talk geological time frames don't' talk in those kind of time frames. They talk thousands to millions of years. And, I would suggest that the really long term barriers are always going to be the geosphere barriers, and it's going to be easier to quality assure them, which is not to say that I don't think we should go ahead and try to design a ten to the fourth year container.

Okay, let me just try and illustrate with a story what I think the problem is with this kind of meeting and why these kind of meetings go on for awhile, time after time. Canadians are pretty quiet guys most of the time. They like to sit back and reflect. They don't say very much until they've had about six beers and then it's another matter. So, we're very reflective guys. So two Canadians decided, okay, let's have a party. So, they go down to the local liquor store and they buy the biggest bottle of rye that they can find. Then they go back into the log cabin -- it's summer and the igloos melted. They get in there and they get three logs of wood. They put one in the middle with the bottle and with two little shot glasses, and they sit on the logs around it, and they pour a couple of glasses of rye. One guy picks up his glass and he says to the other guy, "here", and the other guy slams down his glass and says, "listen, you want to talk or do you want to party?"

(Laughter)

I would suggest it's time for you guys to party.

(Laughter)

Let's get on with it and get into a concept. I have a second little story which is --

(Laughter)

I always like to find one empathizer -- but --. I have a second little story which illustrates another problem with the issue. This was told to me by a Russian. Russians are humorous guys some of the time. You've got to be like that to live there to start with. He was telling me that they used to have no jokes about Gorbachev, but they used to have a lot of jokes about Brezhnev, which would surprise you because you imagine Brezhnev was the kind of guy who would have shot them if they cracked a joke. Referring to that he was a radio comedian and all this kind of stuff --. They told me this little story about Brezhnev opening the Olympic games when they were in Moscow. He was the kind of guy that liked to read his speech. So he picks up his speech and he goes "ooooo - ooooo". Then his assistant says, "Mr. General Secretary, turn to the next page. Those are the Olympic rings."

(Laughter)

The motto is don't -- you guys seem to be bogged down in regulatory limits and things that are conditioning your program, making it very difficult for you to get to page two. So, I guess the point is, get on with it. And it's perhaps not fair for me to say that because we do have an advantage, it's more money and a coordinated effort.

The two concepts that we have, which I think I should just mention, what our present predictions are, because I think it reflects on what I'm going to say -- we have two. The referenced container is Grade 2 Titanium. We think it's a material that we can do corrosion experiments on. We can predict the slack time. We're reasonably confident that we can get somewhere between 1200 years and 6000 years, and the distribution reflects what we think the distribution and the certainties in the input data are. And we can see that some of them will fail early, even as early as 200 years. Some of them, you just can't guarantee they're going to last very long. You've got 130,000 containers, statistically something is going to go wrong.

The second option we have is copper, and we're reasonably confident that we can guarantee minimum life times around twenty to thirty thousand years. Remember our vault is reducing, not oxidizing. And, the spread would be from around twenty to thirty thousand out to ten or eleven years. Well, ten or eleven years is ridiculous of course, but again, the distribution or as many -- of fragments should reflect the uncertainty of the input data that you put in. But the end of the distribution you're concerned about is the low end of the distribution.

So from our point of view, if you would say you believe you could get a ten to the fourth year container, it's obvious what we would say. We would say, well okay we're confident with copper which we think has simple corrosion processes and predictability. We're not so confident with the corrosion resistant material, which we think will have localized corrosion processes and not be so predictable. However, we wouldn't like to drop titanium because we think the potential is there.

Okay, let me go on to another point, and we'll use another analogy. This is how I envision the program down here. I apologize that this is starting to get a little on the repetitive side, but Canadians only know one analogy. Americans only know baseball or football analogies. We only know hockey analogies.

I consider this kind of program to be sort of like a power play in hockey. You've got the attacking team around the outside and there's all kinds of guys. The guy here called retrievability. There's one here called monitoring, and one here called storage for ten to the fourth years. There's one here called storage for a thousand years, and one here called storage and disposal, which is something that has to come one day, an integrated concept from the reactor site to disposal. And then we have the goalie. Because we're desperate and we've got a -- called new materials sitting out in the wing here. Our problem is or the ultimate goal is to get a score, find the ultimate model or the score. Unfortunately, regulating committees have got a big fat goalie with big white pads and a huge glove. Not only that, they have a ruling that says the guy with the puck is not allowed to shoot.

(Laughter)

And these guys hanging around here, these project managers, can skate like hell.

(Laughter)

From the scientific and technical point of view there are two things here. All these guys want to score, but it's not possible for everybody to score at the same time.

Now, I would suggest there are too many factors on your program. If you're going to have monitoring, you've got to put something right in there, a lead which breaches all the barriers that you're trying to use. You automatically introduce the pipe line, if you like, from the waste form all the way out. It's not easy to have this here if you want this. It's not easy to have this here because you've bleached some of the problems like how you design the container, where you leave -- out and all the various other kinds of things. It's not easy to have this if you want this. It's easy to have this if you want this, new materials.

Because yours is an open-ended program with concepts still on the table, it's easy to keep coming up with new ideas, and some of them are very good, very bright. And there's some great materials, but they're not going to score this year. This is a five minute power play. They get a chance after 4-1/2 minutes, but they're not going to score in the first minute. And again, these guys out here are long-range shooters. So, I think it's impossible for you to satisfy all those requirements within one concept.

Okay, what I'd like to do now is just take a little look at the difference between our repository and the one here and see if that suggests any difference in the way you should approach it. And, I'm sure there are a lot of people out there who thought this through in a lot of detail.

(Interruption)

Are my twenty minutes up? I'll take Milton's time. He's had lots of my time.

(Laughter)

There's lots of differences between them. I'm sure there are people out here that thought this through, and this is not necessarily meant to be anything except stimulating. The big difference is that in a way yours goes from benign to not so benign because it goes from dry to wet and it's always oxidizing. Ours, once the damage function goes the other way, it's oxidizing and warm in the beginning, though not as warm as yours, but it should go reducing. So, in the long term we're perhaps a little better off. In the short term, not so well off. In the long term we're really not better off because yours doesn't have much water flowing through it. The pathways to nuclide transport are very small or very short.

So, I would say that the long term, or the intermediate term, in yours is poor because of high temperature and oxidizing conditions. I didn't measure them. In the long term, for ours, it's a little bit better. Radionuclide transport has got to be highly unlikely in your situation. There's not much water going through there. It's only going to move with water except for the gas. In our case, we've got a lot of water going through it. And that's the reason why our regulatory organizations aren't so keen on our reducing model, and why the question of a ten to the fourth year container is addressed to ours. Can we cover up the deficiencies in the geosphere model by elegance in our engineered barrier system.

I would suggest that you have it easy for your thousand years. It's easy for you to justify a container for a thousand years. That's a difficult point for us. We've got to get over that first thousand years. I think it's a little easier for us to get this type of criteria than it is for you because we go reducing.

I'd just like to make a comment also about the multi-barrier concept. There have been a number of concepts here which are multi-barrier. There's been one or two which are monolithic. Now, I have a preference for the multi-barrier, which is not to say that monolithic won't do the job. The reason I think is the following: I think there are certain conditions the way we think. If you have a single monolithic barrier, which is very very thick, and to take -- now this is very schematic -- look at your failure function, the function of time, then eventually it's going to give a long term here. But, it's going to give you a relatively fast -- not relatively fast, but a distribution of failure somewhere down here which may be narrow, and the radionuclide release is going to climb with it.

The one thing the multi-barrier system does for you is align and spread all that out. You may have to concede because you're relying on thinner barriers with potentially catastrophic events. There's going to be a few problems in the early states, but the distributed output of one is the distributed input of the next part of the next barrier and you should get better in distributing as you go down, which means you get maybe a little bit of early release but not so much late release. What you've got with a multi-barrier system is the ability to fine tune both scientifically and politically. When the regulators or the scientific review boards come to you and start querying you on one barrier, if you have more than one you've got an option to change your mind and shift the emphasis of the discussion somewhere else. Well, that's the scientific and valid way to do this when you're doing it on the basis of uncertainty.

(Laughter)

It also has a political advantage and I won't dismiss it. Here you're buried into forcing someone to believe that your one single barrier is as good as you say it is, and I don't think that's easy.

I'd just like quickly to address the question of the choice of material because I think it has an impact on a number of things. There are three possibilities currently on the table. One is corrosion allowance, which I suggest has public warmth. These are things like iron, lead, copper, and stuff that we know a lot about, so everybody feels fairly confident. We could point to a natural analog in some cases. They should be uniform in their corrosion properties, though there is some problem with films when you start talking uniform corrosion. So, everybody feels a little warm about it. And, you would suspect -- certainly we would in our environment -- that ten to the fourth years is a good idea.

The problem with corrosion resistant materials is that you have scientific skepticism. The whole corrosion world out there says, listen we've spent thirty, forty, fifty years trying to understand localized corrosion. You're going to tell us you could model it for a thousand years. So, there's a lot of skepticism here. I think that condition is both in the experimental and modeling approach and I don't think that we should be put off by the way the scientific community necessarily thinks. A thousand years is relatively easy here. Greater than that, there's a little bit more of a problem.

New materials, I would say they have great expectations. If you'll allow me a pun which is not too derogatory, it's hard to out-grade expectations when you don't know what the dickens you're doing.

(Laughter)

That's not a cynical comment. It's a comment that says we have new materials. They potentially have long-term barrier prospects which far exceed some of these other kinds of materials, but we don't have enough data to justify some of their selection.

That really conditions what you do. If you're going to have a model which is required today -- if somebody decides you've got to have this in place within a year, you're going to go this way for ten to the fourth years. You haven't got any choice. You're going to go to the monolithic iron, or you're going to go to copper, or you're going to go to copper with lead, or lead inside something else, or something that we can assure right now. If they're going to ask you for a model in a few years, then you can afford to look at both. If you've got an open-ended some day requirement, then the new materials are still on the table. So, in a way it depends on, are you going to concentrate on tomorrow? Are you going to define a time scale like we have to justify our concept by 1993? I would suggest that completely rules out any option over here. We're willing to take a risk on corrosion allowance with titanium, but not without backup from a having a model here. I think what conditions, in a way, how you choose your material is when you think you're going to have to answer some of the questions.

I'd like to make a couple comments about corrosion in the Yucca Mountain environment. I find it hard to envisage that it won't be localized. If you only have moisture and it's not flooded, then what you envisage is that you get condensation. Whatever it is, it sounds to me like differential aeration on whatever material you've got there. Then you have an experimental and modeling justification problem. I would suggest, based on our experience, and I'm sure there are lots of people here to back that up, that really conditions what kind of process you think there's a possibility of modeling. And, I would suggest that stress corrosion cracking is right out of this game. If you have a material that is going to stress corrosion crack in the environment that you've got, then rule it out, because I think prediction is impossible. I don't think it's impossible in a reactor or in twenty or th: y year time scales. I think that's quite possible. Bu we can't measure crack rates -- that well, and you need to have a pretty good stress analysis of your container which is a finite element calculation with many elements, which is not a simple thing to do. It's going to concentrate stresses. You've got quite a large problem of prediction here, which is combined with mechanical, chemical and electro-chemical, and it's not easy.

If your material is susceptible to pitting --. A pitting is a process which is difficult to accelerate electro chemically, but can be done. George Marsh tried it for Carbon Steels in England. What he came up with was a distribution which was unlimited. He suggested there was always a fine line possibility for fast pitting propagation. In fact, it's not supported by the general observations on pitting, which either broadens out and becomes shallow or the aspect ratio decreases with time. So, acceleration is difficult. It's experimentally easy to look at pitting. So, I would suggest if you're pitting and you're concerned about it, you have to do a statistical evaluation of what's available. It's not easy to get new data on the time scales we're talking about.

However, there is some data available. It's a general knowledge of the process. I wouldn't rule out the material if it necessarily pits, though I would suggest that you'll have a difficulty in getting reasonable data and you'll be forced into statistical analysis.

If your material crevice corrodes, it's our experience, and this is not the place to go into defending our own approach, that you can accelerate it. We think it's either activation controlled or transport controlled by oxygen supply from the outside. The internal environment of the crevice is driven from the outside. We think that you can accelerate that by galvanic coupling techniques or by electro chemical techniques.

The problem is the mode of penetration. With pits it's easy to get a statistical distribution of pits and look at the depth as a probability analysis, and use a probability analysis as a function of depth and time. It's not so easy with crevice corrosion because it's not clear how it's going to propagate. Is it going to be deep and shallow? Is it going to be wide and general? So, you have an experimental problem of justification of the mode of penetration. And, I made a remark yesterday or the day before that corrosion rates are okay, but really you've got to have a look at penetration rates as well, because the penetration rate does not necessarily equal the corrosion rate.

I can induce cracks, and the reason I've put this up separately from stress corrosion cracking is that it is a potential problem with titanium. We don't think it will happen. It's like stress corrosion cracking. You can't predict how fast it's going to be once it goes. The only grace you've got is if you need a lot of hydrogen to get it going, you've got some leeway of prediction in predicting how long it's going to take to get the hydrogen in there, and that's our saving grace in the model for titanium. It's also the reason we're not willing to go beyond a thousand to six thousand years.

BY HOLMES BROWN:

About two minutes.

BY DAVID SHOESMITH:

Okay. I'm going to have to rush.

BY HOLMES BROWN:

Okay.

BY DAVID SHOESMITH:

For the ten to the fourth years to be justified, I think the quality kind of scenario is required. You've got to limit the scope based on susceptibility measures. You've got to get out -- and this applies not just to here -- it applies to all of us. You've got to stop people from second guessing you on microbial corrosion and everything else and decide what's going to happen and get on with looking at it.

If it's localized, I think you've got to take initiation for granted. It's an statistical, unpredictable process that didn't start day one. Are you going to guarantee it's not going start after a thousand years. I think this is an impossible prediction within the frame of a waste management program. So, you would experiment on propagation, determine the variables that control the rate of propagation, and then start from accelerated conditions, change the variables to find out the conditions under which propagation will or will not go. And if your results are unacceptable, then you have to reiterate and redesign your vault, for which you have to take into account perhaps barriers like the gravel one that we talked about yesterday. If your answer is unacceptable, an engineering redesign is obviously in the cards.

Just quickly, to amplify on this point, starting from accelerating conditions, I'll just give you two pieces of data that we used. The top plot shows a crevice current as a function of time in a galvanically coupled -- it's not galvanically coupled. We have a crevice and a -- of a similar material externally coupled to simulate a small crevice with a large -- and you can follow the current -- through that. And, you can assure yourself with a lot of weight change measurements compared to charge measurements that the current does reflect the crevice corrosion rates, so it's not an easy state to get to. So, you initiate crevice corrosion and current flows and you've got a certain amount of oxygen in the system, the potential goes from positive to negative because the system is going from inactive to active. You change the oxygen concentration in steps in your experiment. This was at 95 degrees. You see this thing step down, telling you it's still in an active region. Eventually the oxygen concentration gets full enough and the current starts to die, and the potential starts to go up and it starts to repassivate. You also notice I show a lot of changes in the spread of the noise in this system. The noise tells you a lot about the microstructure of the material.

So, here's an experiment which gives you a threshold or some idea as to how crevice corrosion rates will evolve as the system goes from oxidizing to reducing. Experiments of that kind are essential. What it means is you've admitted there might be a problem. You've demonstrated that there are limits as to how far it can go. I think that's an assurable situation as opposed to trying to deal with initiation.

If I'm running out of time perhaps I should speed up or let go. The rate of hydrogen pickup, if you do it as a function of potential on passive surfaces, you've got to get the negative potential and extrapolate back. This is where a passive corrosion potential would sit with titanium in our environment. This is a big enough margin that you wouldn't be worried about passive pickup of hydrogen. Five year experiments say we can't find any hydrogen pickup. Unfortunately, when you're crevice corroding, you're in an acidic environment inside the crevice, you pick up hydrogen while you crevice corrode. So, you have a problem picking up the hydrogen from the second corrosion process while the first one is going on. This is a difficult process to model, and we haven't gotten too far with it.

I'm getting towards the end. It'll only be another minute.

BY HOLMES BROWN:

Okay.

BY DAVID SHOESMITH:

Finally, I think it's essential to spread the modeling over the whole vault, the statistical distribution. What you've got is a vault which has a statistically meaningful population of failing containers, and we should use that. Just because one container fails early does not necessarily mean they all are. And, this is the only way to handle evolution of vault conditions in a way and that is to have distribution over the whole population. And, finally, it's very easy for us because we sit next door to the people doing this kind of modeling. And, we sit next door to the guy doing this kind of modeling to integrate and go through an beginning process of vault redesign and building the radionuclide models, and then deciding whether they affect this model. And, you go through an beginning model build up process. It's not so easy here where there are so many organizations involved.

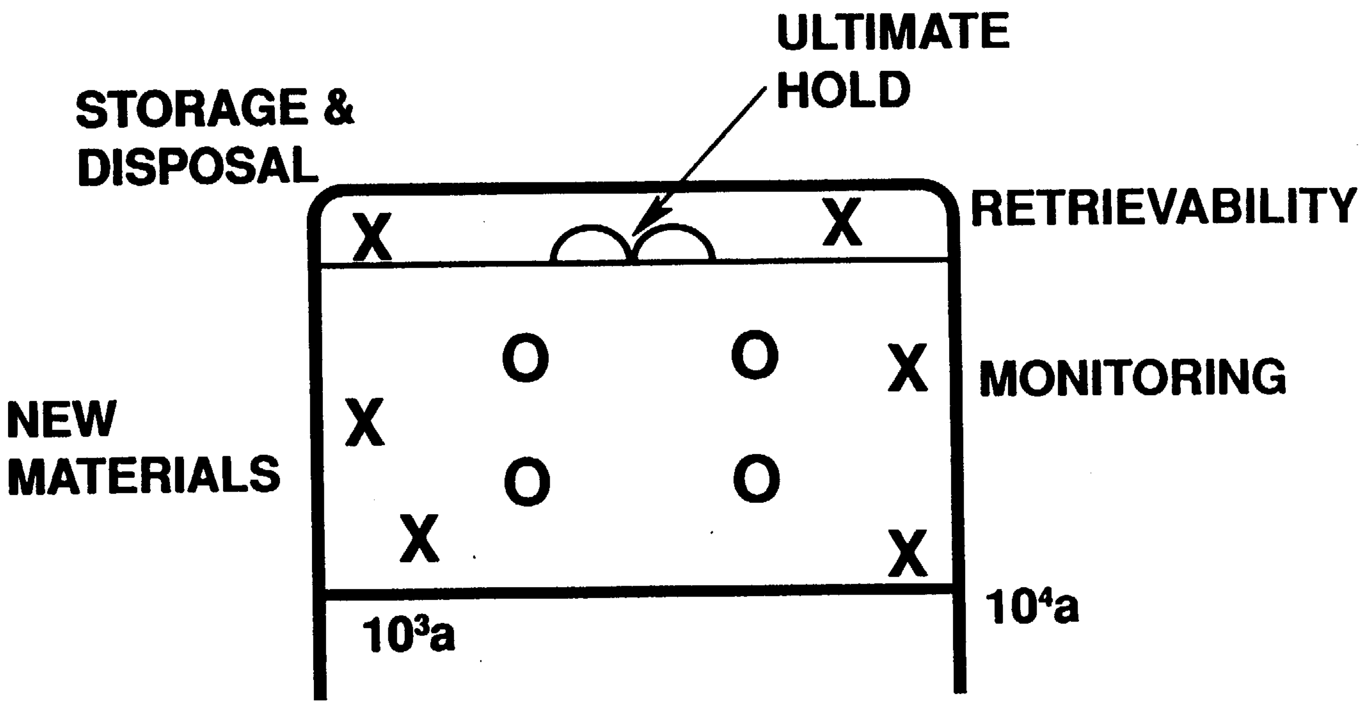
Finally, things to beware of: The major corrosion process may change as vault conditions evolve. To us this wasn't as apparent when we started it as it is now. Our -- conditions go reducing with time, which means they are less likely to get crevice corrosion and more likely to get hydrogen induced cracking. It's not easy to handle that switch in a model. Beware of life time predictions greater than ten to the sixth years. It says you should reevaluate all other failure modes, which includes mechanical and corrosion. If you're going to predict crazy lifetimes, you're effectively having to admit that maybe you overlooked something. So, there is a limit I think to how far a predictive model can go just based on that kind of rationale.

You should check corrosion rates against penetration rates. That's a point I made earlier. I am just schematically showing you that. General engineering says that you have a wall thickness with a certain corrosion allowance. Your general corrosion front may be here. Your penetration front may be quite a way in front of it. These things do not penetrate with a single well-defined front.

An individual penetration going through your corrosion allowance is not failure. If it gets through here it is failure. The general corrosion front going through the corrosion allowance is failure. So, there are a number of definitions and some uncertainty as to what failure means. Use it to distribute the failure times.

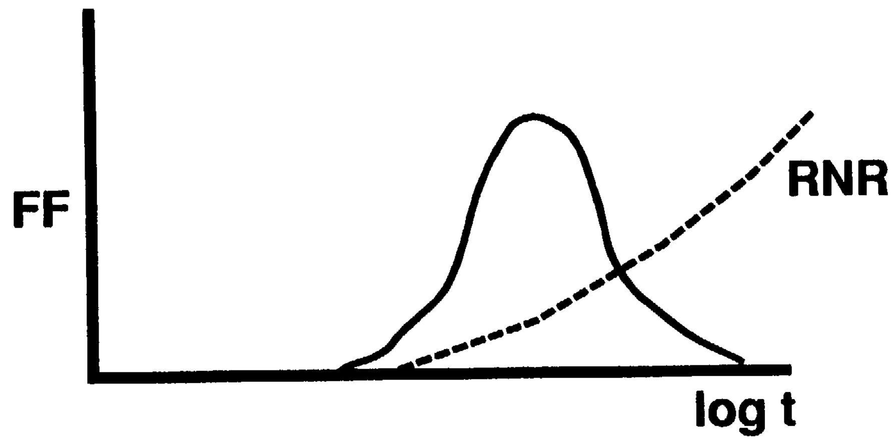
Two final portions; overly complex models. By that I mean complex, not mathematical. Mathematics is just the tool-like experimental approaches are. We shouldn't be concerned that we have mathematical complexity. But if you have conceptual complexity then you're already beyond the point of making an intelligent layman understand what you're doing, and that's not going to be easy.

Finally, over-reliance on the natural analog. Somebody else made the point yesterday. I can't remember who it was. The natural analog just shifts the burden of prediction from your system to the natural analog. These are very good to use once you're on the right track. If you can show that your conditions agree with this, that's fine. But if this is your only rationale, you're in trouble. Thank you for your attention.

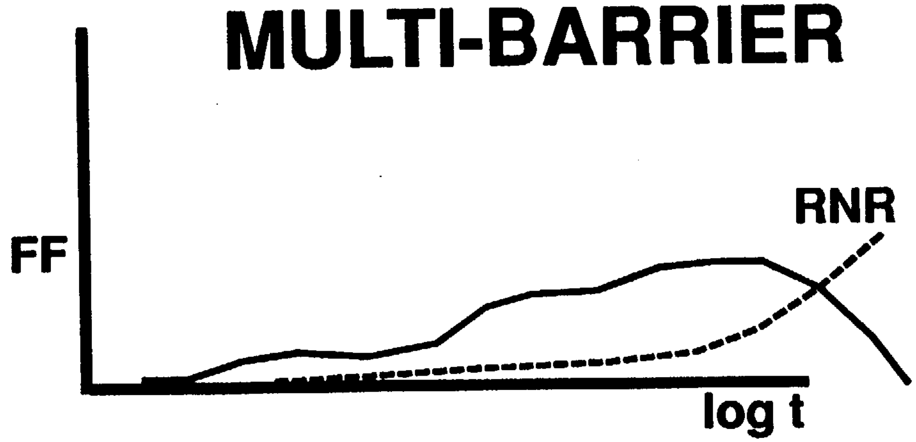


IT WILL BE ALMOST IMPOSSIBLE FOR EVERYONE TO SCORE

SINGLE MONOLITHIC BARRIER



MULTI-BARRIER



- MULTIBARRIERS ALLOW FINE TUNING AND STRATEGIC RETREAT
- POLITICAL & SCIENTIFIC DEFENSE IN DEPTH

CHOICE OF MATERIAL

CORROSION ALLOWANCE (CA)	CORROSION RESISTANT (CR)	NONMETAL (NM)
PUBLIC WARMTH	SCIENTIFIC SKEPTICISM	GREAT EXPECTATIONS
$> 10^4$a	$> 10^3$a	LONG TIME

↑

IF MODEL REQUIRED TODAY: CA

IF MODEL IN A YEAR OR TWO: CA,CR

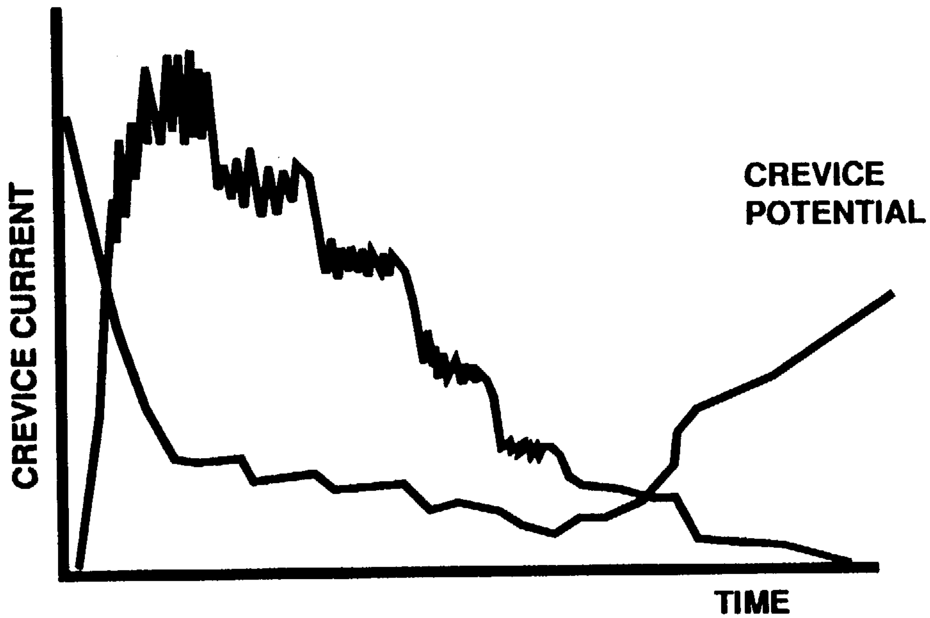
IF MODEL REQUIRED SOMEDAY: CA,CR,NM

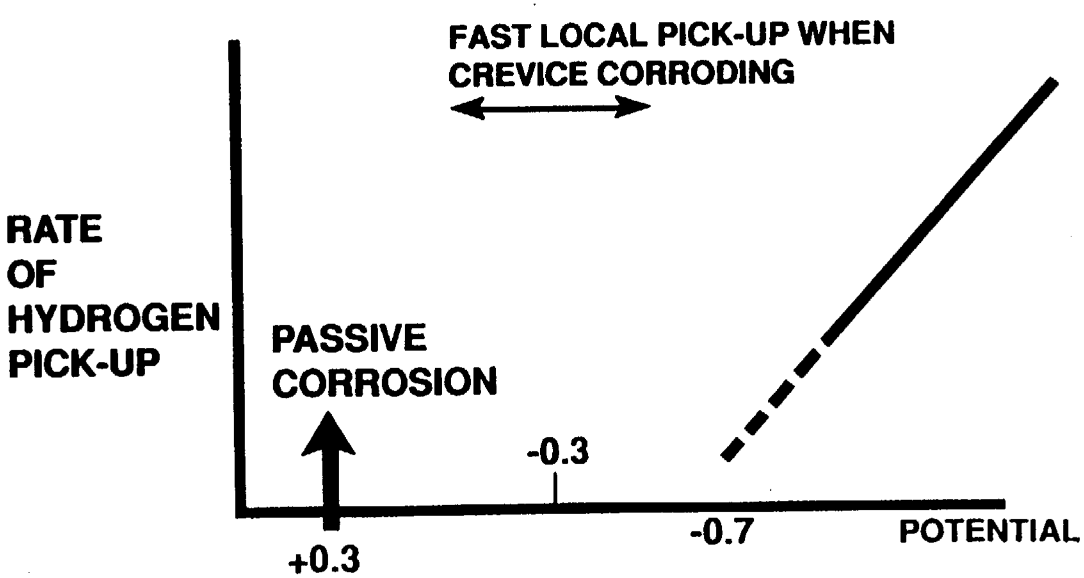
LOOKS LIKE LOCALIZED CORROSION COULD PREDOMINATE AT YUCCA MOUNTAIN

EXPERIMENTAL AND MODELLING JUSTIFICATION A PROBLEM

- SCC
  - PREDICTION IMPOSSIBLE
  - STRESS ANALYSIS
  - CRACK RATE MEASUREMENTS DIFFICULT
- PITTING
  - DIFFICULT TO ACCELERATE
  - AMMENDABLE TO STATISTICS
  - WELL STUDIED
  - SOME DATA AVAILABLE
- CREVICE CORROSION
  - CAN BE ACCELERATED
  - MODE OF PENETRATION DIFFICULT TO ASSESS
- HYDROGEN-INDUCED CRACKING
  - LIKE SCC
  - SOME GRACE WHILE WAITING FOR H ABS.

WKSHPEBS 122/8 1 91





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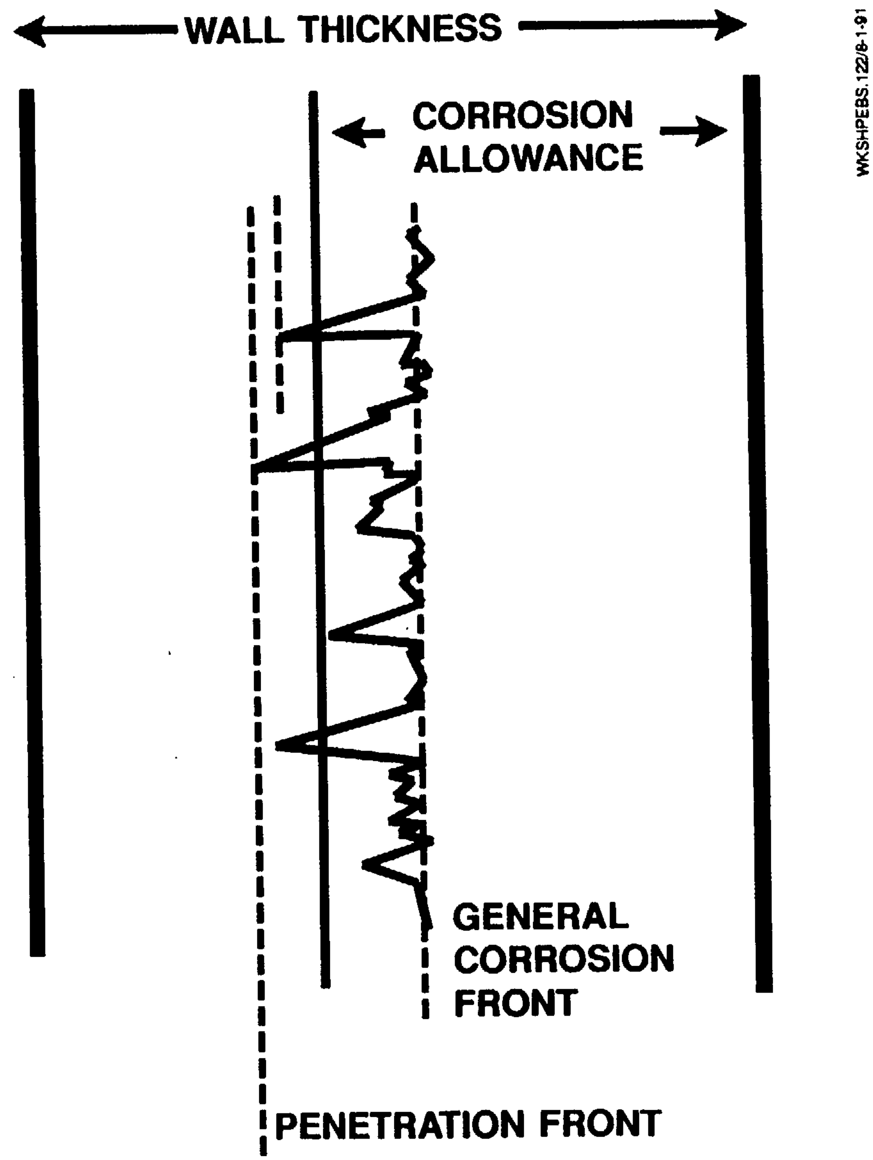
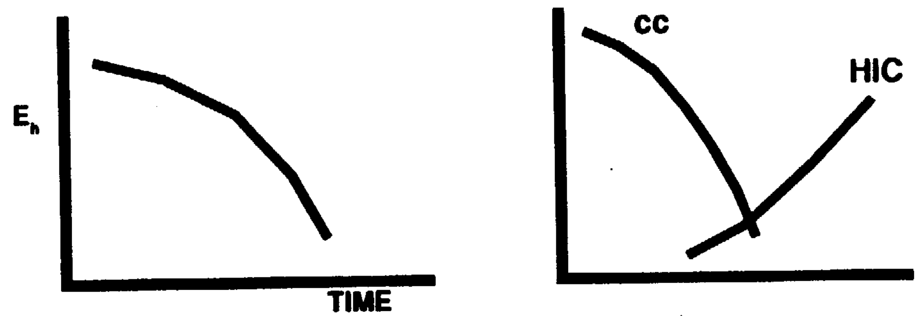

WALL THICKNESS
CORROSION ALLOWANCE
GENERAL CORROSION FRONT
PENETRATION FRONT
WKSHPEBS.122/8-1-91

IF 10^4a TO BE JUSTIFIED

- LIMIT SCOPE BASED ON SUSCEPTIBILITY MEASURE
- TAKE INITIATION FOR GRANTED
- EXPERIMENT ON PROPAGATION
- DETERMINE VARIABLES CONTROLLING RATE
- STARTING FROM AN ACCELERATED CONDITION CHANGE VARIABLES TO FIND CONDITIONS UNDER WHICH PROPAGATION WILL AND WILL NOT GO
- IF RESULTS UNACCEPTABLE, ENGINEER AROUND

BEWARE OF:

1) MAJOR CORROSION PROCESS MAY CHANGE AS VAULT CONDITIONS EVOLVE



2) LIFETIME PREDICTIONS > 10^5, 10^6a

- REEVALUATE OTHER FAILURE MODES, MECHANICAL vs. CORROSION

3) CHECK CORROSION RATES AGAINST PENETRATION RATES

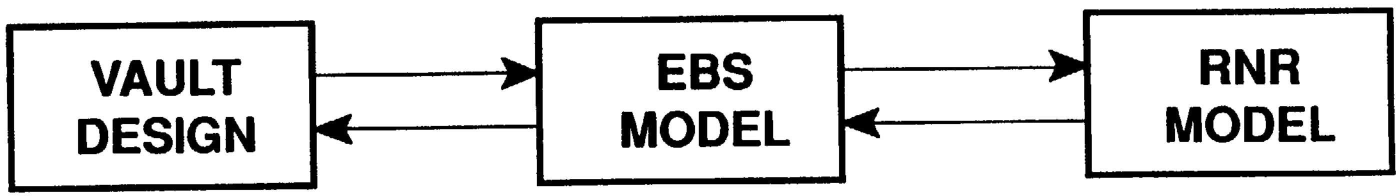
BEWARE OF:

(CONTINUED)

4) OVERLY COMPLEX MODELS (CONCEPTUAL NOT MATHEMATICAL

5) OVER-RELIANCE ON NATURAL ANALOGS

- **SPREAD MODELLING OVER THE WHOLE VAULT FOR STATISTICAL DISTRIBUTION (i.e., CONSIDER THE VAULT AS A STATISTICALLY MEANINGFUL POPULATION OF FAILING CONTAINERS)**



WKSHPEBS 122/8-1 91

moment we have to try and plan for that and try and predict that we can conform to those regulations now.

One of the concerns or confusions that I had in coming to this workshop was the term engineered barrier system versus container. I heard a lot of discussion about containers. And, clearly I understand that those containers can be part of an engineered barrier system. But, I saw a lot of very interesting strong containers that seem to me that they could stand alone and be used as the key elements in an above ground repository system. That's nothing new. That's been suggested as an approach to the whole high-level nuclear waste disposal problem and that is to put this stuff in an above-ground system, in very good containers that we can watch. As they fail, we can replace them and put the stuff in containers again.

So, I raise the question, if you have just tremendously good containers, why bother putting them in the ground and use Yucca Mountain. I'm still confused with that answer except that it's now the law that we have to put this stuff in the ground. It seems to me though if we're going to put it in the ground and use Yucca Mountain since we've already gone through a complicated decision process in choosing that mountain for it's geologic properties and it's long-term geologic status, let's let that mountain work for us then. We don't need such huge containers that are going -- that each one is going to last absolutely, without any doubt, for ten thousand years. When we put this waste in, I think the containers can be smaller and they don't have to be so fail-safe. We don't have to be absolutely sure that every one is going to last ten thousand years. All we have to do is be reasonably assured that within some probability many of them will rupture and leak over that time, after that first thousand years. We want to be sure that they won't leak at such a rate that the materials would come out and will exceed the allowable limits.

So, it's a probability problem. We don't have to design every container absolutely for ten thousand years. We just have to have some reasonable expectation that the majority will last toward those time limits without too many of them failing too soon. That's just part of the science that you have to work out when designing those containers, from what I understand.

In terms of the presentations that were given, I was very positively taken with Lawrence Livermore's presentation on their intention to organize all of the science and to produce a systematic approach for making a decision as to how best to develop the system. It takes advantage of all of our knowledge of the various processes, physical processes, mechanisms, and all in containing radionuclides and holding radionuclides back, transport, so on and so forth. I think that's a very good approach. We need that

YUCCA MOUNTAIN SITE CHARACTERIZATION
ENGINEERED BARRIER SYSTEM
CONCEPT WORKSHOP
JUNE 18, 19, AND 20, 1991

PRESENTATION BY: STEVE SIMONS
TAKEN FROM TRANSCRIPT OF SESSION 3: JUNE 20, 1991

Steve Simons with Pacific Northwest Laboratory. I was invited here as apparently an expert on hydrology. And, I think that was somewhat unfortunate. And, I think probably you could have used more appropriately someone with a background in particularly water chemistry and how that is related to corrosion processes given the focus of what needs to be communicated at this workshop. So, I will thank the DOE sponsor or host for inviting me here, but I will say I do appreciate the opportunities to see what is going on with the waste program once again.

I should probably say something a little bit about myself and this so-called expertise that I know I don't have for this group. All of the experts on this subject in this audience here, I think, know of the tuff system, the Yucca Mountain system, and know a lot about the technology of the container systems that are so well described by the presentations.

I came into my business of doing transport modeling in the mid 80's, and I got involved in modeling the potential transport of radionuclides from high-level waste repositories of different kinds under different kinds of failure scenarios. And, one of the things that we quickly learned in those earlier days of developing transport theories was that the thing that controlled the transport ultimately was the source of distribution, just how fast the material was released, not so much the hydrology or the system. That's true. I mean, that determined how soon things got there and how things came out. But, ultimately it was the source and how actively the source released it's contents. And, that's exactly what you're working on here, of course. It's building a system that will extend the length of time the material stays in the repository. And, given that you put it in a bunch of containers, that these containers fail at a reasonable rate and release the materials slowly enough so that if there was an accident and that this geologic system doesn't work the way we expect it to, that we could accept the environmental consequences and have it fit within regulations over the time that we need to apply those regulations. It's always been a curiosity to me as to whether or not EPA is going to be able to apply the regulations for ten thousand years. Will they be around as an entity of government to apply those things. But, at the thousand years. We just don't know. I mean, the only way we can know some of these things about some of these systems are that we know that have been around for a long time from our past experience, like the mountain and it's history, how it behaves and what's occurred.

So, we have to predict on the basis of what's occurred in the past, not just on the basis of what we think is absolutely -- on the processes. We know that the sun will rise tomorrow, not because we predict it will rise tomorrow. We can be pretty assured that past experience tells us that it has in the past. So, I think that those analogues are very good for reenforcing scientific confidence and public confidence of whether or not a particular kind of approach or system is going to work.

I think that's about all I have to say.

approach to organize the modeling. But I think, and one thing I might remind people of, and I think to be honest to all of us here, and that's the predictability of this whole thing is going to hinge on what we really understand about all of these basic processes that we put together as a system, describing the mechanisms of the system and the models.

Generally I noticed in the questions here, and one question is how should we ask the modelers or have the modelers tell us what parameters they need to do their modeling. That's really the wrong question from my perspective. The question is what parameters and what physical theory do you want in these models. These are the things you have to specify. All we do is write the mathematics and put them into a computer system to see what the quantitative results are --. Models are not magical. They don't come before. First you have to understand and then you develop your quantification scheme afterwards to assess what it is you really know, what you understand about, the generalizations about all these mechanisms and processes.

I appreciated the talks that emphasized experimental procedures, and I've made an effort to verify what they understood about the physical processes that were important. I think that's a procedure that needs to be taken in this system, especially when it comes to the tuff and the unsaturated zone. We need to do some intermediate scale experiments, and bench scale experiments that are scaled down versions of what we expect to occur. We can't just do this all hypothetical and pull things out of text books and publication papers, all this theory, and then just stick it together in a model and then see what it's going to predict and say that's the prediction. One thing I've learned about modeling so far in this area is that I don't think we can predict anything, expect very short term phenomena at very small scales. That's one of the biggest problems right now in modeling and in the science of modeling. Today I think we're just beginning to realize we don't really understand how to project things into the distant future for like ten thousand years in the view of the variability of most real systems. Just because we have an engineering equation that describes some continuing description of how water flows or how corrosion occurs on the surface of metal, and that equation depends on time to infinity, that doesn't mean we can just put in any laboratory time there and extend that to infinity. These theories are not very well known. We don't know how far to extend in time. That's ultimately always going to be our problem, our limit. It's going to be impossible to ever validate any of these models in a way that we can be absolutely certain that the system will hold together and what will occur is what we predicted for ten