UNITED STATES
NUCLEAR REGULATORY COMMISSION
ADVISORY COMMITTEE ON REACTOR SAFEGUARDS
WASHINGTON, DC 20555 - 0001

January 11, 2017

Mr. Michael Weber, Director
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

SUBJECT: ACRS ASSESSMENT OF THE QUALITY OF SELECTED NRC RESEARCH PROJECTS - FY 2016

Dear Mr. Weber:

Attached is our report on the quality assessment of the following research projects:

- Effects of Thermal Aging and Neutron Irradiation on Crack Growth Rate and Fracture Toughness of Cast Stainless Steels and Austenitic Stainless Steel Welds

  NUREG/CR-7184: Crack Growth Rate and Fracture Toughness Tests on Irradiated Cast Stainless Steel

  - The work is professional quality, but does not adequately address uncertainties and sensitivities that might affect one of the report's key findings.

  NUREG/CR-7185: Effects of Thermal Aging and Neutron Irradiation on Crack Growth Rate and Fracture Toughness of Cast Stainless Steels and Austenitic Stainless Steel Welds

  - This project was found to be better than professional quality work that satisfies the research objectives and with some elements of innovation and insight.

- NUREG/CR-7200: Influence of Coupling Erosion and Hydrology on the Long-Term Performance of Engineered Surface Barriers

  - This project was found to be less than satisfactory. With some limitations, the results meet the research objectives.

These projects were selected from a list of candidate projects suggested by the Office of Nuclear Regulatory Research.

We anticipate receiving a list of candidate projects for quality assessment in FY 2017 prior to our March 2017 meeting.

Sincerely,

/RA/

Dennis C. Bley,
Chairman

Attachment: As stated

These projects were selected from a list of candidate projects suggested by the Office of Nuclear Regulatory Research.

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Sincerely,

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Dennis C. Bley,
Chairman

Attachment: As stated

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OFFICE	ACRS	SUNSI Review	ACRS	ACRS	ACRS
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DATE	01/11/17	01/11/17	01/12/17	01/12/17	01/12/17

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Assessment of the Quality of Selected NRC Research Projects by the Advisory Committee on Reactor Safeguards - FY 2016

November 2016

U.S. Nuclear Regulatory Commission
Advisory Committee on Reactor Safeguards
Washington, DC 20555-0001

ABOUT THE ACRS

The Advisory Committee on Reactor Safeguards (ACRS) was established as a statutory Committee of the Atomic Energy Commission (AEC) by a 1957 amendment to the *Atomic Energy Act* of 1954. The functions of the Committee are described in Sections 29 and 182b of the Act. The *Energy Reorganization Act* of 1974 transferred the AEC's licensing functions to the U.S. Nuclear Regulatory Commission (NRC), and the Committee has continued serving the same advisory role to the NRC.

The ACRS provides independent reviews of, and advice on, the safety of proposed or existing NRC-licensed reactor facilities and the adequacy of proposed safety standards. The ACRS reviews power reactor and fuel cycle facility license applications for which the NRC is responsible, as well as the safety-significant NRC regulations and guidance related to these facilities. The ACRS also provides advice on radiation protection, radioactive waste management, and earth sciences in the agency's licensing reviews for fuel fabrication and enrichment facilities and waste disposal facilities. On its own initiative, the ACRS may review certain generic matters or safety-significant nuclear facility items. The Committee also advises the Commission on safety-significant policy issues, and performs other duties as the Commission may request. Upon request from the U.S. Department of Energy (DOE), the ACRS provides advice on U.S. Navy reactor designs and hazards associated with the DOE's nuclear activities and facilities. In addition, upon request, the ACRS provides technical advice to the Defense Nuclear Facilities Safety Board.

ACRS operations are governed by the *Federal Advisory Committee Act*, which is implemented through NRC regulations at Title 10, Part 7, of the *Code of Federal Regulations*. ACRS operational practices encourage the public, industry, State and local governments, and other stakeholders to express their views on regulatory matters.

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Mr. Matthew Sunseri, Retired President and Chief Executive Officer of Wolf Creek Nuclear Operating Corporation

ABSTRACT

In this report, the ACRS presents the results of its assessment of the quality of selected research projects sponsored by the NRC Office of Nuclear Regulatory Research. An analytic/deliberative methodology was adopted by the Committee to guide its review of research projects. The methods of multi-attribute utility theory were used to structure the objectives of the review and develop numerical scales for rating each project with respect to each objective. The results of the evaluations of the quality of the selected research projects are summarized as follows:

- Effects of Thermal Aging and Neutron Irradiation on Crack Growth Rate and Fracture Toughness of Cast Stainless Steels and Austenitic Stainless Steel Welds

  NUREG/CR-7184: Crack Growth Rate and Fracture Toughness Tests on Irradiated Cast Stainless Steel

  - The work is of professional quality, but does not adequately address uncertainties and sensitivities that might affect one of the report's key findings.

  NUREG/CR-7185: Effects of Thermal Aging and Neutron Irradiation on Crack Growth Rate and Fracture Toughness of Cast Stainless Steels and Austenitic Stainless Steel Welds

  - This project was found to be better than professional quality work that satisfies the research objectives and with some elements of innovation and insight.

- NUREG/CR-7200: Influence of Coupling Erosion and Hydrology on the Long-Term Performance of Engineered Surface Barriers

  - This project was found to be less than satisfactory. With some limitations, the results meet the research objectives.

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ABBREVIATIONS

ACRS	Advisory Committee on Reactor Safeguards
AEC	Atomic Energy Commission
AGW	Artificial Ground Water
BWR	Boiling Water Reactor
CASS	Cast Austenitic Stainless Steel
dpa	displacements per atom
CGR	Crack Growth Rate
FEA	Finite Element Analysis
FY	Fiscal Year
IASCC	Irradiation-Assisted Stress Corrosion Cracking
LLRW	Low-Level Radioactive Waste
LWR	Light Water Reactor
NRC	Nuclear Regulatory Commission
PWR	Pressurized Water Reactor
RES	Office of Nuclear Regulatory Research
SCC	Stress Corrosion Cracking
U.S.	United States

1 INTRODUCTION

The Nuclear Regulatory Commission (NRC) maintains a safety research program to ensure that the agency's regulations have sound technical bases. The research effort is needed to support regulatory activities and agency initiatives while maintaining an infrastructure of expertise, facilities, analytical tools, and data to support regulatory decisions.

The Office of Nuclear Regulatory Research (RES) is required to have an independent evaluation of the effectiveness (quality) and utility of its research programs. This evaluation is required by the NRC Strategic Plan that was developed as mandated by the Government Performance and Results Act. Since fiscal year (FY) 2004, the Advisory Committee on Reactor Safeguards (ACRS) has been assisting RES by performing independent assessments of the quality of selected research projects [1-12]. The Committee established the following process for conducting the review of the quality of research projects:

- RES submits to the ACRS a list of candidate research projects for review because they have reached sufficient maturity that meaningful technical review can be conducted.
- The ACRS selects a maximum of four projects for detailed review during the fiscal year.
- A panel of three to four ACRS members is established to assess the quality of each research project.
- The panel follows the guidance developed by the ACRS Full Committee in conducting the technical review. This guidance is discussed further below.
- Each panel assesses the quality of the assigned research project and presents an oral and a written report to the ACRS Full Committee for review. This review is to ensure uniformity in the evaluations by the various panels.
- The ACRS submits an annual summary report to the RES Director.

Based on later discussions with RES, the ACRS made the following enhancements to its quality assessment process:

- After familiarizing itself with the research project selected for quality assessment, each panel holds an informal meeting with the RES project manager and representatives of the user office to obtain an overview of the project and the user office's insights on the expectations for the project with regard to their needs.
- In addition, if needed, an additional informal meeting is held with the project manager to obtain further clarification of information prior to completing the quality assessment.

The purposes of these enhancements were to ensure greater involvement of the RES project managers and their program office counterparts during the review process and to identify objectives, user office needs, and perspectives on the research projects.

An analytic/deliberative decision-making framework was adopted for evaluating the quality of NRC research projects. The definition of quality research adopted by the ACRS includes two major characteristics:

- Results meet the objectives
- Results and methods are adequately documented

Within the first characteristic, the ACRS considered the following general attributes in evaluating the NRC research projects:

- Soundness of technical approach and results
  - Has execution of the work used available expertise in appropriate disciplines?
- Justification of major assumptions
  - Have assumptions key to the technical approach and the results been tested or otherwise justified?
- Treatment of uncertainties/sensitivities
  - Have significant uncertainties been characterized?
  - Have important sensitivities been identified?

Within the general category of documentation, the projects were evaluated in terms of the following measures:

- Clarity of presentation
- Identification of major assumptions

In this report, the ACRS presents the results of its assessment of the quality of the research projects associated with:

- Effects of Thermal Aging and Neutron Irradiation on Crack Growth Rate and Fracture Toughness of Cast Stainless Steels and Austenitic Stainless Steel Welds
  - NUREG/CR-7184: Crack Growth Rate and Fracture Toughness Tests on Irradiated Cast Stainless Steel
  - NUREG/CR-7185: Effects of Thermal Aging and Neutron Irradiation on Crack Growth Rate and Fracture Toughness of Cast Stainless Steels and Austenitic Stainless Steel Welds
- NUREG/CR-7200: Influence of Coupling Erosion and Hydrology on the Long-Term Performance of Engineered Surface Barriers

These projects were selected from a list of candidate projects suggested by RES.

The methodology for developing the quantitative metrics (numerical grades) for evaluating the quality of NRC research projects is presented in Section 2 of this report. The results of the assessment and ratings for the selected projects are discussed in Section 3.

2 METHODOLOGY FOR EVALUATING THE QUALITY OF RESEARCH PROJECTS

To guide its review of research projects, the ACRS has adopted an analytic/deliberative methodology [13-14]. The analytical part utilizes methods of multi-attribute utility theory [15-16] to structure the objectives of the review and develop numerical scales for rating the project with respect to each objective. The objectives were developed in a hierarchical manner (in the form of a "value tree"), and weights reflecting their relative importance were developed. The value tree and the relative weights developed by the Full Committee are shown in Figure 1.

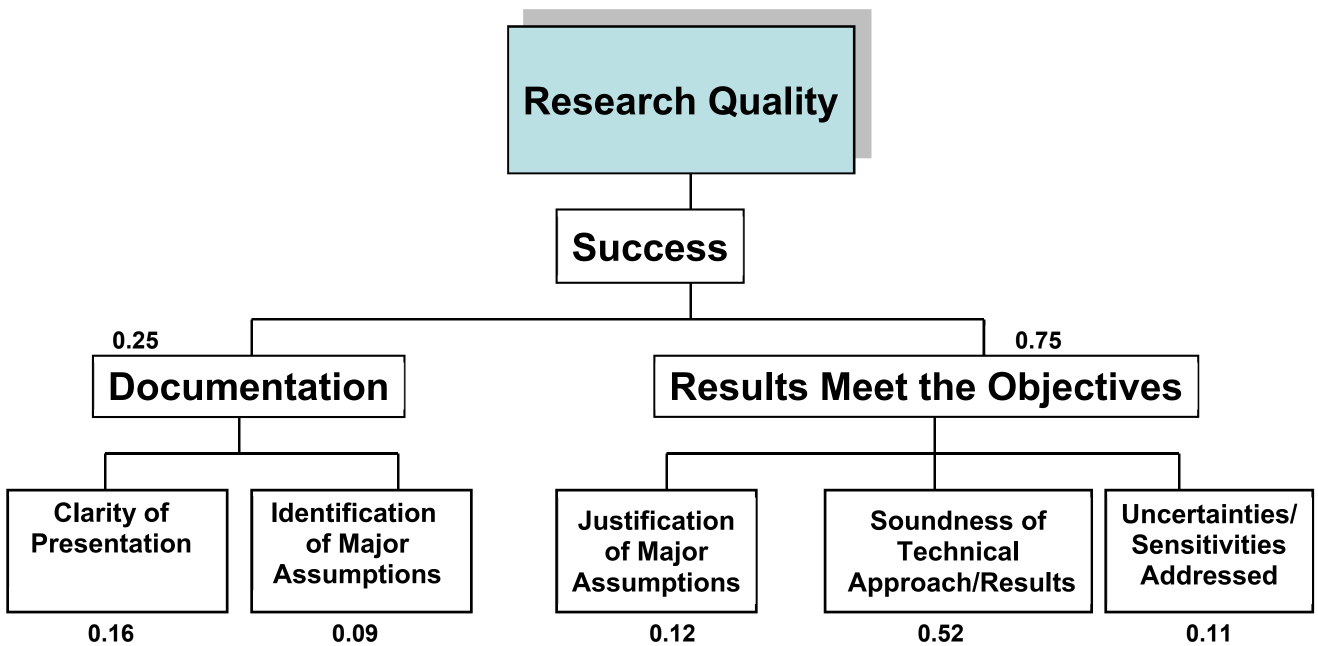

Figure 1. The Value Tree used for Evaluating the Quality of Research Projects

The quality of projects is evaluated in terms of the degree to which the results meet the objectives of the research and of the adequacy of the documentation of the research. It is the consensus of the ACRS that meeting the objectives of the research should have a weight of 0.75 in the overall evaluation of the research project. Adequacy of the documentation was assigned a weight of 0.25. Within these two broad categories, research projects were evaluated in terms of subsidiary "performance measures":

- Justification of major assumptions (weight: 0.12)
- Soundness of the technical approach and reliability of results (weight: 0.52)
- Treatment of uncertainties and characterization of sensitivities (weight: 0.11)

Documentation of the research was evaluated in terms of the following performance measures:

- Clarity of presentation (weight: 0.16)
- Identification of major assumptions (weight: 0.09)

To evaluate how well the research project performed with respect to each performance measure, constructed scales were developed as shown in Table 1. The starting point is a rating of 5, Satisfactory (professional work that satisfies the research objectives). Often in evaluations of this nature, a grade that is less than excellent is interpreted as pejorative. In this ACRS evaluation, a grade of 5 should be interpreted literally as satisfactory. Although innovation and excellent work are to be encouraged, the ACRS realizes that time and cost place constraints on innovation. Furthermore, research projects are constrained by the work scope that has been agreed upon. The score was, then, increased or decreased according to the attributes shown in the table. The overall score of the project was produced by multiplying each score by the corresponding weight of the performance measure and adding all the weighted scores.

A panel of three to four ACRS members was formed to review each selected research project. Each member of the review panel independently evaluated the project in terms of the performance measures shown in the value tree. The panel deliberated the assigned scores and developed a consensus score, which was not necessarily the arithmetic average of individual scores. The panel's consensus score was discussed by the Full Committee and adjusted in response to ACRS members' comments. The final consensus scores were multiplied by the appropriate weights, the weighted scores of all the categories were summed, and an overall score for the project was produced. A set of comments justifying the ratings was also produced.

Table 1. Constructed Scales for the Performance Measures

SCORE	RANKING	INTERPRETATION
10	Outstanding	Creative and uniformly excellent
8	Excellent	Important elements of innovation or insight
5	Satisfactory	Professional work that satisfies research objectives
3	Marginal	Some deficiencies identified; marginally satisfies research objectives
0	Unacceptable	Results do not satisfy the objectives or are not reliable

3. RESULTS OF QUALITY ASSESSMENT

3.1 Effects of Thermal Aging and Neutron Irradiation on Crack Growth Rate and Fracture Toughness of Cast Stainless Steels and Austenitic Stainless Steel Welds

Introduction

Cast austenitic stainless steel (CASS) is used extensively in reactor coolant loops and reactor internals in nuclear plants (PWRs and BWRs). Differing from wrought stainless steel (SS), which is entirely austenitic, CASS materials have a duplex microstructure consisting of austenite and ferrite phases. The ferrite phase increases the tensile strength and improves resistance to stress corrosion cracking (SCC). As initially installed, CASS also exhibits good fracture toughness properties, comparable to wrought austenitic stainless steel, making it highly resistant to fracture under plant loads during normal operation and abnormal events such as earthquakes. However, it is susceptible to loss of toughness after extended operation at reactor operating temperatures (thermal aging) and exposure to neutron irradiation for extended periods (radiation embrittlement). Micro-chemical changes to wrought and CASS materials and their welds due to irradiation also increase their susceptibility to irradiation-assisted stress corrosion cracking (IASCC).

This quality review effort considered two reports: NUREG/CR-7184, "Crack Growth Rate and Fracture Toughness Tests on Irradiated Cast Stainless Steel" [17]; and NUREG/CR-7185, "Effects of Thermal Aging and Neutron Irradiation on Crack Growth Rate and Fracture Toughness of Cast Stainless Steels and Austenitic Stainless Steel Welds" [18]. The research described in these reports addresses a user need to evaluate whether neutron irradiation, in combination with thermal aging, produces loss of fracture toughness and increased environmental crack growth in CASS material that is greater than that from either mechanism acting alone and to update existing methods for evaluating these effects. The ongoing research will be used by the staff and the industry in aging management programs to provide adequate assurance that the structural integrity of reactor internals can be maintained during license renewal periods.

Summary of the Research

NUREG/CR-7184 presents the results of crack growth rate and fracture toughness tests on three grades of CASS material irradiated in the Halden reactor to a low dose of 0.08 displacements per atom (dpa) at a flux of 5.56×10^{19} n/cm^2; E > 1 MeV. The tests included a total of 11 samples:

- 2 control samples (unirradiated, unaged)
- 4 irradiated, unaged
- 2 unirradiated, aged
- 3 irradiated and aged

The research results are illustrated in Figures 2 and 3. Figure 2 shows that, while some environmental effects on crack growth rates (CGRs) are seen in the new data, the CASS material continues to exhibit good resistance to both corrosion fatigue and SCC before and after thermal aging and irradiation, and is bounded by a prior bounding curve for environmental effects (e.g., the Shack & Kassner CF curve from NUREG/CR-6176 [19]). The toughness reduction effect illustrated in Figure 3 shows that both neutron irradiation and thermal aging, acting alone, produce significant reduction in toughness. The report argues that the combined effect of thermal aging and irradiation damage can reduce the fracture resistance of CASS to a greater extent than either effect alone (right-hand, brick-colored bars in the figure). However, as discussed in the Quality Assessment section below, we question the statistical validity of this observation.

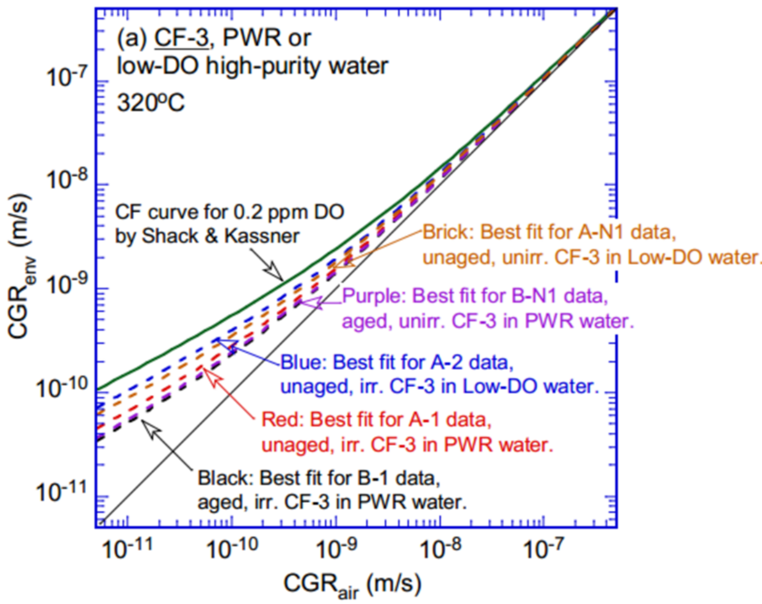

Figure 2 – Crack Growth Rate Test Data from NUREG/CR-7184 Compared to Prior Disposition Curve for Cast (CF) Materials in PWR or Low Dissolved Oxygen (DO) Environments (A, B, N1, etc. refer to Test Specimens)

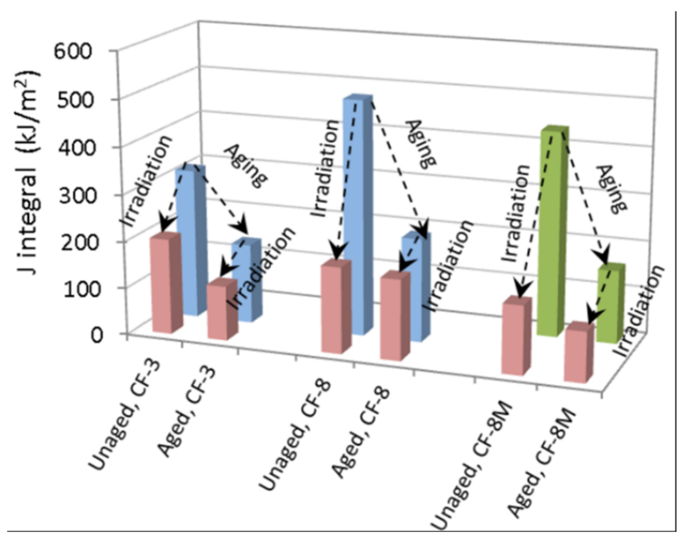

Figure 3 – Fracture Toughness Data from NUREG/CR-7184 Illustrating Toughness Reduction Observed due to Thermal Aging and Irradiation Embrittlement of Various Grades of Cast (CF) Materials

NUREG/CR-7185 contains a broad literature review of thermal and neutron embrittlement data on CASS materials and austenitic SS welds and an update of the prior assessment methodology to include the new data. The objectives of the project were to:

- Update the prior methodology for estimating the loss of fracture toughness during extended service at reactor operating temperatures
- Define threshold neutron fluence above which irradiation effects are significant
- Develop disposition curves for IASCC growth rates for these materials
- Identify information gaps in the data
- Examine combined effects of thermal aging and irradiation on embrittlement

The report reviews the mechanism of thermal embrittlement in CASS materials and austenitic SS welds. In prior work by Argonne National Laboratory (NUREG/CR-4513, Revision 1, August 1994 [20]), correlations were developed for material toughness after long-term aging of these materials in reactor environments. The extent of embrittlement was correlated to the ferrite content and chemical composition of the CASS material. The current NUREG/CR updates the prior work in a number of areas. Its applicability is extended to CASS materials with higher ferrite content (>25%) and for CF-8M steels, addressing dependency on nickel content. Common lower-bound toughness curves are also defined for various grades of CASS materials of unknown chemical composition. The report also reviews the susceptibility to thermal aging of austenitic SS welds, which possess a duplex structure similar to CASS, but with generally lower ferrite content.

Neutron irradiation can likewise degrade the fracture toughness of wrought and cast austenitic SSs and their weldments. Based on data from fast reactor irradiated austenitic SSs, the effects of neutron exposure on the fracture toughness have been divided into three regimes: little or no loss of toughness below an exposure of ≈1 dpa, substantial decrease in toughness at exposures of 1–10 dpa, and no further reduction in toughness above a saturation exposure of 10 dpa. The NUREG/CR reports that fracture toughness trends for SSs irradiated under light water reactor (LWR) conditions are similar to that observed for fast reactor irradiations. A fracture toughness trend curve is developed that bounds the existing neutron embrittlement data.

The report identifies a number of information gaps that need to be filled to increase confidence in aging management programs for these materials in long term reactor service. The more significant of these include:

- Additional data on austenitic SS welds aged at reactor operating temperature are needed to better establish the lower-bound toughness curve for thermally aged welds
- Existing IASCC susceptibility data for CASS materials and austenitic SS welds are too limited to accurately establish the IASCC CGRs of these materials in LWR environments.
- There are few or no fracture toughness data on LWR irradiated austenitic SS and CASS materials for dose levels of 1.0–10.0 dpa.
- Additional fracture toughness (e.g., J-R curve) data on the combined effects of thermal and neutron embrittlement of austenitic SS welds and CASS materials are needed to accurately define the lower-bound fracture properties of these materials in LWR environments.

- Lastly, on the topic of toughness in general, the report observes, based on recent data, that fracture toughness can be further reduced in LWR environments relative to that in air, which has been the environment for much of the testing to date.

ACRS Quality Assessment

The two reports address the same general topic. However, they are actually quite different in scope and technical content. Because of these differences, the review panel performed separate evaluations, rather than combine the two into a single review. The consensus scores from the ACRS reviews of the two projects are shown in Tables 2 and 3 below.

NUREG/CR-7184 - The overall assessment score of NUREG/CR-7184 was evaluated to be 4.7. The work is of professional quality, but does not adequately address uncertainties and sensitivities that might affect one of the report's key findings.

Table 2. Summary Results of ACRS Assessment of the Quality of the Project NUREG/CR-7184, "Crack Growth Rate and Fracture Toughness Tests on Irradiated Cast Stainless Steel"

Performance Measures	Consensus Scores	Normalized Weights	Weighted Scores
Clarity of presentation	5.0	0.18	0.90
Identification of major assumptions	5.0	0.10	0.50
Justification of major assumptions	N/A	N/A	N/A
Soundness of technical approach/results	4.7	0.59	2.77
Treatment of uncertainties/sensitivities	4.0	0.13	0.52
		Overall Score	**4.7**

Clarity of Presentation *(Consensus Score: 5.0)*

We observe the report to be well written and consistent with high quality professional work. We, therefore, assigned the report a score of 5.0 on this performance metric.

Identification of Major Assumptions *(Consensus Score: 5.0)*

NUREG/CR-7184 did not specifically identify any assumptions. However, the test program used generally accepted procedures (and associated assumptions) for this type of testing. Chapter 2 of the report describes the test procedures used, including test materials, test samples, sample irradiation process, test facility and details of the crack growth rate and toughness testing. These are documented in the report in a professional manner that is appropriate for the nature of the work. In keeping with past ACRS reviews of such projects, the review team considered this chapter to be a surrogate for identification of assumptions, and accordingly assigned a score of 5.0 to this metric (professional quality work).

Justification of Major Assumptions *(Consensus Score: N/A)*

As noted, this report utilized standard practices for this type of testing and did not identify any assumptions. Therefore, the review panel concluded that this evaluation metric is not applicable to the subject project. Weighting factors for the other applicable performance metrics used in the assessment have been normalized to account for this fact, so that the total weighting of the metrics used sums to 1.0.

Soundness of Technical Approach/Results *(Consensus Score: 4.7)*

The test program was performed and documented meticulously in NUREG/CR-7184. The test specimens included three grades of CASS materials commonly used in reactor coolant loops and internals, and each material was tested in the unaged (control group), aged alone, irradiated alone, and aged then irradiated conditions. The test samples were prepared and tested in accordance with industry standards, and detailed results are reported for each sample. In addition to the test results, the report documents fractographic examinations of each sample, allowing the researchers to confirm the validity of the tests based on fracture morphology.

The review panel assessment concluded that, although the conduct of the tests was professional work, two aspects of the program, described in more detail below, caused it to fall short of meeting all research objectives. We, therefore, assigned it a score of 4.7 (slightly less than satisfactory, professional work that satisfies all research objectives).

Treatment of Uncertainties/Sensitivities *(Consensus Score: 4.0)*

The report discusses scatter and uncertainty in the crack growth rate data in several places, stating that, "given the large scatter of the data sets and the inherent uncertainty in short-duration CGR tests like these, the difference is statistically insignificant". However, no such statement is made with regard to the fracture toughness testing. While scatter in toughness testing is generally less than that in CGR tests, it is not insignificant, and the post-irradiation differences (brick-colored bars in Figure 3) between irradiated-unaged and irradiated-aged toughness are not very large (20-30%). These stated differences are exaggerated by the fact that the report presents toughness in terms of J-Integral, which in a pure sense is proportional to the fracture toughness, K_{Jc}, squared. Including this square root effect, the actual difference in measured toughness should be reported as 9-14%, which is well within the expected scatter band of fracture toughness testing. Thus, data do not substantiate the report's most significant finding, "The combined effect of thermal aging and irradiation damage can reduce the fracture resistance of CASS to a higher extent than any one of them can achieve alone." It is based on just one test per material grade, and the small toughness differences observed between irradiated-unaged and irradiated-aged material could easily be overwhelmed by experimental uncertainty.

Another unaddressed uncertainty concerns the irradiation levels to which the samples were exposed (0.08 dpa). This fluence level is extremely low relative to doses experienced by CASS materials in reactor internals. Testing at this low fluence level is considered meaningful for initial scoping, since damage to the ferrite microstructure is expected to occur at relatively low fluence. However, the report doesn't discuss whether the results represent a saturated condition or whether increased neutron exposure could lead to further damage. ACRS has subsequently learned that irradiation of additional samples is continuing in the Halden reactor, to higher fluence levels (3 dpa), which will be tested in the future. This is significant and should have been discussed in the NUREG/CR.

NUREG/CR-7185 – The consensus ACRS evaluation of NUREG/CR-7185 is shown in Table 3. The overall assessment score is 5.9 (better than professional quality work that satisfies the research objectives and includes some elements of innovation and insight).

Table 3. Summary Results of ACRS Assessment of the Quality of the Project NUREG/CR-7185, "Effects of Thermal Aging and Neutron Irradiation on Crack Growth Rate and Fracture Toughness of Cast Stainless Steels and Austenitic Stainless Steel Welds"

Performance Measures	Consensus Scores	Normalized Weights	Weighted Scores
Clarity of presentation	6.0	0.18	1.08
Identification of major assumptions	5.0	0.10	0.50
Justification of major assumptions	N/A	N/A	N/A
Soundness of technical approach/results	6.0	0.59	3.54
Treatment of uncertainties/sensitivities	5.7	0.13	0.74
		Overall Score	**5.9**

Clarity of Presentation *(Consensus Score: 6.0)*

The panel observed the report to be exemplary of a well-written literature review and evaluation. The objectives of the work are clearly stated, as are the major findings and conclusions. The author includes theoretical discussions of the applicable degradation mechanisms as well as a comprehensive review of new data published in the twenty-plus years since his prior report on this topic. Gaps in available data are discussed in sufficient detail to evaluate the sufficiency of current and planned industry and NRC-sponsored research.

Identification of Major Assumptions *(Consensus Score: 5.0)*

NUREG/CR-2185 is a literature review performed to compile and evaluate data and update prior methodology. Where assumptions are involved, they are stated in the report in a professional manner that is appropriate for the nature of the work.

Justification of Major Assumptions *(Consensus Score: N/A)*

The report did not attempt to justify the major assumptions of the various analysis and testing methods included in the review. As previously discussed, it is a compilation and analysis of testing conducted by others. Therefore, the review panel concluded that this valuation metric is not applicable to the subject project. Weighting factors for the other applicable performance metrics used in the assessment have been normalized to account for this fact, so that the total weighting of the metrics used sums to 1.0.

Soundness of Technical Approach/Results *(Consensus Score: 6.0)*

This report provides an excellent review and analysis of data on degradation of CASS and SS weld material spanning the period from 1994 to the present. The approach taken by the author is sound and comprehensive. It couples theoretical metallurgical principles with laboratory data to quantify the influence of the many variables affecting the toughness and environmentally assisted crack growth properties of these materials in operating LWR environments. The fundamental influence of the key variables has been assessed, and the limitations of the supporting research identified. The analyses and data are used to update previously published methodologies for assessing the extent of degradation of these materials in various pressurized water reactor and boiling water reactor components, as influenced by CASS material grade, ferrite content, time and temperature of operation, neutron fluence levels, and reactor coolant environment.

The author’s assessment methodologies and correlations, in both this report and his prior 1994 report, exhibit a degree of innovation and insight that goes beyond a simple literature review and data compilation. They allow the multitude of variables influencing the degradation mechanisms to be addressed in a practical manner by engineers performing materials aging analyses.

Treatment of Uncertainties/Sensitivities *(Consensus Score: 5.7)*

While this category is not strictly applicable to a literature review project such as this, the review panel has chosen to evaluate “Identification of Information Gaps” in the Argonne National Laboratory report as a surrogate for this evaluation metric. Identification of information gaps in the data is one of the stated report objectives, and the author has itemized these needs in each of the major report areas – thermal aging, IASCC crack growth rates, neutron embrittlement, and combined effects of thermal and neutron embrittlement. Such gaps are the major source of uncertainty in the industry’s ability to quantify the effects of CASS material degradation on aging management programs for long term nuclear plant operation.

3.2 Influence of Coupling Erosion and Hydrology on the Long-Term Performance of Engineered Surface Barriers

Engineered barriers are used in waste containment facilities to limit human and animal contact with waste, to control ingress and egress of gases, and to limit exposure of waste to water sources by controlling percolation. Barriers for low-level radioactive waste (LLRW) and uranium mill tailings sites are designed to control percolation, radon emission, and erosion for a service life of at least 1000 years. Erosion can severely diminish the integrity of the barrier by exposing buried waste or reducing the barrier thickness sufficiently to make the waste more susceptible to percolation.

This study entitled NUREG/CR-7200, "Influence of Coupling Erosion and Hydrology on the Long-Term Performance of Engineered Surface Barriers," was conducted by individuals from the Geological Engineering Department at the University of Wisconsin-Madison. It was jointly supported by the U.S. Nuclear Regulatory Commission, the U.S. Geological Survey, and the U.S. Department of Energy.

The objective of this study was to evaluate design strategies that couple erosion and hydrology for barriers of LLRW disposal facilities. Results from the study provide guidance on the selection of cover designs and erosion control features. Effects of climate, types of surface layers, surface slope length and grade, and types of vegetation were evaluated for their impacts on the long-term performance of engineered surface covers. A landform evolution model and a hydrological flow model were selected to simulate these variations in a parametric study. Landform evolution modeling considered four main factors affecting fluvial erosion: (1) climate, (2) soil, (3) vegetation, and (4) topography. Several scenarios were evaluated for semi-arid and humid sites. The topography of the Grand Junction Uranium Mill Tailings Disposal Site in Grand Junction, CO was used as an assumed realistic reference case for the study.

General Observations

This is a limited scope parametric study that evaluates combinations of key parameters that couple erosion and hydrology in consideration of earth barriers for LLRW disposal facilities. The study completed long-term (1000 year) parametric simulations with the SIBERIA landform evolution model and the SVFLUX hydrologic model. Erosion was simulated using the SIBERIA landform evolution model, whereas hydrology was simulated using the variably saturated flow model SVFLUX. Climate, material used for the surface layer, barrier type (resistive versus water balance), topography of the landform, erosion protection systems, and vegetation were varied systematically to assess how they influence erosion and percolation. The duration of the study horizon is a service life of at least 1000 years for barriers for LLRW and uranium mill tailings sites to control percolation, radon emission, and erosion.

The study is a solid and respectable effort that provides a compendium of results that are useful for considering the effects of variations in the selected model parameters. The individual scores for this project are shown in Table 4, and the combined weighted consensus score is 4.2. This consensus score reflects the recognition that this study presents results from a parametric study utilizing readily available data and models. The study is generally thorough relative to the input assumptions and utilization of the computational codes.

Table 4. Summary Results of ACRS Assessment of the Project NUREG/CR-7200, "Influence of Coupling Erosion and Hydrology on the Long-Term Performance of Engineered Surface Barriers"

Performance Measures	Consensus Scores	Weights	Weighted Scores
Clarity of presentation	4.3	0.16	0.69
Identification of major assumptions	4.0	0.09	0.36
Justification of major assumptions	3.3	0.12	0.40
Soundness of technical approach/results	4.3	0.52	2.24
Treatment of uncertainties/sensitivities	4.3	0.11	0.47
		Overall Score	**4.2**

Comments and conclusions within the evaluation categories are provided below.

Clarity of presentation: (Consensus Score: 4.3)

The introduction to this study communicates the content of subsequent sections, including: background information on erosion processes and erosion models, a description of the reference site, results of the erosion and hydrologic modeling, and implications of coupling erosion and hydrologic barrier performance. The text of the study is clear regarding these matters.

This study provides an examination of variations in parameters for hydrology and erosion. The authors also indicate that computer modeling is being used to evaluate design strategies to understand the relationship between hydrology and erosion, although no real 'strategy' is described other than to employ the computer models and to communicate their results. The study provides a compendium of computer model results from the codes SIBERIA and SVFLUX for combinations of barrier design, surface layer, presence of vegetation, and slope topography for the relationship between erosion and hydrology.

The task objectives, the motivation for varying selected parameters, and intended use of results from this study are not clearly stated within the report. Because this context is omitted, the reader is left wondering about the adequacy of this effort. During our discussion with the staff, we learned that there was a user need document specifying that the research project is to investigate which features and factors are most important to keep engineered surface covers performing at an optimum level. This user need is addressed by selected variations in the input parameters to the models. The user need also specifies that the research project should include the effects of climate on the long-term performance of engineered surface covers and how the features and designs of long-term performing covers may differ depending on varying meteorological conditions of the site. It appears that this user need is addressed by the authors' assumed variations in model parameters for a 1000 year span.

The descriptions of the models utilized in the study are detailed and somewhat confusing. The justification for the selection of SIBERIA is not clear.

The study is thorough in its treatment of the stated parameters and their variations. The study's structure and organization are satisfactory.

Identification of major assumptions: (Consensus Score: 4.0)

Identification of major assumptions is largely absent in the study. Major assumptions include the assumption that the Grand Junction Uranium Mill Tailings Disposal Site in Grand Junction, CO is a representative site for wide application, and the assumption that results from the application of SIBERIA and SVFLUX models for the Grand Junction site are applicable to other sites. Not identifying these as major assumptions at the outset of the study detract from, or potentially limit, the applicability of this study to other sites.

Additional major assumptions include the types of engineered covers considered in the project, and absence of consideration of mechanisms other than erosion and percolation that can expose the wastes (e.g., bio-intrusion). These choices reflect the major assumption that the analytical models, and their results, are applicable, valid and yield correct results when run for the 1,000 year simulations. While the choice of these parameters represents assumptions critical to the study's conclusion, the study describes these choices simply as the methods used, as opposed to describing them as assumptions.

The study's conclusions would have been stronger if these major assumptions had been specifically identified at the outset.

Justification of major assumptions: (Consensus Score: 3.3)

As noted above, the choice of the Grand Junction, CO site as the surrogate for this study is the critical, but unstated, major assumption for the study. Its choice is likely due to the availability of data from that site. While understandable, that critical major assumption is coupled with the additional unstated assumption that the study data from the Grand Junction, CO site is applicable elsewhere. We agree that these assumptions are acceptable in this limited scope parametric study. We observe that the study's conclusions would have been stronger if these major and critical assumptions had been justified.

Similarly, there is little justification of minor assumptions, although one can defend use of the parameters as 'common sense' for how soil behaves over time with entraining fluid flowing over it. Examples of this are assumptions within the two selected computer programs and the selected parameters that are broadly applicable. For example, Mountain Big Sagebrush was assumed to be the prominent vegetation in the semiarid climate and Bluestem Prairie Grass was assumed to be the prominent vegetation in the humid climate. Justification for those choices is not communicated. Tailings were assumed to behave similarly as silt and were assigned properties of Boardman silt from the University of Wisconsin-Madison soil bank. Likewise, the justification for this assumption is not stated. On the other hand, assumptions for vegetation parameters are clearly stated in Section 3.7. The study's conclusions would have been stronger if these minor assumptions had been justified.

Section 2.2.2 states that: "The following landform evolution models were evaluated in this study: SIBERIA, ARMOUR, CAESAR, GOLEM, CASCADE, and CHILD. These models were included because they have been used in practice, tested, and verified. Other landform evolution models were available but were not considered because they have not been verified or used in practice." The basis of the choice of the model used for each simulation that was performed is unclear, although SIBERIA appears to have been preferred.

Soundness of technical approach/results: (Consensus Score: 4.3)

Assessment of the soundness of the technical approach was assessed based on the applicability and accuracy of the tools, or analytical models, used for the study. The analytical 'tools' for this study are the computer codes SIBERIA and SVFLUX, with SIBERIA being calibrated by the WEPP code. The study explains that SIBERIA was chosen because it has been successfully parameterized and run for many sites in Australia and Argentina, and because it is a landform evaluation model that has high spatial resolution, the ability to model layers of different materials, and has been validated with field and laboratory experiments. The study would have been stronger if the limitations of SIBERIA as applied to this project had been described. Action was taken by the authors to calibrate SIBERIA by matching erosion rates predicted by SIBERIA to average erosion rates predicted by WEPP. WEPP was used because it is mechanistic, and input parameters for WEPP are readily available. This action is appropriate, and was necessary.
Hydraulic modeling was conducted with the variably saturated flow model SVFLUX. SVFLUX was chosen because it provides reliable hydrological predictions for covers when parameterized realistically. There is no assessment of the accuracy of this model nor is there communication in the study regarding efforts to calibrate it. Failure to calibrate, or validate, SVFLUX for this application is a weakness in the study.

It is not clear whether the simulated results have been validated through field data. Nevertheless, results from this study can be used qualitatively as general guidance for cover designers and can inform design strategies that couple erosion and hydrology.

Treatment of uncertainties and sensitivities: (Consensus Score: 4.3)

This project consists of a parametric study using features and factors that may be important to the performance of engineered covers. Variations of climate, soil, vegetation and topography in humid as well as semi-arid sites are analyzed. In addition, two types of barriers – resistive barrier and water balance barrier – are used in the analysis. There is no formal treatment of uncertainty or sensitivity in this study. Rather, uncertainties and sensitivities are treated by providing variations in input parameters for multiple studies. The extent of the study's examination of the combinations of these variables provides an acceptable approach for treating uncertainties and sensitivities. Variables that were treated in the analyses include covers comprised of rip-rap, topsoil, and topsoil mixed with gravel (gravel admixture), conventional resistive barriers and water balance barriers with a capillary break, and simulations with and without vegetation with native plants for each climate. Vegetated rip-rap, topsoil, and gravel admixture surfaces were simulated to determine how the type of surface layer affects erosion. Each surface was simulated in semi-arid and humid climates using resistive and water balance barriers. Topography representative of the Grand Junction, CO site was used for all simulations as a base topography so that surface layer effects could be compared while keeping site topography constant. How the Grand Junction, CO site data applies to other potential waste sites is not discussed. The study assumes, without directly stating, that the variations in parameters that were applied to the Grand Junction site are adequate to address uncertainties and sensitivities that would be present in other potential waste sites.

The conclusions of the study would have been stronger if uncertainties and sensitivities had been formally addressed.

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