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November 21, 1985 MRB-0484

Mr. Joel Haugen
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WM Project: WM-10, 11, 16
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WM Record File: 101
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Dear Joel:

Subject: Final Reports of the Ad Hoc Corrosion Panel's Review of the Corrosion Programs of the Repository Projects

Reference: Letter, J. C. Haugen to M. J. Steindler, Request for Review of the Corrosion Programs of the Repository Projects, January 11, 1985

We transmit ten sets of the final reports (3) of the Ad Hoc Panel on Corrosion. The reports are submitted in fulfillment of your request to me of January 11, 1985 (reference 1).

The Panel reviewed the corrosion programs of the three repository projects (BWIP, NNWSI, and SRP) and of the MCC. The final report of the MCC review was previously transmitted to you on April 18, 1985 (MRB-0432).

Initial drafts of the enclosed reports were assembled from individual reports prepared by Panel members that were submitted to the OTC of the MRB. The initial drafts were reviewed at a meeting of the Panel scheduled solely for that purpose; final member comments on the resulting draft versions were incorporated to prepare the final versions transmitted herewith. We assume that any further distribution of these reports are the responsibility of the MIO.

The Ad Hoc Panel conducting the review consisted of two members of the Materials Review Board who are expert in the area of corrosion science, four expert consultants from universities, one expert consultant from the U.S. Nuclear Regulatory Commission, plus myself as Chairman. Two of the academic consultants also have had experience in industry, and another has had a history of noteworthy service with the National Bureau of Standards. The Panel members are:

H. Birnbaum	U. of Ill., MRB Member
D. Duquette	Rensselaer Polytechnic Institute
W. Gerberich	U. of Minn., MRB Member
T. Jungling	U.S. Nuclear Regulatory Commission
J. Kruger	Johns Hopkins - formerly NBS
R. Wei	Lehigh University - formerly U.S. Steel
B. Wilde	Ohio State University - formerly U.S. Steel
M. Steindler	Argonne National Lab, Chairman

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We believe the transmittance of these reports discharges the responsibilities of the Panel as described in the various letters to me from your office. I commend to your attention the outstanding quality of the Panel and the significant effort expended by the members in this review. It is clear that the project participants in the review meeting were also impressed by the depth of expertise and understanding of the subject matter commanded by the Panel members.

Unless additional requests requiring the services of the Panel members are received in the near future, it is our intent to let all contracts and arrangements for service on the Panel lapse at the end of their normal period.

Sincerely,

Martin J. Steindler, Chairman
Materials Review Board
Chemical Technology Division

MJS:rr

Enclosures: Final Reports (3) of the Review of the Corrosion Programs of the Repository Projects by the Ad Hoc Corrosion Panel
1. BWIP
2. NNWSI
3. SRP

cc: (w/enclosures)
A. Schriesheim, OTD
S. Vogler, ANL/MIO

cc: (w/o enclosures)
Members of Ad Hoc Panel

See Ltr. to Haugen from Steinder 11-21-85

Rec'd 9-30-87

Report of the Review of the BWIP Corrosion Program by the Ad Hoc Corrosion Panel

SUMMARY

The Ad Hoc Corrosion Panel, acting by request of DOE, reviewed the corrosion program of the BWIP project. The conclusions of the Panel are based on (1) materials prepared for the Panel by BWIP, (2) presentations by BWIP to the Panel, and (3) responses of BWIP to inquiries by the Panel.

The principal conclusions of the Panel are:

1. The BWIP management is highly-focused, mission- and success-oriented, and milestone driven. However, the corrosion program is not firmly directed to the need to meet regulatory criteria.

2. Success of the corrosion program's strong emphasis on the uniform corrosion of reference and back-up materials requires convincing and coherent demonstrations that localized corrosion phenomena can be excluded as failure modes in expected repository environments in the 300- to 1000-year time frame. A plan for such demonstrations was not evident.

3. Critical issues such as the identification of potential critical failure modes, the extrapolation of short-term data to long-term predictions, and the development of models based on well-understood mechanisms have not been adequately addressed. Therefore, there appears to be no firm basis for assessing the necessary quality and relevance of data.

4. The corrosion program includes consideration of most failure modes, but not in a comprehensive and integrated manner, nor with the emphasis that the various modes should command.

5. Inadequate attention has been given to the altered metallurgical structures that will occur in and near closure welds of the very thick sections of container material, and the likely increased susceptibility to failure by localized corrosion. Plans for back-up closure modes were not evident.

6. Decision-making processes appear to be held closely within the BWIP corrosion program management. Expertise from the outside, or from its contractors, is not generally utilized. The level of expertise in corrosion and metallurgy on the internal management staff appeared inadequate for the task.

7. BWIP corrosion management does not appear to seek or welcome external reviews of program planning activities, or of experimental results obtained under it. The attitude is generally

negative toward review panels, and the MCO system. Internal reviews, as presently constituted and which BWIP considers to be adequate and sufficient, are ineffective and not relevant.

8. There are no plans by BWIP for external review of data for licensing prior to submission to the NRC.

Basalt

A. Introduction

An Ad Hoc Panel initially established to review the corrosion program of the Materials Characterization Center (MCC) was reconvened at the request of DOE to review the parts of waste repository programs concerned with the corrosion of metallic waste package components. This report concerns the review of the corrosion program of the Basalt Waste Isolation Project (BWIP).

The Ad Hoc Panel was initially established by the Chairman of the Materials Review Board (MRB) following a request by Joel C. Haugen, Manager of the Materials Integration Office (MIO) of the Chicago Operations Office of the U.S. Department of Energy (letter, J. C. Haugen to M. J. Steindler, July 11, 1984). In January 1985, the MIO requested that the Ad Hoc Panel also review the corrosion programs of the repository projects (letter, J. C. Haugen to M. J. Steindler, January 11, 1985).

The Panel met in Richland, Washington, on June 18 and 19, 1985, with staff members of the BWIP project. The Panel also met in executive session on the evening of June 18th and on September 23 and 24. This report largely follows the requests for specific information contained in the letters from DOE that served as the charter for the Panel.

B. Scope of the Review

The MIO request stated that it "has been directed by the Office of Geologic Repositories to examine the repository projects' corrosion programs using the same guidelines as for the ... (MCC) ... Review ... The basis of the review will be the criteria documents of the NRC (10 CFR 60) and the EPA (40 CFR 191). As for the MCC review, the repository programs should be reviewed to the same standards as given in the letter Haugen to Steindler, July 11, 1984."

The Panel was requested to respond to the following three questions:

1. Are all the corrosion mechanisms that are likely to be operative in the repository environments being addressed, either by the BWIP or included among the "key data" to be reviewed by the MRB?;

2. Are the tests being developed by the MCC and those proposed by the projects adequate to quantify the corrosion or penetration rates associated with those mechanisms?; and

3. Are the quality of the BWIP work and the MCC/project interactions adequate to assure development and review of "key data" of sufficient scope and quality to show compliance with NRC and EPA criteria?

Though the principal focus of the review was the above three questions, the review was not restricted solely to them. As in the MCC review, ancillary issues related to the overall performance of the project arose, were discussed and some are included in this report.

C. Results of the Review

The first part of the review responds to the three specific questions. The second part addresses ancillary issues and provides further detailed explanations considered germane to the review.

1. Responses to Questions

Q1. Are all the corrosion mechanisms that are likely to be operative in the repository environments being addressed, either by the BWIP or included among the "key data" to be reviewed by the MRB?;

The two parts of the question are considered separately.

Part 1: Are all the corrosion mechanisms ... being addressed ... by the BWIP ...?

The Panel concluded that all corrosion mechanisms are not being adequately addressed. While many corrosion mechanisms are being considered, the major effort of the program is aimed at general/uniform corrosion and is believed to be misdirected. BWIP is cognizant of other corrosion mechanisms but is exploring only some of those that they consider credible. The Panel concludes that the adequacy and the focus of the overall program relative to its objective is deficient.

The project's current focus on general corrosion appears to be motivated by two principal and related factors: the expected anoxic environment of the repository, and the selection of low carbon and low alloy steels as the reference and back-up candidates for construction of the metal components of the waste package. The key rationale for these selections was the evidence, obtained in the screening process, that localized corrosion might be avoided for service in reducing environments. The evidence to support the materials selection decisions was considered by the Panel to be generally weak, and the Panel expected considerable emphasis in current programs to generate data that corroborated these decisions. This emphasis was generally lacking.

The inadequacies of the program include, for example, lack of attention to the following: stress corrosion cracking (SCC) in environments containing Cl^-, CO_3^{-2}, and S-containing species; hydrogen embrittlement; long-term metallurgical changes; crevice corrosion; intergranular attack; welding effects.

The Panel believes that it is incumbent on BWIP to demonstrate its presumption that low carbon steels do not suffer any form of significant localized corrosion in the

basalt repository environment which BWIP judged to be reducing. The Panel found the plan for accomplishing this demonstration not adequate. Some examples are as follows.

Studies of the effect of welding as related to localized corrosion phenomena do not appear to be part of the planned corrosion program even though thick metal sections are part of the current design for the waste package. Aggravating environmental factors that appear to be inadequately considered in the program include the presence of chlorides, carbonates, and sulfides. Stress corrosion cracking of steels due to carbonates has been observed at temperatures greater than 60°C; chlorides are known to induce hydrogen evolution through various corrosion reactions, and sulfur (in various forms) can have serious impacts on all forms of corrosion. Further, there is a possibility that the anoxic repository environment may be altered locally by the accumulation of corrosion products, especially in crevice locations, thus giving rise to altered local redox potentials.

Efforts are being made in the BWIP program to address the issues of environmental crack growth and pitting, and electrochemical measurements are being made to address pitting initiation, pitting propagation, and some corrosion mechanisms.

In summary, it is the conclusion of the Panel that while the BWIP corrosion program did address some of the important corrosion mechanisms, the program was not based on an evident thorough, comprehensive, or well-developed plan. The presentations have not convinced the Panel that a sound scientifically based philosophy exists with which to address the difficult questions of material selection, development of test methods, data extrapolation, and life prediction.

Part 2: Are all the corrosion mechanisms ... being addressed ... [or] included among the "key data" to be reviewed by the MRB?

The Panel concluded that little of the BWIP-related "key data" are to be reviewed by the MRB.

In its presentation, BWIP presented three classifications of data: (1) "licensing data" are all data generated for licensing purposes using BWIP-approved procedures, (2) "key data" are data generated on the most probable corrosion mode, defined by BWIP to be general corrosion for low carbon and low alloy steels, and (3) "MRB Review" data are data generated by the MCC in BWIP "benchmark" testing. Only those data designated by BWIP as MRB review data (which is likely to include only uniform corrosion data) will be submitted to the MRB. This includes data to be generated by

the following three test methods: MCC-105.1, Static Pressure Vessel Test; MCC-105.4, Flow-By Autoclave Test; and MCC-105.5, Air-Steam Test. The indicated test methods appear to be limited to uniform corrosion although qualitative information on pitting may also be obtained. Thus, most of the data that fall under the BWIP categories of licensing data and key data (which is likely to include data on localized corrosion) would not be reviewed by the MRB. The definitions provided by BWIP are contrary to the term "key data" in the context of the requests to the Panel by DOE.

Q2. Are the tests being developed by the MCC and those proposed by the projects adequate to quantify the corrosion or penetration rates associated with those mechanisms?

This questions is also divided into two parts.

Part 1: Are the tests being developed by the MCC ... adequate ...?

This part of the question, relating to the MCC, is not germane to the review of the Corrosion Programs of BWIP.

Part 2: Are the tests ... proposed by the project adequate ...?

The response of the Panel to this question is NO. The response is based on the observations that the issues such as reproducibility, ability to make quantitative extrapolations, the applicability and relevancy of the tests have not been addressed.

Q3. Are the quality of the project (BWIP) work and the MCC/project interactions adequate to assure development and review of "key data" of sufficient scope and quality to show compliance with NRC and EPA criteria?

Part 1: Are the quality of the project (BWIP) work ... adequate to assure ...?

The Panel concluded that the data obtained on uniform corrosion of the alloys selected for candidate materials are of reasonably high quality for short-term tests. However, the quality may not be adequate for extrapolation to long-term performance in the absence of an extrapolation model based on mechanistic understanding. Further, some of the studies of pitting corrosion and crack growth appear to be sound. The absence of significant work on other localized corrosion phenomena and the lack of attention to metallurgical changes in and near welds prevented an evaluation of the quality of this part of the program.

The Panel does not believe that the effort on modeling and predictive studies is adequate. The bases of the models described by BWIP were derived from literature data that were obtained under conditions not obviously pertinent to the repository. Further, the models seem to lack a defensible mechanistic base and the Panel failed to find appropriate appreciation by the BWIP for the necessity of such a base.

The Panel noted that the BWIP program had, up to now, no persons directly assigned who were expert in statistics. Further, except for some of the contractors to BWIP, the project staff was perceived to be weak in expertise in the corrosion field.

Part 2: Are the quality of the ... MCC/project interactions adequate to assure ...?

The Panel posed questions to BWIP management concerning this point. The responses made it clear that the Panel would not be provided with answers. In the opinion of BWIP, the question was not part of the Panel's concerns.

The Panel, nevertheless, concluded that the MCC/BWIP project interactions are not adequate for the purposes stated in the question. The one significant interaction between BWIP and the MCC is the generation by the MCC of "benchmark" data for test procedures principally involving uniform corrosion. Other procedures and test data from BWIP will not be sent through the MCC/MRB system. In its current role with BWIP, MCC appears to be serving principally in the role of a contractor performing those services specifically requested by BWIP. Demonstration of compliance with NRC and EPA criteria did not appear to be a specific target of the program as evidenced by absence of sufficient attention to localized corrosion effects, absence of clearly defined performance targets, and absence of efforts at development and testing of meaningful models.

The Panel further observed that BWIP management (1) does not approve of the objectives and purposes of the MCO system, (2) does not intend to utilize this system for review of its procedures and data (with the possible exception of "benchmark" data already described), and (3) perceives no need for independent external review of procedures and data prior to submission to the NRC.

2. Other Issues and Observations

The Panel is aware that the scope of its activities, defined by the Haugen letter, could be narrowly interpreted as dealing only with answers to the three questions. It is the unanimous conclusion of the Panel,

however, that the topic of corrosion is of major importance to the repository performance and that this conclusion is shared by DOE. The Panel has, therefore, elected to provide ancillary comments that deal with issues related to the corrosion program and about which Panel members have great concern or strong feelings. These issues were developed in response to inquiries and discussions initiated by both the Panel and the project. In some instances, the ancillary comments represent an extension of observations summarized above.

a. Technical Issues

The following technical issues were identified by the Panel as issues that either (1) are not currently being adequately addressed, or (2) are being adequately addressed but not properly integrated into a thorough and self-consistent program.

1. Definition of Failure Modes

In its presentations, BWIP ranked probable failure modes in the following order of decreasing importance: uniform corrosion, pitting corrosion, intergranular attack, and environmentally assisted cracking (including stress corrosion cracking and hydrogen assisted effects). The Panel concluded that BWIP has not adequately established its basis for such a ranking.

Major deficiencies in the current program include but are not limited to inadequate attention to crevice effects due to varying degrees of contact of metal surfaces with packing material, the presence of hydrogen, particularly in occluded regions (due both to radiolytic decomposition of groundwaters and the corrosion process itself), and the possible degradation of weldments by various mechanisms previously mentioned.

The Panel believes the much enhanced emphasis by BWIP on general corrosion, compared to localized corrosion, is misplaced. While general corrosion will undoubtedly occur, the likelihood of failure by localized corrosion seems to the Panel to be greater than failure by general corrosion. Selection of carbon steels and low alloy steels, and the current corrosion program were based principally on the perceived lack of susceptibility to localized phenomena. The Panel believes that, for this approach to be credible, the program must be focused clearly and unequivocally on an adequate demonstration that failure by localized phenomena can be avoided. Although BWIP is addressing some of the forms of localized attack, the Panel concluded that the effort is not integrated to ensure a design that meets the objectives.

The Panel noted that the reference design of the waste package and its emplacement is relatively new and that the design influences the basis and nature of the corrosion program. The expected ten-year BWIP program for testing of some of the corrosion mechanisms appears to conflict with the stated schedule of submission of a license application unless DOE does not expect to provide adequate corrosion data in such an application. This conflicting situation is exacerbated by the lack of early attention to potentially important failure mechanisms, including those that affect the closures.

2. Characterization of the Environment

The Panel observed that BWIP has made a significant effort to characterize the repository environment. However, recognition should be made in planning tests that the bulk environment may not be representative of the environments adjacent to regions of potential localized attack. The local environments may not always be reducing since corrosion products may accumulate, particularly in locations such as crevices, and change the local redox potentials. Thus, the Panel concluded that a safer and more conservative approach would include in the testing the bounding of expected conditions at somewhat higher oxidizing potentials than anoxic conditions would indicate.

The characterization has also revealed the presence of several chemical species known to have potential damaging effects to metallic components: some sulfur compounds, arsenic, chlorides, and carbonates. The Panel failed to find inclusion of these species in the planning of the corrosion testing program. The Panel notes that carbonates are capable of inducing SCC and chlorides may induce hydrogen evolution through corrosion reactions. The potential for producing hydrogen embrittlement may be aggravated by the presence of arsenic and some sulfur compounds.

3a. Materials Selection

The BWIP basis for materials selection was corrosion resistance, fabricability including container closure, availability, and cost. The process of materials selection included literature surveys, and early screening studies. On this basis, BWIP selected low carbon steel as the reference material, and low alloy steel, OFHC copper, and 90Cu-10Ni cupronickel as the back-ups. BWIP stated that all candidate materials display acceptable corrosion resistance under anoxic conditions. Further, the evidence available to BWIP suggested that localized corrosion could be avoided for service in reducing environments.

Higher alloys were considered by BWIP to have certain drawbacks: e.g., nickel alloys were susceptible to pitting, titanium to hydriding, and stainless steels to stress corrosion cracking.

BWIP cited five principal references as constituting the basis for materials selection. Three of these are publicly available through the National Technical Information System (NTIS), and one was provided to the Panel by BWIP for this review.* The evidence contained in the four available references to support the materials selection decision was considered by the Panel to be generally weak, and the Panel expected considerable emphasis in current programs to generate data that corroborated the decisions. This emphasis was generally lacking.

3b. Uniform Corrosion

The uniform corrosion program uses the conventional approach of exposure of the material to be tested to a relevant environment, followed by weight measurements after different periods of exposure with a planned maximum period of about ten years. It would be useful to include in situ electrochemical polarization measurements as a check against corrosion weight-loss measurements and to detect possible changes of mechanism with time and temperature.

The most significant gaps in the program are the lack of sound advanced planning on determinations of mechanisms and the development of adequate models. For example, data obtained to date indicate marked changes in corrosion rates of low-carbon steel at differing temperatures. These data imply a change of mechanism. Development of a systematic methodology to understand the mechanism has not been undertaken. The Panel believes that, lacking this fundamental basis, the data are not adequate for use in extrapolating performance to the repository and its time scale.

4. Pitting and Crevice Corrosion

The work in the area of pitting corrosion using electrochemical procedures was judged by the Panel to be one of the better activities in the current corrosion program. It was noted by the Panel that this was one area in which there is mechanistic consideration. However, it is not clear to the Panel how the information on pitting and/or mechanisms

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* Available from NTIS: PNL-2990 (1979), PNL-3198 (1980), PNL-3483 (1980).
Provided by BWIP: RHO-BWI-ST-15 (1981).
Not publicly available: BWIP SD-RE-TRP-011 (1982).

determined in this activity is to be used for design, modeling, and extrapolation, i.e., how it is to be integrated into the corrosion program as a whole.

The approach used in the work involves measurement of the corrosion potential to determine whether excursions of this potential above the critical pitting potential occur. No plans have been revealed to establish the accuracy of the pitting potential determinations, to determine whether the pitting potential changes over long periods, and to ascertain, if possible, whether a system exhibiting a corrosion potential below the measured pitting potential will not pit. Also, the results of this work show a tendency toward pitting of low-carbon and low-alloy steels at relatively active potentials that seem to be at variance with the assessments (in the materials screening process) that the likelihood of pitting is low. It is not clear how project management intends to use this information.

The Panel concluded that the attention given to crevice corrosion is inadequate. The Panel felt that extensive opportunities for crevice corrosion exist because of the potential for uneven contact of packing material with metallic components. BWIP stated that crevice corrosion is being addressed by pitting corrosion experiments. The Panel noted, however, that crevice initiation occurs by a different mechanism than pit initiation and should be addressed separately.

5. Stress Corrosion

The Panel concluded that a reasonable start has been made in the area of stress corrosion, but the effort has not been coordinated into a systematic and thorough corrosion program. The effort is directed toward establishing whether there exists a threshold of stress intensity below which the rate of crack growth is acceptably low and, if so, how it varies with changing environmental conditions. It is not clear at this time how the data obtained from this effort are to be used by program management.

6. Long-Term Metallurgical Changes

Long-term metallurgical changes may be important during the canister lifetime even in simple metallurgical structures such as mild steel. Among these are solute segregation to interfaces, modification of the metallurgical structure in the vicinity of the weld, and redistribution of the hydrogen in solid solution in response to the residual stress patterns in the vicinity of the closure and in response to the (modest) thermal gradient which will exist

in the container walls. All of these point towards the importance of local failure modes, particularly in the vicinity of the closure.

It is not clear to the Panel that these phenomena are being properly addressed.

7. Radiation Damage and Hydrogen Effects

BWIP recognizes the importance of potential effects of the radiation field on corrosion mechanisms. BWIP is relying on the shielding of the very thick-walled container to reduce or eliminate radiation effects. While the thick shields may be effective in essentially eliminating radiation effects on uniform corrosion, it is likely that even the reduced radiation levels will affect localized corrosion at the tips of cracks, crevices, or pits initiated by other mechanisms. Further, such radiation levels can produce species that lead to hydrogen damage, especially in reducing environments that have high hydrogen fugacities.

The Panel concludes that the BWIP program relating to radiation damage is deficient in several of the above areas.

8. Closure of the Container

The Panel found little evidence that the corrosion problems exacerbated by, for example, residual stresses, changes in metallurgical structure, crevices associated with welding or other closure modes, are being addressed or considered.

Because of the metallurgical properties and residual stresses of the heat affected zone, this area is likely to be the most susceptible region of the waste package to failure. The Panel found no evidence that the fusion and heat affected zones are being tested for corrosion resistance or other failure modes. The Panel observed that other closure modes are not being considered, even though potential corrosion rates or hydrogen embrittlement susceptibility at welded closures may be intolerably high.

9. Modeling and Extrapolation

The Panel concluded that several of the models and extrapolation methods currently being used by the BWIP project for preliminary assessment are simplistic, not defensible from a mechanistic point of view, and may yield misleading results. The Panel does not underestimate the difficulty of extrapolating to the very long periods associated with repository disposal by utilizing short-term

data. However, appreciation on the part of the BWIP project for the difficulties associated with life prediction appeared to be lacking.

Modeling and extrapolation for life prediction require at least a minimal understanding of the mechanisms by which degradation processes proceed. The Panel did not see much evidence that work leading to the improvement of such understanding, either from the point of view of mechanisms or degradation modes, is in progress or planned.

10. Data Quality and Quality Assurance

The Panel noted that presentations in the area of Quality Assurance (QA) were extensive. The QA system is concerned with the details of methods, procedures, and documentation of the data production process. The Panel also noted that these elaborate and extensive quality assurance measures do not address the question of applicability, relevancy, and general utility of the data being obtained. The Panel observed that there is a risk that obsession with QA measures may result in (1) an unwarranted degree of comfort in data quality (and a subsequent neglect of adequate program planning), and (2) a stifling of scientific virtuosity and initiative. Preoccupation with QA may be a factor in the judgments that the Panel has made relative to program management. The Panel also concluded that the significant resources expended on QA did not appear to be commensurate with the modest apparent benefits that could be expected from such expenditures.

11. Leadership, Management, and Review Processes

The Panel concluded that BWIP management of the Corrosion Program is decisive, albeit myopic, and exercises a strong control. The management process is highly focused, mission- and success-oriented, and milestone driven. The Panel believes that these attributes are not necessarily synonymous with success.

It appeared to the Panel that decision-making processes related to program planning may be held too closely within the Richland organization; corrosion expertise available from the outside or even from within its own contractor operations are not generally utilized. The level of expertise of BWIP in corrosion appeared to be relatively low, considering the importance of the topic to the success of the repository program.

Further, it appears to the Panel that BWIP management does not seek or welcome external independent reviews of its program planning activities, or of the experimental results

obtained under it. The Panel was told that the project has been subjected to multiple external reviews and that these reviews are generally perceived to be an impediment to meeting milestones. In addition, a BWIP Review Committee selected by DOE is to meet every six months, and among other things, reviews the Corrosion Program and management decisions related to it. The Panel learned that this Committee contains no persons recognized as corrosion experts or material scientists and has never reviewed the BWIP corrosion program. The Panel questioned the effectiveness of such a review process.

The Panel thus concluded that there is no acceptance by BWIP management that external review is necessary.

The Panel learned that the funds supporting the corrosion program are believed adequate by BWIP management. At the indicated level of funding, the Panel believes these funds should have allowed BWIP to do much better at developing plans, procedures, and a data base for the task at hand.

The Panel views the intense adherence to milestones and the consequent successdriven program management as potentially hazardous to the timely development of the high-quality data and substantiation of models that will be needed for licensing. This concern was amplified in the discussions with BWIP management on the issues of examining phenomena that arose during experiments but were not described in the governing statement of work. The Panel concludes that the subcontractors who are part of the BWIP program should be provided with more extensive opportunities to explore potentially pertinent phenomena and ideas that may be important to the program.

The Panel concludes that the consequences of the management deficiencies are reflected in the absence of coordinated program plans that guide the program with technically significant principles. In addition, the absence of outside review allows BWIP to feel satisfied with the current technical activity and direction, even though it appeared to the Panel that the major technical problems are not being addressed. Thus, the expenditure of resources appears to the Panel to be highly inefficient and unlikely to satisfy the technical requirements for demonstrating compliance with regulatory criteria in a timely fashion.

Report of the Review of the NNWSI Corrosion Program
by the Ad Hoc Corrosion Panel

SUMMARY

The Ad Hoc Corrosion Panel, acting by request of DOE, reviewed the corrosion program of the NNWSI project. The conclusions of the Panel are based on (1) materials prepared for the Panel by NNWSI, (2) presentations by NNWSI to the Panel, and (3) responses of NNWSI to inquiries by the Panel.

The principal conclusions of the Panel are:

1. The NNWSI corrosion program is led by an enthusiastic management, but lacks focus. The program appears to suffer from some gaps in expertise in the NNWSI staff that are important to the achievement of program goals.

2. Because much of the work is still performed in a scoping/screening mode, the selection of reference and back-up materials should be considered tentative pending further accumulation of data.

3. NNWSI has not fully considered the range of problems which stem from the metastability of the 18Cr-8Ni types of stainless steels either in the form of bulk metal or welded structures. Back-up container closure modes are not evident.

4. Type 304L stainless steel is still being extensively studied and used as the reference material even though (1) a consultant has concluded that it is not a preferred material, (2) its metastability gives rise to many different problems in demonstrating satisfactory performance, and (3) alternative materials with potentially superior qualities seem to be available.

5. NNWSI has recognized the pertinent corrosion mechanisms but has not addressed them in ways that are relevant to regulatory criteria.

6. Many tests are being performed or planned but there is a lack of clarity on how the data are to be applied. Insufficient attention has been given to test procedures and data as they relate to compliance requirements.

7. Methods of extrapolating short-term experimental results to long-term performance are not in place, and plans for such extrapolation work are not well developed. Therefore, there appears to be no firm basis for assessing the necessary quality and relevance of data.

8. There is little on-going work that promises to lead to the improved understanding of the mechanisms of potential failure modes that are needed for developing models and methods of extrapolation to long-term performance.

9. Program management does not now avail itself of technical reviews of the program or external technical guidance for planning.

10. Interactions of the project with the MCC are minimal, strained, and nonproductive. It appears unlikely that NNWSI will promote a change in this relationship. The project appears to believe that the MCC duplicates what already is available via ASTM, NACE, etc., and that the latter are appropriate and qualified review bodies.

A. Introduction

An Ad Hoc Panel initially established to review the corrosion program of the Materials Characterization Center (MCC) was reconvened at the request of DOE to review the parts of waste repository programs concerned with the corrosion of metallic waste package components. This report concerns the review of the corrosion program of the Nevada Nuclear Waste Storage Investigations (NNWSI) project.

The Ad Hoc Panel was initially established by the Chairman of the Materials Review Board (MRB) following a request by Joel C. Haugen, Manager of the Materials Integration Office (MIO) of the Chicago Operations Office of the U.S. Department of Energy (letter, J. C. Haugen to M. J. Steindler, July 11, 1984). In January 1985, the MIO requested that the Ad Hoc Panel also review the corrosion programs of the repository projects (letter, J. C. Haugen to M. J. Steindler, January 11, 1985).

The Panel met in Livermore, California, on June 20 and 21, 1985, with staff members of the NNWSI project. The Panel also met in executive session on the evening of June 20th and on September 23 and 24. This report largely follows the requests for specific information contained in the letters from DOE that served as the Charter for the Panel.

B. Scope of the Review

The MIO request stated that it "has been directed by the Office of Geologic Repositories to examine the repository projects' corrosion programs using the same guidelines as for the ... (MCC) ... Review ... The basis of the review will be the criteria documents of the NRC (10 CFR 60) and the EPA (40 CFR 191). As for the MCC review, the repository programs should be reviewed to the same standards as given in the letter Haugen to Steindler, July 11, 1984."

The Panel was requested to respond to the following three questions:

1. Are all the corrosion mechanisms that are likely to be operative in the repository environments being addressed, either by the NNWSI or included among the "key data" to be reviewed by the MRB?;

2. Are the tests being developed by the MCC and those proposed by the projects adequate to quantify the corrosion or penetration rates associated with those mechanisms?; and

3. Are the quality of the MCC work and the MCC/project interactions adequate to assure development and review of "key data" of sufficient scope and quality to show compliance with NRC and EPA criteria?

Though the principal focus of the review was the above three questions, the review was not restricted to them. As in the MCC review, ancillary issues related to the overall performance of the project arose, were discussed and some are included in this report.

C. Results of the Review

The first part of the review responds to the three specific questions. The second part addresses ancillary issues and provides further detailed explanations considered germane to the review.

1. Responses to Questions

Q1. Are all the corrosion mechanisms that are likely to be operative in the repository environments being addressed, either by the NNWSI or included among the "key data" to be reviewed by the MRB?;

The two parts of the question are considered separately.

Part 1: Are all the corrosion mechanisms ... being addressed ... by the NNWSI ...?

The Panel concluded that NNWSI has recognized the pertinent corrosion mechanisms but has not addressed them in ways that are relevant to the goals of the program. NNWSI admits, and the Panel agrees, that the corrosion program still pursues much of its work in the form of scoping/screening studies. Hence, the Panel feels that the selection of reference and back-up materials has been made on an inadequate data base and should be considered tentative. The Panel noted that the corrosion program does include consideration of the behavior of welds, believed to be the most critical part of the canister assembly related to corrosion.

Several deficiencies in the present program were identified by the Panel. These include lack of attention to hydrogen-induced cracking from the inside out, the sensitivity of martensitic structures to hydrogen embrittlement, hydrogen effects in radiation fields, and a fracture mechanics testing program. The NNWSI program has not paid sufficient attention to the variability in the composition of the stainless steels. The allowed range of compositions can affect the failure mode of these alloys.

NNWSI has not considered the range of problems which stem from the metastability of the 18Cr-8Ni types of stainless steels. These include possible long-term transformation of the metastable austenite phase to stable martensite with the concomittant changes in sensitivity to failure modes.

Part 2: Are all the corrosion mechanisms ... being addressed ... [or] included among the "key data" to be reviewed by the MRB?

It appears to the Panel that the question is, in part, somewhat premature for NNWSI. There is an absence of comprehensive planning that identifies the methods by which the goals of the corrosion program can be achieved. The consequent lack of focus of the corrosion program appeared to the Panel to be a major deficiency. The NNWSI project has not made an identification of key data. NNWSI management stated that it expects to be using standard ASTM, NACE, or other test methods or review processes at later stages, but expressed concern that the standards organizations cannot meet the NNWSI time schedule. Moreover, there is no plan to submit procedures or key data through the MCO system. The Panel agrees with the concern about schedules and also concludes that the lack of standard review of test methods and data is a serious deficiency.

The relationship between the MCC and NNWSI appeared to be limited and not satisfactory to NNWSI. The project has participated in some of the MCC workshops to which they were invited, but the concept that the MCO system could be useful in assuring data quality has apparently not been accepted.

Q2. Are the tests being developed by the MCC and those proposed by the projects adequate to quantify the corrosion or penetration rates associated with those mechanisms?

This questions is also divided into two parts.

Part 1: Are the tests being developed by the MCC ... adequate ...?

The response to this question relating to the MCC is not germane to the review of the corrosion programs of NNWSI.

Part 2: Are the tests ... proposed by the projects adequate ...?

The Panel concluded that the response to the question when viewed in terms of long-term performance is NO. The Panel stated in the response to question 1 that most of the corrosion mechanisms are recognized. However, it is not clear that data from many of the tests currently being performed will allow a prediction of long-term performance. The Panel also noted that methods of extrapolating results to long-term performance are not in place, and that the plans for developing the understanding necessary for such extrapolation are not well developed.

The Panel recognizes that the corrosion program does address many of the important issues. The Panel notes that the project staff apparently does not have the high level of expertise required in the area of metallurgical sciences to

design and evaluate critical tests. The difficulties are associated principally with the materials chosen as prime candidates, the 18Cr-8Ni austenitic stainless steels. These are complex alloys and are known to be metastable and a) convert to martensitic structures upon cold work (or other mechanical damage), and b) are known to precipitate second phases (e.g., carbides, nitrides, sigma). Welding may result in additional metallurgical changes that aggravate the problem.

The absence of planning exacerbates the difficulties of developing data on selected failure mechanisms (e.g., stress corrosion cracking and hydrogen embrittlement from long-term metallurgical instabilities) by test methods now employed. The Panel considers the approach, stated by NNWSI, of conducting tests under what appear to be the worst plausible repository conditions and accepting materials that show no failure as naive and unrealistic. This approach does not recognize the incubation time for initiation of a crack or pit or long-term metallurgical changes. The Panel noted that many tests are being performed or planned but that there is a lack of a focus on how the data are to be applied. Such focus is needed in the planning of a pertinent corrosion program.

Q3. Are the quality of the NNWSI work and the MCC/project interactions adequate to assure development and review of "key data" of sufficient scope and quality to show compliance with NRC and EPA criteria?

Part 1: Are the quality of the NNWSI work ... adequate to assure ...?

The Panel did not examine the matter of data quality in depth. The Panel was much more concerned with the kind of data being obtained, and the compatibility of those data with a thorough and comprehensive program. As indicated elsewhere, the Panel concluded that the program lacked focus, i.e., NNWSI has not developed a rationale or basis for conversion of corrosion data to those necessary for licensing, nor did NNWSI present a rationale outlining what data would be needed for licensing. It appeared that insufficient attention has been given to test procedures and data as they relate to compliance requirements. The Panel found no quantitative performance requirements, and, particularly, no methodology for making reliable extrapolations to long-term performance. Thus, objective standards on data quality and relevance are not apparent and evaluation is therefore not made.

The Panel observes that the extensive effort of data collection has been in progress at NNWSI for about three years, was in progress before that under the direction of ONWI, and that some work had been done at Sandia. The Panel viewed with concern the lack of progress in defining the performance of metal barriers compared with the project schedule, especially since operational plans to focus the program are not yet formulated. Hence, the Panel concludes that, based on a series of major deficiencies that jeopardize reaching the milestone goals of the program, the quality and scope of the NNWSI corrosion program are inadequate to show compliance with regulatory criteria on the schedule set by DOE.

Part 2: Are the quality of ... the MCC/project interactions adequate to assure ...?

MCC/NNWSI interactions are minimal. NNWSI does not appear to be clear on what role MCC is playing or should play, and has not pursued the subject other than responding to invitations to participate in MCC workshops. The MCC has not been active in interactions and the MCC liaison to NNWSI has not visited Livermore. It appears to the Panel that the NNWSI has the impression that the MCC duplicates what already is available via ASTM and NACE, and believes that ASTM/NACE are appropriate and qualified review bodies. The Panel concludes that the MCC/NNWSI interaction is minimal, strained, and not productive, and that it is unlikely that NNWSI will promote a change in this relationship.

2. Other Issues and Observations

The Panel is aware that the scope of its activities, defined by the Haugen letter, could be narrowly interpreted as dealing only with answers to the three questions. It is the unanimous conclusion of the Panel, however, that the topic of corrosion is of major importance to the repository performance and that this conclusion is shared by DOE. The Panel has, therefore, elected to provide ancillary comments that deal with issues related to the corrosion program and about which Panel members have great concern or strong feelings. These issues were developed in response to inquiries and discussions initiated by both the Panel and the project. In some instances, the ancillary comments represent an extension of observations summarized above.

a. Technical Issues

1. Definition of Failure Modes

The identification of failure scenarios made by NNWSI appears to be appropriate, recognizing that detailed ranking cannot now be definitive because insufficient data have been developed by the project. Changes may be expected as additional data are obtained.

The Panel believes that the emphasis on localized effects (intergranular attack, stress corrosion cracking, pitting, crevice corrosion, hydrogen embrittlement) compared to uniform corrosion is appropriate, taking into account the repository environment and the selection of 18Cr-8Ni austenitic stainless steels as reference materials.

The Panel views the inclusion of copper and copper alloys as candidate metals to be less a technical decision than one based on other factors. The failure modes of copper and its alloys can be substantially different ~~than~~ from those for stainless steels. The NNWSI program has no apparent program for the definition of failure modes for copper alloys.

2. Characterization of the Environment

The NNWSI presentation suggested that the chemical nature of the expected tuff environment was reasonably well understood, and that the J-13 well water composition was considered a reasonable approximation of the expected liquid phases. Gas phase compositions expected in the repository have not been defined. However, it was noted that an exploratory shaft would not be constructed until 1986. The composition of pore water expected for the repository is not known and hence the J-13 water composition may not be representative. The Panel concluded that the currently used range of environmental parameters may be inadequate to bound the actual repository conditions, especially in the early period of emplacement when high temperatures and radiation fields may coexist with liquid water.

3. Materials Selection

The NNWSI basis for selection of austenitic stainless steels was

- excellent corrosion resistance
- excellent fracture toughness
- readily fabricated and welded.

On this basis, NNWSI selected 304L as the reference grade, and 316L and 321 as alternatives.

The Panel notes, however, that the experience history and the history of failures of these alloys is relatively short. The historical list of localized degradation phenomena is long, and has grown with an increasing number of new applications. Low-temperature sensitization, for example, has been recognized only within the history of the Nuclear Reactor Program.

The Panel noted that a consultant to NNWSI investigated just one degradation mode--low temperature sensitization--and stated that "... 304L would not be the preferred alloy of construction for nuclear waste storage canisters."* The Panel observes that, in contrast with this recommendation, 304L is still being extensively tested and used as the reference grade.

An advantage of these alloys is that they have low uniform corrosion rates in the expected repository environments. NNWSI recognizes that these materials are susceptible to localized corrosion attack and internal metallurgical changes (both short- and long-term, depending on temperature), and that these are aggravated by welding. The Panel believes that NNWSI has not appreciated the difficulty of demonstrating that certain of these phenomena will not jeopardize waste package integrity over the time span of 300 to 1000 years. The Panel noted that the approach, espoused by NNWSI, of testing alloy behavior under worst plausible repository conditions is not sound and is likely to fail. The Panel concludes that a program that adequately demonstrates reasonable immunity to all of the potential failure modes requires considerable planning and technical effort that has not yet been expended by NNWSI.

The Panel is concerned that NNWSI management may become wedded to the materials selected, even though the developing data base may indicate a change in the course of the program.

The basis for considering copper and copper alloys appeared to the Panel to be less than clear. It appears that these metals are to be extensively studied in the near term. The Panel heard little that would allow the conclusion that expertise on behavior of copper exists in the NNWSI program or that careful planning of the program for copper has been done. The Panel concludes that resources used in the study of copper in the program may not be well expended unless this area is treated more seriously and technically than appeared likely.

4. <u>Pitting and Crevice Corrosion</u>

These failure modes are among the main concerns of NNWSI and they are paying a great deal of attention to both. The NNWSI effort on cyclic polarization is collecting extensive data but lacks planning and a clear definition of the

*Attachment 7 to letter (MRB-0418), L. B. Ballou and R. D. McCright to M. J. Steindler, 3/14/85.

application of these data to licensing. The Panel believes that expert guidance to specify test objectives is needed. This guidance could be from internal sources, but external sources may be required. Other mechanistic studies could also benefit from assistance in planning. The Panel believes that these comments apply particularly towards establishing reliable values for the pitting potential in relevant environments, how they change with time, and whether assurance can be obtained that a metallic system will not pit if the corrosion potential is less than the properly measured pitting potential.

The Panel concluded that while a significant experimental effort is being expended in studies on corrosion potentials, the studies are not obviously directed at a focused goal leading to answering of licensing questions. The testing resembles a screening effort. The Panel was unable to identify the application of results to modeling or prediction of performance.

5. Stress Corrosion

The NNWSI is relying on U-bend, C-ring, and slow strain rate tests to characterize stress corrosion. The program includes the study of pre-cracked specimens to determine crack propagation rates, but has not addressed the problem of measuring the very low rates that may be relevant for a thousand-year time period. The overall approach of NNWSI towards environmentally sensitive fracture is based on the presumed existence of a long-term threshold stress intensity for cracking.

The Panel considered the use of U-bend, C-ring, and fracture mechanics testing redundant. The Panel believes that C-ring and U-bend tests were suitable for screening purposes. Efforts on these and the planned fracture mechanics-based testing require functional planning to ensure that the application of the data is in concert with their quality and also the licensing-related program goals.

6. Long-Term Metallurgical Changes

The Panel noted that NNWSI is concerned about long-term, low-temperature sensitization of austenitic stainless steels. In addition, there are a large number of problems that may arise because these alloys are metastable. For example, lowering the carbon content to decrease sensitization reactions makes some stainless steels even more susceptible to martensitic transformation. It is not clear to the Panel that these phenomena are being properly addressed or that their existence is appreciated.

7. Radiation Effects and Hydrogen Damage

The Panel concluded that radiation effects are being considered, but the resultant potential for hydrogen damage is not. NNWSI has found that uniform corrosion is not affected by the presence of radiation. However, the effect of hydrogen species obtained from both corrosion and radiolysis reactions is not being addressed. This problem may be further exacerbated by transformation to martensitic structures.

8. Closure of the Container

The Panel concluded that this area is the least well-addressed in the corrosion programs. The emphasis on stainless steels makes it particularly important in light of the metastabilities of such alloys. Currently the only closure mode being addressed is welding. Welding may introduce either obvious or subtle changes in microstructure in the weldment and in heat-affected zones, and can lead to sensitization, preferred corrosion of second phases in the weldment or HAZ, hydrogen embrittlement, preferred SCC paths, etc. The Panel believes the NNWSI program lacks metallurgists who are sufficiently familiar with stainless steels and their joining problems.

The Panel notes the absence of planning for a back-up method of closure should the problems associated with the failure modes of welds not be totally resolvable. In addition, little planning for closure of alternative metal candidates such as copper alloys was evident to the Panel.

9. Modeling and Extrapolation

The Panel did not find a well formulated plan by NNWSI for the extrapolation of relatively short-term stress corrosion cracking tests for the 1000-year repository period. The current effort is based on the assumption of the existence of thresholds (principally critical potentials for localized corrosion and critical stress intensities for environmentally sensitive fracture). The Panel recognizes that the modeling effort is not yet of broad scope, principally because of the exploratory character of much of the current work. The Panel concludes that until a systematic approach to modeling and accelerated testing is developed, the experimental program will continue to lack the focus needed to ensure that data from it are useful.

Modeling and extrapolation for life prediction requires at least a minimal understanding of the mechanisms by which degradation processes proceed. The Panel did not see much

evidence of work leading to the improvement of such understanding, either from the point of view of mechanisms or degradation modes.

10. Data Quality and Quality Control

The Panel noted that there appears to be little effort at present on quality assurance or quality control. The Panel concluded that this is understandable considering the present state of the technical programs (i.e., screening/scoping stage); however, considerations of more rigorous attention to such approaches must come soon. Related to these issues are NNWSI views and perceptions of the potential roles in their program of the MCO and standards organizations. Comments on these views are provided elsewhere.

11. Leadership, Management, and Review Processes

The Panel perceives that this project is lead by an enthusiastic management but lacks focus. Further, the Panel notes that multiple assignments for managers may represent an unwarranted extension of work load and skills. The project appears to suffer from having some gaps in expertise (metallurgy and corrosion). Depending on the area of management, there appear to be some divergent views on the overall approach to waste package problems.

Program management does not now avail itself of technical reviews of the program or external technical guidance for planning. While the Panel observed a managerial attitude that seems to be aimed toward acquisition of such external help, the Panel is puzzled by the extensive time (three years or more) during which no such expert help has been obtained or identified. The Panel does recognize that DOE priorities of the past have been in part responsible for the lack of attention to the waste package problems of NNWSI.

The Panel is concerned by the apparent lack of communication between the designers and the materials technologists. It appeared to the Panel that designers have not fully communicated clear definitions of stresses and service conditions, and their requirements for materials properties data. Similarly, the materials engineers have failed to define and prioritize the potential failure modes.

Report of the Review of the SRP Corrosion Program by the Ad Hoc Corrosion Panel

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SUMMARY

The Ad Hoc Corrosion Panel, acting by request of DOE, reviewed the corrosion program of the SRP project. The conclusions of the Panel are based on (1) materials prepared for the Panel by SRP, (2) presentations by SRP to the Panel, and (3) responses of SRP to inquiries by the Panel.

The principal conclusions of the Panel are:

1. The corrosion program is deficient in strong and knowledgeable leadership, is subject to the debilitating effects of apparent neglect by upper management, has been unable to focus on appropriate technical goals and results in uncertainty that the DOE schedules can be met with data of acceptable quality.

2. A deficiency in the SRP management group is the absence of expertise in the understanding of the behavior of materials with respect to metallurgical changes, the various failure modes due to environmental exposures, and the experimental tools available to improve the state of knowledge.

3. The lack of detailed information on repository environments is inhibiting the generation of useful data and calls into question the results of selection processes for candidate materials.

4. Though many corrosion mechanisms have been noted, SRP intends to consider uniform corrosion as the principal container failure mode and plans to engineer around all other potential failure modes. SRP fails to recognize the need to convincingly demonstrate the ability to avoid these other failure modes.

5. A convincing demonstration of the absence of localized failures to meet repository requirements will require expertise that is not evident in the SRP program participants.

6. The SRP program does not include extensive efforts to improve the mechanistic understanding of corrosion processes on which modeling and extrapolation of long-term behavior is to be based. Therefore, there appears to be no firm basis for assessing the necessary quality and relevance of data.

7. The SRP position is that "key data for licensing" would receive no external review prior to submission to NRC. Reliance is to be placed on internal review. Project management has a negative attitude toward the MCO review of test procedures and data, and has little or no intention of using MCO on a broad scale. There is no substantial evidence that SRP can develop key data that meet the quality and scope requirements of the NRC and the EPA.

8. The overall corrosion effort was found to be parochial. Outside judgments relating to planning and interpretation of results were neither solicited nor welcomed.

A. Introduction

An Ad Hoc Panel initially established to review the corrosion program of the Materials Characterization Center (MCC) was reconvened at the request of DOE to review the parts of waste repository programs concerned with the corrosion of metallic waste package components. This report concerns the review of the corrosion program of the Salt Repository Project (SRP).

The Ad Hoc Panel was initially established by the Chairman of the Materials Review Board (MRB) following a request by Joel C. Haugen, Manager of the Materials Integration Office (MIO) of the Chicago Operations Office of the U.S. Department of Energy (letter, J. C. Haugen to M. J. Steindler, July 11, 1984). In January 1985, the MIO requested that the Ad Hoc Panel also review the corrosion programs of the repository projects (letter, J. C. Haugen to M. J. Steindler, January 11, 1985).

The Panel met in Columbus, Ohio, on July 1 and 2, 1985, with staff members of the SRP project. The Panel also met in executive session on the evening of July 1st and September 23 and 24. This report largely follows the requests for specific information contained in the letters from DOE that served as the charter for the Panel.

B. Scope of the Review

The MIO request stated that it "has been directed by the Office of Geologic Repositories to examine the repository projects' corrosion programs using the same guidelines as for the ... (MCC) ... Review ... The basis of the review will be the criteria documents of the NRC (10 CFR 60) and the EPA (40 CFR 191). As for the MCC review, the repository programs should be reviewed to the same standards as given in the letter Haugen to Steindler, July 11, 1984."

The Panel was requested to respond to the following three questions:

1. Are all the corrosion mechanisms that are likely to be operative in the repository environments being addressed, either by the SRP or included among the "key data" to be reviewed by the MRB?;

2. Are the tests being developed by the MCC and those proposed by the projects adequate to quantify the corrosion or penetration rates associated with those mechanisms?; and

3. Are the quality of the SRP work and the MCC/project interactions adequate to assure development and review of "key data" of sufficient scope and quality to show compliance with NRC and EPA criteria?

Though the principal focus of the review was the above three questions, the review was not restricted solely to them. As in the MCC review, ancillary issues related to the overall performance of the project arose, were discussed, and some are included in this report.

C. Results of the Review

The first part of the review responds to the three specific questions. The second part addresses ancillary issues and provides further detailed explanations considered germane to the review.

1. Responses to Questions

Q1. Are all the corrosion mechanisms that are likely to be operative in the repository environments being addressed, either by the SRP or included among the "key data" to be reviewed by the MRB?;

The two parts of the question are considered separately.

Part 1: Are all the corrosion mechanisms ... being addressed ... by the SRP ...?

Many corrosion mechanisms have been noted by SRP, but SRP intends to consider only uniform corrosion and plans to engineer around all other potential failure modes. The Panel concluded that the SRP fails to recognize the need to demonstrate the ability to avoid these other failure modes. As part of such a demonstration, SRP must define a credible environment. The casual nature of the description of the expected environment by SRP, particularly the presence of significant liquid waters and hydrogen sulfide in solution or in the gas phase, led the Panel to the conclusion that SRP management does not appreciate the impact of such aspects of the environment on corrosion processes.

The Panel concludes that the attempt to engineer around all but uniform corrosion is unlikely to be successful, particularly for the welded closure of the primary material, and the selected back-up material.

Part 2: Are all the corrosion mechanisms ... being addressed ... [or] included among the "key data" to be reviewed by the MRB?

Based on the SRP response, the Panel concluded that the answer is NO.

It appears that little data will be submitted to the MRB. SRP management does not consider the MRB to be an appropriate review entity for either procedures or data (especially the latter). SRP questions the submission of procedures to the MRB on two bases: 1) MRB action is too slow, and 2) rejection would be expected. The consequence of both factors, according to the SRP, is delay of the program. The Panel found the second point (rejection of submissions) to be particularly telling.

SRP makes the following distinction for "key data": 1) key data for licensing are those that will support the

conclusion that the waste package design meets the required containment function, and 2) key data for submission to the MRB are those selected by the SRP as being appropriate and advisable for submission. Thus, SRP intends to be the sole arbiter as to what, if any, key data would be submitted to the MRB. The stated SRP position is that key data for licensing would receive no external review. The Panel was told that SRP will arrange for internal review or review in an unspecified manner by DOE.

The Panel concludes that the submission of key data for review by the MRB are not part of the processes or plans of the SRP. This conclusion is reinforced by emphatic statements from SRP management. Hence, review of key data on the variety of corrosion mechanisms likely to be operative is apparently not part of the SRP program.

Q2. Are the tests being developed by the MCC and those proposed by the projects adequate to quantify the corrosion or penetration rates associated with those mechanisms?

This questions is also divided into two parts.

Part 1: Are the tests being developed by the MCC ... adequate ...?

The response to this question relating to the MCC is not germane to the review of the Corrosion Programs of SRP.

Part 2: Are the tests ... proposed by the projects adequate ...?

The response of the Panel to this question is NO. The Panel concludes that the SRP test program is not adequate to quantify corrosion rates and identify corrosion mechanisms. Among the deficiencies are the following: inadequate description of the environment (e.g., sulfur compounds, water), inadequate demonstration of the avoidance of localized attack, lack of a sound basis for materials selection, and the omission of consideration of the metallurgical aspects of closure and long-term metallurgical changes.

The SRP has identified a set of tests that include a broad range of mechanisms potentially operative in a salt repository environment. Even in the absence of definitive information on the repository environment, this set of tests is deficient. Moreover, tests carried out to date appear to the Panel to be largely of a screening type, not designed or able to yield sound data on mechanisms or for extrapolation of long-term performance. Hence, a judgment on the adequacy of the proposed tests suffers from too little experience within SRP and an absence of a clear target. The Panel

believes that, on the basis of the on-going program, mechanistic data and data needed to support predictive models may not be available from the SRP program or, at least not in a timely manner. The Panel concludes that only the uniform corrosion studies are likely to yield data adequate to quantify rates and mechanisms.

Q3. Are the quality of the SRP work and the MCC/project interactions adequate to assure development and review of "key data" of sufficient scope and quality to show compliance with NRC and EPA criteria?

Part 1: Are the quality of the SRP work ... adequate to assure ...?

A formalized SRP QA system is in effect. The SRP and the Panel agree that conformance with the established QA system is necessary but not sufficient to ensure the usefulness, reliability, and relevance of data. The Panel believes that these issues related to licensing are not being addressed by SRP.

Part 2: Are the quality of ... the MCC/project interactions adequate to assure ...?

The Panel concluded that SRP/MCC interactions are not particularly productive. The main use of the MCC seems to be an editorial one, i.e., rewriting and reformating selected SRP procedures to meet MRB requirements. The MCC has apparently not been involved in planning and developing SRP tests, in assisting in the development of an overall program, or in the generation of data.

SRP management considers the MRB process as unnecessary and appears to view the MRB with apprehension. The SRP management describes the MRB process as slow, likely to result in rejection of SRP submissions and one that jeopardizes the timeliness of their program. SRP has no plans to submit data to the MRB. The Panel notes that SRP has no direct experience with the MRB approval process. The SRP plans to evaluate their data by an internal review process prior to submission to DOE and NRC. By this procedure there will be no independent external review of the SRP data prior to licensing.

The Panel observes that the SRP has no apparent plans or procedures in place that relate the corrosion program to the process of showing compliance with regulatory requirements. The effective rejection of the MCO system, coupled with the self-determination of key data and their quality, appears to lead to the consequence that SRP data will be submitted by DOE to the licensing process where the

data will receive their first thorough external evaluation. This procedure is, in the judgment of the Panel, accepted by SRP and implemented with the approval of the DOE field office. Thus, the Panel has been provided with no substantial evidence that SRP, with or without interaction with the MCO, can develop key data that meet the quality and scope requirements of the NRC and EPA.

2. Other Issues and Observations

The Panel is aware that the scope of its activities, defined by the Haugen letter, could be narrowly interpreted as dealing only with answers to the three questions. It is the unanimous conclusion of the Panel, however, that the topic of corrosion is of major importance to the repository performance and that this conclusion is shared by DOE. The Panel has, therefore, elected to provide ancillary comments that deal with issues related to the corrosion program and about which Panel members have great concern or strong feelings. These issues were developed in response to inquiries and discussions initiated by both the Panel and the project. In some instances, the ancillary comments represent an extension of observations summarized above.

a. Technical Issues

The following technical issues were identified by the Panel as issues that either (1) are not currently being adequately addressed, or (2) are being adequately addressed but not properly integrated into a thorough and self-consistent program.

1. Definition of Failure Modes

The SRP believes that uniform corrosion is the only plausible failure mode that can be quantified. It is, therefore, the only failure mode that is being addressed. This SRP approach is predicated on the materials selection and design processes that eliminate the importance of localized corrosion phenomena. The Panel does not believe that this concept is viable.

The Panel found no support for the assumption that the repository environment can be controlled sufficiently to ensure that uniform corrosion remains the dominant corrosion mechanism over the required time period. One candidate alloy, Ti Code 12, is already known to most likely fail by hydrogen embrittlement.

Finally, the Panel notes that demonstration of the absence or insignificance of localized failure modes to meet repository requirements is difficult under the best circumstances and will require talents that are not evident among the SRP program participants.

2. Characterization of the Environment

The SRP is dealing with seven sites. The Panel learned that major variability of chemical environments can be expected within candidate formations and concluded that these variations would negate extrapolation of corrosion results for a given fixed environment. Thus, the Panel concludes that the lack of detailed information on the repository environments inhibits generation of useful data and calls into question the results of selection processes for candidate materials.

3. Materials Selection

A low carbon steel, A-216, was chosen as the primary reference material principally because of its cost, fabricability, and the expectation that its only failure mode would be uniform corrosion at an acceptably low rate. Actual SRP test data showed that the corrosion resistance of A-216 steel was inferior to a number of other alloys tested, including AISI 1020, a wrought material. It is generally known that heat-to-heat variations in cast steels of the A-216 type can be fairly broad within specification limits (e.g., pearlite distribution), and corrosion behavior may vary accordingly. Wrought products, on the other hand, are inherently more uniform, both from the point of view of mechanical properties and corrosion performance, and have narrower specification limits. Therefore, it was not clear to the Panel why A-216 is being retained as a reference material. There was no indication that SRP was considering a change.

Ti Code 12 was selected as the back-up material. SRP is aware of the potential seriousness of hydrogen embrittlement problems, and is conducting tests to quantify hydrogen pick-up. SRP appears to be generating this additional information in order to justify disqualifying Ti Code 12. The Panel noted that available data should be more than sufficient to displace Ti Code 12 on the basis of hydrogen embrittlement and hydrogen pick-up. However, the selection of this alloy by Sandia for the WIPP program posed institutional problems that overshadowed the technical considerations.

The Panel concluded that the selection of A-216, a steel which is apparently inferior to other materials tested in the SRP program, illustrates the weakness in the material selection process. Further, adherence to titanium alloys with a likely dismissal at a later date endangers the ability to provide a sound alternate candidate on the basis of well-developed data. The Panel believes these risks to be substantial and in need of rectification.

4. Pitting and Crevice Corrosion

The propagation of pits is being studied but pit initiation is not. The Panel believes that pit initiation should be included in parametric studies that reflect sensitivity to the parameters of time, temperature, and environment. The Panel questioned whether the simulation of pits by using small pre-drilled holes in specimens will yield demonstrably useful results.

The Panel also noted that electrochemical methods, which are judged to be among the most suitable techniques, were not being used for studying pitting and crevice corrosion. The Panel was unable to discern the application of any other test methods that could yield data useful for supporting or refuting the possibility of these corrosion modes. The Panel recognizes the experimental and statistical difficulties in studies of the initiation of pitting and crevice attack but believes that the absence of such studies are detrimental to the characterization of the resistance of metals, especially carbon steels, to these types of attack.

5. Stress Corrosion

The Panel believes that relegation of SCC to a low-priority status is incorrect.

SRP has set up a testing program that uses a variety of loading configurations. The SRP test program does not appear to be based on a thorough, consistent, and well thought-out process grounded in mechanistic understanding. The data obtained thus far exhibit considerable and expected scatter, making extrapolation to lifetime predictions questionable. The Panel believes that other test protocols may be necessary to yield acceptable and useful results.

The Panel notes that the attempt to obtain crack-growth rates by use of cyclic loading may produce data irrelevant to stress corrosion cracking, because SCC crack growth in carbon steels may occur by a different mechanism than that of corrosion fatigue. Also, it is not likely that two to seven-day slow-strain-rate tests will yield data useful to extrapolate behavior to 300 to 1000 years.

6. Long-Term Metallurgical Change

The SRP has no apparent plan for evaluating whether or not hydrogen attack in cast or low alloy steels is a problem (e.g., CH_4 formation) and whether or not spontaneous strain-aging occurs at low temperatures over long time periods in or near welds. Furthermore, phenomena such as temper embrittlement, which are not normally considered to be of

significance for short time exposures, may occur as a result of the very long time ageing associated with the repository. The SRP has not addressed how such changes might affect overall degradation and/or interact with other corrosion or embrittlement mechanisms.

7. Radiation Effects and Hydrogen Process Damage

Hydrogen pick-up by Ti Code 12 (tested at PNL) suggests that hydrogen embrittlement may be a problem for this material. Yet, this corrosion mechanism does not appear to have a high priority in the test program.

SRP is conducting tests to determine hydrogen absorption rates of Ti Code 12 under irradiation conditions. Apparently, linear extrapolation of hydrogen absorption to a three-hundred-year period in a number of environments gives some of the SRP management confidence that Ti Code 12 is a good back-up material. On the other hand, there were indications by some members of the SRP staff that Ti Code 12 should be disqualified because of its problems with hydrogen.

For low alloy steels, see comments under Long-Term Metallurgical Changes.

8. Closure of the Container

The attention given to problems that may be caused by welded closures was judged by the Panel to be inadequate. Metallurgical changes, such as the formation of martensite in low alloy steels, are known to increase susceptibility to hydrogen embrittlement as well as to other forms of localized attack. This will be aggravated by the expected presence of H_2S, that has been all but ignored in the testing program.

The Panel notes the absence of planning for a back-up method of closure should the problems associated with the failure modes of welds not be totally resolvable.

9. Modeling and Extrapolation

The Panel found no indication that the SRP has adequately addressed the difficult issue of long-term reliability and extrapolation of data. A mathematical model for selection of test parameters has been developed in which key corrosion test parameters are initially selected on the basis of best educated guesses of expected corrosion rates by a group of experimenters. The effort is apparently led by a statistician on the SRP staff. The activities of the group appear to be restricted to considerations of uniform

corrosion, and no plans were evident to the Panel that would extend the model to include localized corrosion effects. Although it appeared that none of the corrosion data generated by the SRP program has been used in the model directly, the best guesses of the group likely reflected those data in some measure. The Panel observed that the SRP program does not provide significant efforts to improve the mechanistic understanding of corrosion processes in the SRP environment. Hence, the only means of incorporating corrosion mechanisms into the modeling process is the knowledge and experience of each expert. Further, the modeling group has not provided (and perhaps has not been asked to provide) guidance with respect to the quality of the data that is needed for use in reliability assessments. The Panel was unable to determine whether the consensus method (sometimes applied to business decision making) has demonstrable merit for its present application, whether the selection of key parameters by this process will be complete, and whether SRP intends to use these estimates based on, at best, short-term data for extrapolation to repository times. The Panel was shown little information on the results obtained by the modeling group and thus was not able to evaluate either the composition of the group of experts or the quality of its output.

10. Data Quality and Quality Control

Formalized QA procedures are in effect to assure complete documentation and retention of records, proper authorizations for plans and experiments, etc. These formalized procedures do not address the important aspects of program planning, i.e., what kind of data is needed, the relevance and usefulness of data once obtained, or accuracy and precision determinations. SRP has stated that they will rely heavily on expert opinion for assessments of the quality of data and their underlying procedures, but they do not have such a review procedure in place. The Panel is not aware how this will be accomplished and is concerned about the efficacy of this process.

The Panel has not undertaken a detailed examination of the quality of the experimental results on uniform corrosion. However, even a preliminary examination reveals that the data quality is not adequate for long-term extrapolation, particularly in view of the unexpected changes in rates (and possibly mechanisms) already evident in their data. Most other studies appear to represent screening efforts. The Panel could not judge the quality of data on localized corrosion since none had yet been obtained. The Panel notes, however, that the applicability and quality of corrosion data to be used for predictions and modeling are

likely to be closely related to the extent of knowledgeable planning that precedes the experiments. Such planning has not been evident.

11. Leadership, Management, and Review Processes

The Panel noted that the central core of SRP management does not provide strong technical leadership.

The Panel concludes that a deficiency in the SRP management group is the absence of expertise in the understanding of the behavior of materials with respect to metallurgical changes, the various failure modes due to environmental exposures, and the experimental tools available to improve the state of knowledge. The experimental corrosion program is conducted entirely by external subcontractors with reliance placed on the technical expertise of such subcontractors. The Panel believes that this mode of operation, to be successful, requires strong technical coordination at the policy-making level that is sensitive to the technical contributions from subcontractors, and a willingness to modify programs as additional information (subcontractor and other) becomes available. The Panel discerns that technical direction and coordination are lacking in the SRP.

It was noted that the upper management levels of SRP did not appear to consider the metal barrier portion of the overall program a significant problem and hence did not warrant more than four part-time people. The overall corrosion effort of SRP was viewed by the Panel to be parochial and outside judgments were neither solicited nor welcomed.

The Panel found that there is no apparent external review process of the experimental SRP corrosion effort in place. The program management has a negative attitude toward the MCC/MRB review of test procedures and data, and has little or no intention of using MCC/MRB on a broad scale. Reliance is to be placed on internal review and the ultimate acceptance (or rejection) of licensing information by the NRC.

The Panel was informed that corrosion-related studies applicable to a salt repository had been started in 1978 by SRP/ONWI. It is not clear to the Panel why, after seven years, the SRP has not produced a coherent program plan and substantive data pertinent to regulatory requirements. The Panel has reservations concerning the applicability of the consensus test matrix methodology to the corrosion problems attending the licensing of a repository.

The Panel concludes that the SRP corrosion program is deficient in a strong and knowledgeable leadership, has been subject to the debilitating effects of apparent neglect by upper management, has been unable to focus on appropriate technical goals, and results in serious uncertainty that the DOE schedule can be met with data of acceptable quality.

MATERIALS REVIEW BOARD

AD HOC CORROSION PANEL

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MEETINGS OF PANEL

RICHLAND, WA	NOV. 8-9, 1984 (WITH MCC)
O'HARE	FEB. 12, 1985 (RE: MCC REPORT)
RICHLAND, WA	JUNE 18-19, 1985 (WITH BWIP)
LIVERMORE, CA	JUNE 20-21, 1985 (WITH NNWSI)
COLUMBUS, OH	JULY 1-2, 1985 (WITH SRP)
O'HARE	SEP. 23-24, 1985 (RE: BWIP, NNWSI, AND SRP REPORTS)

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AD HOC CORROSION PANEL

BASES FOR CONCLUSIONS REGARDING MCC, BWIP, NNWSI, AND SRP

1. CHARTER LETTERS FOR PANEL FROM DOE-HQ AND MIO.
2. REGULATIONS.
3. MATERIAL SUBMITTED TO PANEL IN RESPONSE TO REQUESTS FROM CHAIRMAN.
4. MATERIAL PRESENTED TO PANEL BY PROJECTS.
5. DISCUSSION BETWEEN PANEL AND PROJECT STAFF.

FOCUS OF CONCLUSIONS

1. CHARTER LETTER QUESTIONS AND PANEL MEMBER VIEWS ON RELATED ISSUES.
2. UNPLEASANT BUT REALISTIC, BASED ON CONCERNS ABOUT THE SUCCESS AND SCHEDULE OF THE DOE-OCRWM MISSION.

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GENERAL AND COMMON FINDINGS - ALL REVIEWS

1. THE REQUIRED BROAD RANGE OF CORROSION STUDIES THAT ARE NEEDED TO SATISFY NRC/EPA CRITERIA ARE ABSENT. ONLY SELECTED CORROSION FAILURE MODES ARE BEING STUDIED, BASED ON WHAT IS EASY TO DO, WHAT CAN BE EASILY EXTRAPOLATED, OR TESTING TECHNIQUES FAMILIAR TO STAFF. THE NEED TO SHOW ABSENCE OR INSIGNIFICANCE OF OTHER FAILURE MODES IS GENERALLY NOT APPRECIATED OR PART OF PROGRAM PLANNING.

2. SOME IN-HOUSE EXPERTISE IN CORROSION AND METALLURGY IS ABSENT OR WEAK, RESULTING IN TECHNICALLY WEAK PROGRAM LEADERSHIP. A MAJOR IN-HOUSE EXPERIMENTAL CORROSION EFFORT IS BEING PURSUED BY ONLY ONE PROJECT.

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GENERAL AND COMMON FINDINGS - ALL REVIEWS (CONT'D)

3. ALL PROJECTS HAVE REJECTED THE USE OF MCO SYSTEM AS ORIGINALLY INSTITUTED BY MSC. NO SIGNIFICANT USE OF THE MCO SYSTEM AND THE HANDBOOK IS PLANNED BY ANY PROJECT. INVOLVEMENT OF THE MCC IN PLANNING THE OVERALL CORROSION PROGRAM FOR OCRWM IS NIL.

4. THERE IS A GENERAL ABSENCE OF OPERATIONAL PLANNING FOR THE UPCOMING LICENSING PROCESS. PROJECTS HAVE NOT IDENTIFIED WHAT IS NEEDED FOR LICENSING. CONCERNS OVER DATA QUALITY, VISIBILITY OF THE PROGRAM, AND LONG-TERM EXTRAPOLATION AND MODELING OF ESTABLISHED FAILURE MECHANISMS ARE NOT PART OF THE NEAR-TERM PROGRAM CONFIGURATION.

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SUMMARY OF FINDINGS - MCC

1. MCC DOES NOT HAVE ITS OWN CORROSION PROGRAM. ROLE OF MCC IN CORROSION (NOW) SIMPLY PROVIDES LABORATORY SERVICES.

2. CORROSION MECHANISMS BEING ADDRESSED ARE UNIFORM CORROSION AND A MODEST EFFORT ON STRESS-CORROSION CRACKING. LIKELY FAILURE MODES ARE NOT BEING ADDRESSED BY THE MCC.

3. QUALITY OF WORK IS NOT ADEQUATE AND RESULTS MAY NOT BE REPOSITORY RELEVANT. ACCELERATED TESTS ARE NOT BEING DEVELOPED.

4. MCC-PROJECT INTERACTIONS ARE UNSATISFACTORY. A ONE-DIRECTIONAL RELATIONSHIP WITH TWO OF THE PROJECTS EXISTS. LITTLE OTHER TECHNICAL INTERACTIONS WITH PROJECTS WERE EVIDENT.

5. MCC PROGRAM NEEDS FOCUS AND DIRECTION. ANTICIPATED RESOURCES FOR MCC CORROSION WILL PROBABLY NOT OVERCOME MALAISE OR UNSUITABILITY OF STAFF FOR THE FORMIDABLE TASK OF DEVELOPING AND IMPLEMENTING A COMPREHENSIVE PROGRAM.

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SUMMARY OF FINDINGS - BWIP

1. BWIP CORROSION PROGRAM FOCUSED ON UNIFORM CORROSION. INSUFFICIENT ATTENTION TO DEMONSTRATION THAT OTHER MODES ARE NOT SIGNIFICANT. PLANS FOR THE LATTER ARE NOT EVIDENT. INADEQUATE ATTENTION IS GIVEN TO CLOSURE PROBLEMS THAT ARE EXACERBATED BY THICK CONTAINER WALLS.

2. QUANTIFICATION OF CORROSION RATES AND EXTRAPOLATION OF THESE RATES ARE NOT ADEQUATELY CONSIDERED. MODELING EFFORT IS INADEQUATE AND NOT REPOSITORY RELATED.

3. EXTERNAL REVIEW OF DATA FOR LICENSING PRIOR TO SUBMISSION TO NRC NOT PLANNED. OUTSIDE EXPERTISE NOT USED AND EXTERNAL REVIEWS OF PROGRAM AND RESULTS ARE ACTIVELY DISCOURAGED. IN-HOUSE EXPERTISE IN CORROSION IS WEAK.

4. CORROSION RESULTS NOT OBVIOUSLY RELATED TO REGULATORY REQUIREMENTS.

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AD HOC CORROSION PANEL

SUMMARY OF FINDINGS - NNWSI

1. INADEQUATE BASIS FOR MATERIAL SELECTION OF STAINLESS STEEL AND AGAINST ADVICE OF CONSULTANT. MUCH OF CORROSION PROGRAM STILL IN SCOPING/SCREENING STAGE. PROBLEMS ASSOCIATED WITH CLOSURES NOT BEING ADDRESSED.

2. PROGRAM PLAN IDENTIFYING WAY TO REACH CORROSION GOALS NOT AVAILABLE. MODEL DEVELOPMENT AND EXTRAPOLATION ISSUES NOT BEING ADDRESSED. APPLICATION OF CURRENT EXPERIMENTAL RESULTS NOT OBVIOUS.

3. NO EXTERNAL REVIEW OR GUIDANCE FOR PROGRAM IN PLACE.

4. INTERACTION WITH MCC MINIMAL AND STRAINED. PLANNED SUBMISSIONS THROUGH MCO SYSTEM MINIMAL.

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SUMMARY OF FINDINGS - SRP

1. ABSENCE OF PERTINENT REPOSITORY INFORMATION MAKES MATERIALS SELECTION QUESTIONABLE AND INHIBITS COLLECTION OF USEFUL DATA.

2. UNIFORM CORROSION THE ONLY FAILURE MODE CONSIDERED. SRP POLICY OF ENGINEERING AROUND ALL OTHER (MORE LIKELY) MODES BELIEVED TO BE UNWORKABLE. EFFORT TO SHOW LOCALIZED CORROSION TO BE INSIGNIFICANT IS INADEQUATE.

3. MODELING AND MECHANISM STUDIES TO SHOW COMPLIANCE WITH REGULATIONS ARE NOT CORRELATED WITH EXPERIMENTAL PROGRAM OR ARE ENTIRELY ABSENT.

4. NO INTENT TO SUBMIT TO EXTERNAL REVIEW BY MCO SYSTEM WAS EVIDENT.

5. SRP STAFF LACKS EXPERTISE IN IMPORTANT METALLURGY AND CORROSION AREAS. KNOWLEDGEABLE LEADERSHIP OF PROGRAM NOT EVIDENT. ABILITY TO MEET OVERALL LICENSING MILESTONES APPEARS ABSENT.

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