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

November 17, 2015

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 2015

Dear Mr. Weber:

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

- Uranium Sequestration During Biostimulated Reduction and In Response to the Return of Oxic Conditions in Shallow Aquifers
  - This project was found to be more than satisfactory, a professional work that satisfies research objectives and with some important elements of innovation and insight
- Weld Residual Stress Finite Element Analysis Validation: Part 1 – Data Development Effort
  - This project was found to be more than satisfactory, a professional work that satisfies research objectives and with some important elements of innovation and insight

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 2016 prior to our March 2016 meeting.

Sincerely,

/RA/

John W. Stetkar,
Chairman

Enclosure: As stated

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Assessment of the Quality of Selected NRC Research Projects by the Advisory Committee on Reactor Safeguards - FY 2015

November 2015

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. John W. Stetkar (Chairman), Principal, Stetkar & Associates, Hot Springs, Arkansas

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 two research projects are summarized as follows:

- Uranium Sequestration During Biostimulated Reduction and In Response to the Return of Oxic Conditions in Shallow Aquifers
  - This project was found to be more than satisfactory, a professional work that satisfies research objectives and with some important elements of innovation and insight

- Weld Residual Stress Finite Element Analysis Validation: Part 1 – Data Development Effort
  - This project was found to be more than satisfactory, a professional work that satisfies research objectives and with some important elements of innovation and insight

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ABBREVIATIONS

ACRS	Advisory Committee on Reactor Safeguards
AEC	Atomic Energy Commission
AGW	Artificial Ground Water
FEA	Finite Element Analysis
FY	Fiscal Year
NRC	Nuclear Regulatory Commission
RES	Office of Nuclear Regulatory Research
SCC	Stress Corrosion Cracking
WRS	Welding Residual Stresses
xLPR	eXtremely Low Probability of Rupture

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 [1-11]. 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

- The 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:

- Uranium Sequestration During Biostimulated Reduction and In Response to the Return of Oxic Conditions in Shallow Aquifers

- Weld Residual Stress Finite Element Analysis Validation: Part 1 – Data Development Effort

These two 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 [12-13]. The analytical part utilizes methods of multi-attribute utility theory [14-15] 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.

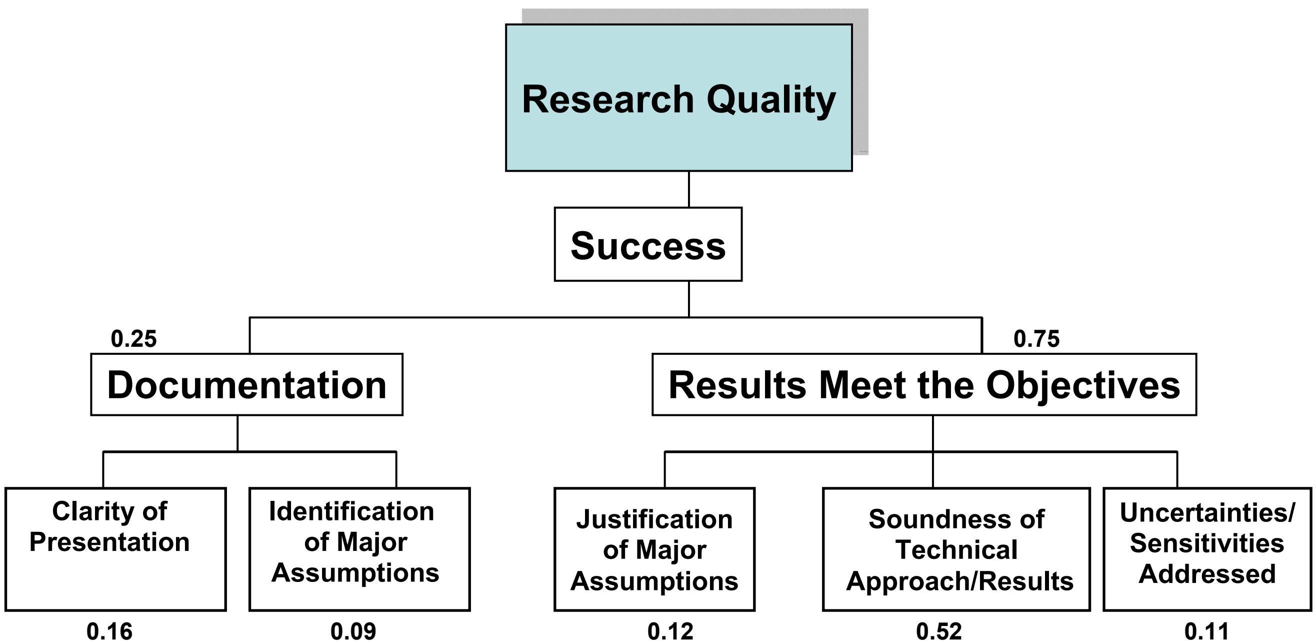

Figure 1. The Value Tree used for Evaluating the Quality of Research Projects

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.

As discussed in Section 1, 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 Uranium Sequestration during Biostimulated Reduction and In Response to the Return of Oxic Conditions in Shallow Aquifers

Uranium extraction and processing have resulted in contamination of groundwater and sediments at many locations worldwide. Development of effective strategies for remediation of uranium contamination in groundwater has focused largely on using *in situ* treatment processes because of the high costs associated with traditional pump and treat methods. *In situ* stimulation of indigenous microbial populations in aquifers by electron donor addition and the concept of biostimulated reduction as a remediation strategy to immobilize uranium have been the foci of many field and laboratory investigations over the past 20 years.

The NRC staff, in collaboration with experts from the U.S. Geological Survey, Kent State University, and Pacific Northwest National Laboratory has recently completed a study of uranium sequestration during biostimulated reduction and in response to the return of oxidizing conditions in shallow aquifers. The results of this effort are documented in NUREG/CR-7178 [16]. The scope of this quality review is limited to this report.

The focus of the study is to evaluate remobilization of uranium after biostimulation in response to the return to oxidizing conditions through long-term (>100 pore volumes) column experiments using sediments from the Old Rifle site, a shallow aquifer contaminated from uranium ore milling and remediated through the Uranium Mill Tailings Remedial Action program. The primary goal of this study was to evaluate the remobilization of uranium sequestered during biostimulated reduction under conditions in which biostimulation and concomitant uranium reduction extended well into sulfate reduction to enhance precipitation of reduced sulfur phases such as iron sulfides [16].

<u>**General Observations**</u>

This report presents the results of a thorough proof-of-principle small-scale test that utilized actual soil from a candidate bio-remediation site and that utilized artificial ground water (AGW) that was prepared with rigorous discipline to produce results confirming uranium retention and reduction that are credible and useful. The effluent and solid phase measurements from the test columns during and after the biostimulation stage suggest that stimulation and growth of indigenous microbial population in aquifer sediment by addition of an electron donor and carbon source may be an effective means of removing dissolved uranium from contaminated groundwater.

This is an important study of biotic effects on the oxidation state and consequently the solubility of uranium in ground water. The study is very well done. It goes beyond an expected professional product, particularly since the investigators had to develop and refine sensitive analytical techniques as well as adapting newly developed methods for the research. It should be also noted that the technology behind the work may have some applicability to recovery of the damaged reactors at Fukushima.

The consensus scores for this project are shown in Table 2. The score for the overall assessment of this work was evaluated to be 7.1 (more than satisfactory, a professional work that satisfies research objectives with some important elements of innovation and insight).

Table 2. Summary Results of ACRS Assessment of the Quality of the Project, "Uranium Sequestration during Biostimulated Reduction and In Response to the Return of Oxic Conditions in Shallow Aquifers"

Performance Measures	Consensus Scores	Weights	Weighted Scores
Clarity of presentation	8.0	0.16	1.28
Identification of major assumptions	5.5	0.09	0.50
Justification of major assumptions	4.5	0.12	0.54
Soundness of technical approach/results	8.0	0.52	4.16
Treatment of uncertainties/sensitivities	5.5	0.11	0.60
		Overall Score	**7.1**

Comments and conclusions within the evaluation categories are provided below.

Clarity of Presentation *(Consensus Score: 8.0)*

The authors did an excellent job describing the work and providing sufficient data so the reader could understand the bases of conclusions. They provided sufficient review of the past work and background information to put the work in context. They acknowledged and described procedural failures in their experiments. They faced up to and successfully met the challenge in the graphical presentation of a large amount of multidimensional data.

The authors provided a thorough and most interesting description of the experimental methods. Though the experiment involved three measurement columns, there were not replicate measurements for any column, which makes it difficult to understand experimental error. There is potential for error since the columns are of modest diameter (~5cm), so the column walls will have effects not seen in the field. Indeed, photographic evidence in Chapter 3 suggests flow was not radially uniform across columns in some cases. Furthermore, the packing of the columns is not necessarily consistent with field packing densities, and this can be important for porous medium flow. Regardless of these experimental challenges, the investigators do a good job describing the packing of the columns.

The document presents a comprehensive description of the test and test protocol. The comprehensive description notwithstanding, the document would have benefitted by communicating that this experiment is, appropriately, a small-scale proof-of-principle experiment. Stating that with emphasis may not be necessary, but the chemistry results from the small columns are assumed to be representative of results over large land areas. Hence, the issue of scale should have been made clear. To the authors' credit, the testing was conducted on three small columns that are adequate to prove the chemistry of the bio-remediation process, and the testing was conducted for a sufficient length of time to allow understanding of the soil-dynamics to enable the test results to be credible.

Identification of Major Assumptions *(Consensus Score: 5.5)*

The authors focused on chemical and biological assumptions in their presentation of the results and largely overlooked the hydraulic assumptions. They do a much better job explicitly identifying the assumptions of their modeling in Chapter 5 of the report.

While not specifying the major assumptions, the authors took actions to account for the assumptions that a scientifically oriented reader would consider essential for the experimental results to be credible. Sediments from an actual site were used for column biostimulation experiments. The sediment was collected from the aquifer from within the contamination zone from the Old Rifle uranium mill, but not in areas of the aquifer where *in situ* biostimulation experiments had been previously conducted. The authors responsibly created AGW that was then used for the column experiments. The AGW was developed to simulate the average major ion chemistry of groundwater sampled at the Old Rifle site.

Justification of Major Assumptions *(Consensus Score: 4.5)*

The authors provided limited justification for the assumptions in the report. Many of the assumptions are probably not important if it is taken, as seems to be the case, that the experiments are an effort to identify major effects that should be taken into account should more definitive experimentation be undertaken. A problem in the report is the assumption that differences in results for the three columns are just due to treatment differences and are not the result of variability either in the nature of the samples used to charge the column or the inherent variability in results from porous medium flow. This issue could have been resolved to an important extent by having at least one replicate column.

Soundness of Technical Approach/Results *(Consensus Score: 8.0)*

The authors conducted thorough protocols that simulated field conditions to the greatest degree practical, for time durations that make practical sense. To their credit, the authors went to great lengths to ensure the fidelity of their test conditions to actual field conditions. The authors undertook a very difficult problem whose results depended upon very sensitive measurements. The authors went beyond what would be expected in the development and validation methods not routinely available and explored the usefulness of newly developed methods. Critiques of the experimenters' approach are that the experimental matrix did not include replicate experiments to assess experimental variability which might be of some importance in flow through a porous medium, and there were failings in the experimental procedures that resulted in incorrect solutions being used for a period in an experiment. In spite of this, the investigators recovered masterfully from the procedural failures.

Treatment of Uncertainties/Sensitivities *(Consensus Score: 5.5)*

The experimental undertaking was to identify sensitivities for bacterial reduction of hexavalent uranium to less soluble tetravalent uranium. The authors did a good job identifying chemical and biological sensitivities. We appreciated the careful description of measures taken to avoid bio-contamination of earth samples. The work will provide, in fact, a good basis for the construction of a formal factorial or partial factorial experiment if this is needed. The authors did attempt to address some of the uncertainties identified in their results. The authors seemed, however, to largely overlook the challenges of liquid flow through a porous medium and especially radial dispersion in flow velocities. The outcome of the work is that we have only a notion of the overall experimental error. Indeed, in most cases the authors do not report uncertainties in measured quantities. See, for example, descriptions on the column packing (Table 2 in page 2-7 of the report), where it should have been easily possible to provide readers with some understanding of uncertainty and variability. The authors do a much better job characterizing the detection limits and uncertainties in their analytic methods.

3.2 Weld Residual Stress Finite Element Analysis Validation: Part 1 – Data Development Effort

Welding residual stresses (WRS) are a major factor affecting the integrity of pressure boundary and other critical components in nuclear power plants. Numerous incidents of environmentally induced cracking have occurred in operating plants over the past thirty years, leading to major repairs, enhanced inspection programs, and application of mitigating measures to reduce or eliminate the problems. The majority of these incidents were attributed to stress corrosion cracking (SCC) which occurs in the presence of a susceptible material, a corrosive environment, and near or above yield level stresses. The affected components were generally designed in accordance with the ASME Boiler and Pressure Vessel Code, which limits stresses to a fraction of yield, so one would expect such cracking to be precluded. However, the Code limits address only applied stresses due to pressure, external forces, and thermal transients, leaving the responsibility to designers and fabricators to address fabrication effects, such as residual stresses, as well as environmental effects on the materials.

As part of their efforts to address these SCC problems, industry and the NRC staff have developed sophisticated finite element analysis (FEA) methods to predict residual stresses in welded components. These have been used for a number of purposes, including:

1. Crack growth analyses when flaws are detected, to determine the need for and urgency of repair or replacement actions.
2. Analyses of the potential for crack initiation and projected growth of initiated flaws when inspections have not yet been performed.
3. Evaluation of mitigation and repair activities, many of which rely on minimizing unfavorable WRS and/or producing favorable (compressive) WRS.

Because of the complexity of the WRS analysis process, however, a wide range of FEA software, material properties, and analysis assumptions are used by the practitioners in this field. There are currently no detailed guidance or generally accepted validation criteria for such analyses. NUREG-2162 [17] reports on the first phase of a multi-phased RES program aimed at filling these voids. The scope of this quality review is limited to this report.

Summary of the Research

The objectives of the subject research project are to:

- Validate axisymmetric FEA modeling as a predictive tool for WRS, using robust experimental methods.
- Support the NRC's Office of Nuclear Reactor Regulation in development of appropriate WRS/flaw evaluation review guidelines.
- Perform independent confirmatory research on industry guidance for executing WRS analysis.
- Assess and evaluate the near-term adequacy of industry's mitigation activities where WRS minimization is necessary.
- Improve WRS finite element analysis predictive methodologies.
- Determine estimates for WRS uncertainty distributions, which are needed in probabilistic analyses (e.g., xLPR Project – eXtremely Low Probability of Rupture).

NUREG-2162 documents the initial phases of a joint effort with industry in which several prototypical pressurized water reactor vessel/piping samples were fabricated, which are representative of components in which serious SCC problems have been observed in the field. The samples ranged from relatively small, ~8 inch diameter nozzles to large, thick components typical of reactor vessel outlet nozzles (~35 inch diameter and up to 9 inches thick).

Various state-of-the art methods for measuring residual stresses were reviewed at the outset of the project and evaluated on a series of small scientific specimens. These included diffraction-based and strain-relief type measurement techniques. The evaluation compared the measurements to one another as well as to analytical predictions. Results from the diffraction-based techniques exhibited high scatter, especially near the specimen surfaces. Through-thickness strain relief measurements provided the most reliable results, and were therefore chosen as the primary method for the remainder of the program.

The essence of this research was a series of "double-blind" studies of WRS measurements and analyses of the samples, in which neither the experimenters nor the analysts knew of each other's results until all of the results were compiled and reported. The results are illustrated by the following figures from an international round robin study conducted on one of the sample types, a 14 inch diameter mockup of a pressurizer surge nozzle fabricated expressly for this program (Figures 2 and 3).

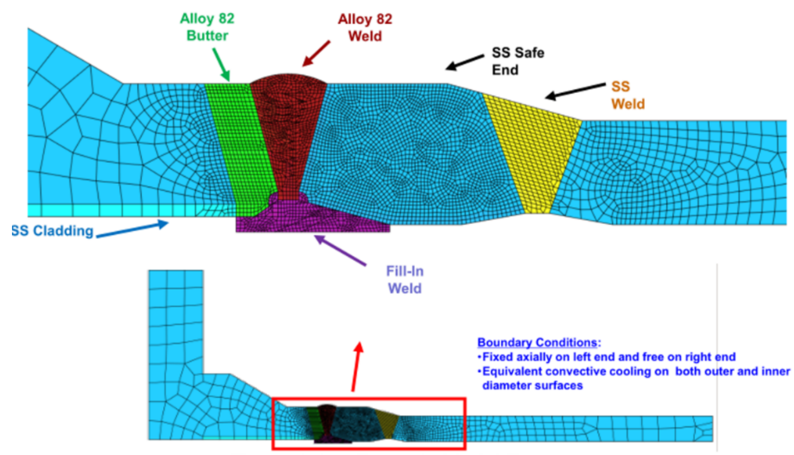

Figure 2 – Moderate Diameter (14 inch) Pressurizer Surge Nozzle used in the Double Blind International Round Robin Program Comparing Various Analyses with Measurements [17]

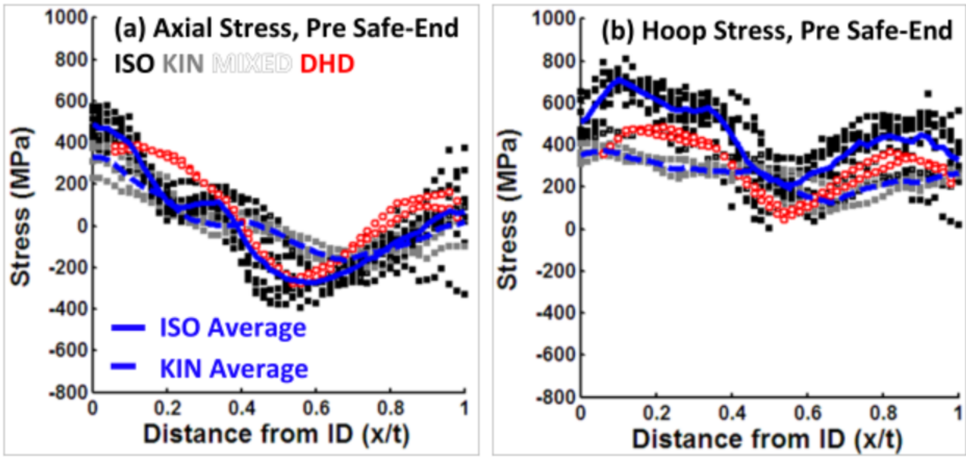

Figure 3 – Typical Results from the Double-Blind International Round Robin Program [17]

The black and grey data points in Figure 3 represent analysis results from the thirteen organizations who participated in the study, reported as stress versus normalized distance from the inside surface (x/t) at a section through the center of the Alloy 82 weld (purple region in Figure 2).

Reviewing the plots, it is seen that both the analyses and measurements predicted very high tensile WRS near the inside surface of the weld (x/t = 0), well above the yield strength of the Alloy 82 material (~265 MPa). That is, of course, consistent with the observation of SCC in numerous nozzles of this type. There is reasonable agreement in the average trends of the analyses (characterized by the blue curves) and the experimental measurements (red curves). Somewhat disconcerting, however, and indicative of the challenges faced in this validation effort, is the large degree of scatter among the analytical results; the range of individual results deviated from the averages by as much as 200 MPa in some cases.

Chapter 7 of the NUREG demonstrates the difficulties of developing quantitative, objective acceptance criteria with such large uncertainties in WRS prediction. Therefore, development of modeling guidelines to minimize analyst-to-analyst uncertainty will be important for establishing acceptance criteria. An accurate description of WRS uncertainty distributions for probabilistic assessments is another industry need. Lessons learned in modeling practices from this work are being applied in the xLPR project.

The consensus scores for this project are shown in Table 3. The score for the overall assessment of this work was evaluated to be 7.2 (more than satisfactory, a professional work that satisfies research objectives with some important elements of innovation and insight).

Table 3. Summary Results of ACRS Assessment of the Quality of the Project, "Weld Residual Stress Finite Element Analysis Validation: Part 1 – Data Development Effort"

Performance Measures	Consensus Scores	Weights	Weighted Scores
Clarity of presentation	8.0	0.16	1.28
Identification of major assumptions	5.0	0.09	0.45
Justification of major assumptions	N/A	0.12	N/A
Soundness of technical approach/results	7.5	0.52	3.90
Treatment of uncertainties/sensitivities	6.2	0.11	0.68
		Overall Score	**7.2 (rescaled)**

Comments and conclusions within the evaluation categories are provided below.

Clarity of Presentation *(Consensus Score: 8.0)*

NUREG-2162 is meticulously written and clearly presented. There is a clear discussion of the regulatory purpose of the research, as well as its objectives. The report contains clear, easy to understand descriptions of the various samples fabricated for the project with excellent graphics and plots of the results. The conclusions of the various project phases, as well as of the report in general, are comprehensive and well-stated.

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

NUREG-2162 is largely a compilation and evaluation of analyses and testing performed by others, the major assumptions of which and justifications thereof are (presumably) documented in those works and not repeated in the NUREG. Chapter 2 of the NUREG provides an overview of the various WRS measurement techniques and analytical models and the significant parameters and assumptions involved in each. These are summarized in the report in a professional manner that is appropriate for the nature of the work.

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

This report did not attempt to justify the major assumptions of the various analysis and testing methods, since as previously discussed, it is a compilation and comparison of analysis and testing work conducted by others. Justification of the various assumptions is addressed in those works and was not repeated in the NUREG. Therefore, the review panel concluded that this evaluation metric is not applicable to the subject project. The weight factors for the other performance measures were proportionately rescaled so as to yield a total weight of 1.0.

Soundness of Technical Approach/Results *(Consensus Score: 7.5)*

There is no question as to the soundness of the technical approach applied in this project. The samples were accurate reproductions of a range of components that have experienced SCC problems in service. The WRS measurement techniques represented the state of the art in that discipline, and as discussed, were evaluated on a series of small scientific specimens. Only those methods that performed well in those tests were applied to the prototype samples. Analyses were requested from and performed by a broad range of domestic and international practitioners, and the results were presented and compared to the measurements fairly and professionally.

Treatment of Uncertainties/Sensitivities *(Consensus Score: 6.2)*

Continuation of this research is planned to establish the proper approaches to quantify and integrate both modeling and experimental uncertainty. In order to prepare for this work, the last section of this report is devoted to a WRS uncertainty scoping study. The authors describe the magnitude of the uncertainty that will need to be addressed in future work as it has been displayed in the analytical and experimental results. The project team made an earnest effort to evaluate the uncertainties inherent in the results presented in the previous sections. While the full range of analytical results exhibited huge scatter, the average of the analytical results were in reasonable agreement with the experimental measurements, and some results were clearly within a reasonable range of the measurements. The fact that many of the analyses were outside of this range, however, points to the need for more guidance on analytical techniques and validation criteria for licensing applications of such analysis.

In Section 7, the team discusses these challenges and presents the proposed approach to investigate modeling uncertainties in detail, segregating the components that contribute to the overall uncertainty. This is not straight-forward, given the complexity of the analytical models. Accordingly, the team performed and documented a reasonably detailed uncertainty scoping study to demonstrate how this type of approach could be put into practice. While the general evaluation approach is built from typical uncertainty analysis fundamentals, this is a new application for the complex models used here. This work thus sets the stage for the future research. Providing this level of analysis detail and approach demonstration early in the program is especially valuable.

4. REFERENCES

1. Letter Dated November 18, 2004, from Mario V. Bonaca, Chairman, ACRS, to Carl J. Paperiello, Director, Office of Nuclear Regulatory Research, NRC, Subject: ACRS Assessment of the Quality of Selected NRC Research Projects.

2. Letter Dated November 5, 2005, from William J. Shack, Acting Chairman, ACRS, to Carl J. Paperiello, Director, Office of Nuclear Regulatory Research, NRC, Subject: ACRS Assessment of the Quality of Selected NRC Research Projects - FY 2005.

3. Letter Dated October 17, 2006, from Graham B. Wallis, Chairman, ACRS, to Brian Sheron, Director, Office of Nuclear Regulatory Research, NRC, Subject: ACRS Assessment of the Quality of Selected NRC Research Projects - FY 2006.

4. Letter Dated October 19, 2007, from William J. Shack, Chairman, ACRS, to Brian Sheron, Director, Office of Nuclear Regulatory Research, NRC, Subject: ACRS Assessment of the Quality of Selected NRC Research Projects - FY 2007.

5. Letter Dated October 22, 2008, from William J. Shack, Chairman, ACRS, to Brian Sheron, Director, Office of Nuclear Regulatory Research, NRC, Subject: ACRS Assessment of the Quality of Selected NRC Research Projects - FY 2008.

6. Letter Dated September 16, 2009, from Mario V. Bonaca, Chairman, ACRS, to Brian Sheron, Director, Office of Nuclear Regulatory Research, NRC, Subject: ACRS Assessment of the Quality of Selected NRC Research Projects - FY 2009.

7. Letter Dated November 15, 2010, from Said Abdel-Khalik, Chairman, ACRS, to Brian Sheron, Director, Office of Nuclear Regulatory Research, NRC, Subject: ACRS Assessment of the Quality of Selected NRC Research Projects - FY 2010.

8. Letter Dated September 19, 2011, from Said Abdel-Khalik, Chairman, ACRS, to Brian Sheron, Director, Office of Nuclear Regulatory Research, NRC, Subject: ACRS Assessment of the Quality of Selected NRC Research Projects - FY 2011.

9. Letter Dated October 22, 2012, from J. Sam Armijo, Chairman, ACRS, to Brian Sheron, Director, Office of Nuclear Regulatory Research, NRC, Subject: ACRS Assessment of the Quality of Selected NRC Research Projects - FY 2012.

10. Letter Dated November 21, 2013, from J. Sam Armijo, Chairman, ACRS, to Brian Sheron, Director, Office of Nuclear Regulatory Research, NRC, Subject: ACRS Assessment of the Quality of Selected NRC Research Projects - FY 2013.

11. Letter Dated November 25, 2014, from John W. Stetkar, Chairman, ACRS, to Brian Sheron, Director, Office of Nuclear Regulatory Research, NRC, Subject: ACRS Assessment of the Quality of Selected NRC Research Projects - FY 2014

12. National Research Council, *Understanding Risk: Informing Decisions in a Democratic Society.* National Academy Press, Washington, DC, 1996.

13. Apostolakis, G.E., and Pickett, S.E., "Deliberation: Integrating Analytical Results into Environmental Decisions Involving Multiple Stakeholders," *Risk Analysis*, 18:621-634, 1998.

14. Clemen, R., *Making Hard Decisions*, 2nd Edition, Duxbury Press, Belmont, CA, 1995.

15. Keeney, R.L., and H. Raiffa, *Decisions with Multiple Objectives: Preferences and Value Tradeoffs*, Wiley, New York, 1976.

16. U.S. Nuclear Regulatory Commission, "Uranium Sequestration during Biostimulated Reduction and In Response to the Return of Oxic Conditions In Shallow Aquifers," NUREG/CR-7178, December 2014.

17. U.S. Nuclear Regulatory Commission, "Weld Residual Stress Finite Element Analysis Validation: Part 1 – Data Development Effort," NUREG-2162, March 2014.