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

September 16, 2009

Dr. Brian Sheron, 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 2009

Dear Dr. Sheron:

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

- Crack Growth Rates and Metallographic Examinations of Alloy 600 and Alloy 82/182 from Field and Laboratory Materials Testing in PWR Environments
    - Documentation and strategy of this project were found to be of marginal quality. Methods used in the research were acceptable. The results marginally satisfy the research objectives.
- Diversity Strategies for Nuclear Power Plant Instrumentation and Control Systems
    - This project was found to be of professional quality. The results meet the research objectives.

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

During the course of the preparation of this report, you met with some ACRS members to discuss potential enhancements to our review process for the quality assessment of selected NRC research projects. The enhancements that were suggested focused on ensuring more direct involvement of RES project managers in the process and on soliciting the user office perspectives on the research products. You agreed to propose appropriate mechanisms for implementing these enhancements and submit them to the ACRS for consideration during its FY 2010 quality assessment review.

We anticipate receiving a list of candidate projects for quality assessment in FY 2010 as well as RES proposal for implementation of any enhancements to our review process prior to our October 8-10, 2009 meeting.

Dr. William Shack did not participate in the Committee's deliberations regarding the quality assessment of the research project on Crack Growth rates and metallographic Examinations of Alloy 600 and Alloy 82/182 from Field and Laboratory Materials Testing in PWR Environments.

Sincerely,

*/RA/*

Mario V. Bonaca
Chairman

Enclosure: As stated

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Letter to Brian Sheron, Director, Office of Nuclear Regulatory Research from Mario V. Bonaca, Chairman, ACRS, dated September 16, 2009

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# Assessment of the Quality of Selected NRC Research Projects by the Advisory Committee on Reactor Safeguards - FY 2009

**July 2009**

**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. Naval 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* (FACA), which is implemented through NRC regulations at Title 10, Part 7, of the *Code of Federal Regulations* (10 CFR Part 7). 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**, Principal, Stetkar & Associates, Lake Forest, California

# ABSTRACT


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

- Crack Growth Rates and Metallographic Examinations of Alloy 600 and Alloy 82/182 from Field and Laboratory Materials Testing in PWR Environments
  - Documentation and strategy of this project were found to be of marginal quality. Methods used in the research were acceptable. The results marginally satisfy the research objectives
- Diversity Strategies for Nuclear Power Plant Instrumentation and Control Systems
  - This project was found to be of professional quality. The results meet the research objectives.

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# ABBREVIATIONS

| | |
|---|---|
| ACRS | Advisory Committee on Reactor Safeguards |
| ASME | American Society of Mechanical Engineers |
| AEC | Atomic Energy Commission |
| ANL | Argonne National Laboratory |
| BTP | Branch Technical Position |
| BWR | Boiling Water Reactor |
| CCF | Common Cause Failure |
| CFR | Code of Federal Regulation |
| CGR | Crack Growth Rate |
| CRDM | Control Rod Drive Mechanisms |
| DCE | Diversity Criterion Effectiveness |
| DOE | Department of Energy |
| FACA | Federal Advisory Committee Act |
| FY | Fiscal Year |
| GPRA | Government Performance and Results Act |
| MAUT | Multi-Attribute Utility Theory |
| NDE | Nondestructive Examination |
| NRC | Nuclear Regulatory Commission |
| NRR | Office of Nuclear Reactor Regulation |
| ORNL | Oak Ridge National Laboratory |
| PWSCC | Primary Water Stress Corrosion Cracking |
| PWR | Pressurized Water Reactor |
| RES | Office of Nuclear Regulatory Research |
| SCC | Stress Corrosion Cracking |
| SOW | Statement of the Work |
| 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 (GPRA). Since fiscal year 2004, the Advisory Committee on Reactor Safeguards (ACRS) has been assisting RES by performing independent assessments of the quality of selected research projects [1-5]. The Committee has established the following process for conducting the review of the quality of research projects:

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- 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 Committee submits an annual summary report to the RES Director.

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

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

Within the first characteristic, 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:

- Crack Growth Rates and Metallographic Examinations of Alloy 600 and Alloy 82/182 from Field and Laboratory Materials Testing in PWR Environments
- Diversity Strategies for Nuclear Power Plant Instrumentation and Control Systems

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 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 [6-7]. The analytical part utilizes methods of multi-attribute utility theory (MAUT) [8-9] 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.

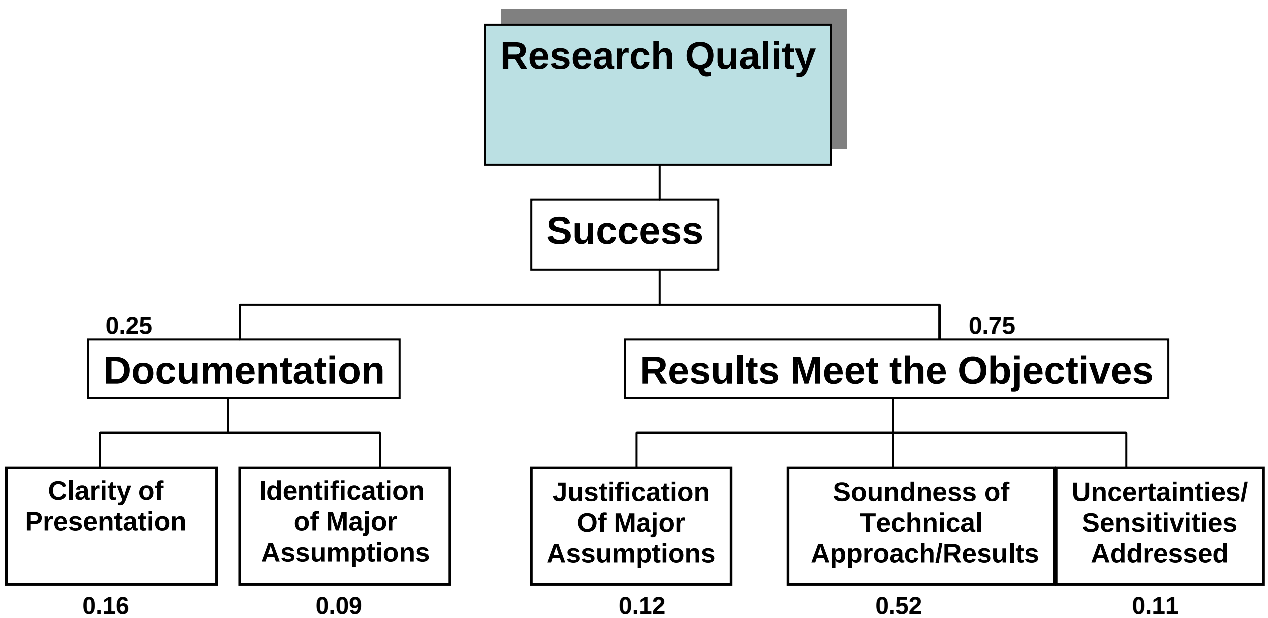



Figure 1. The value tree used for evaluating the quality of research projects

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.

The value tree, weights, and constructed scales were the result of extensive deliberations of the whole ACRS. As discussed in Section 1, a panel of three 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 Crack Growth Rates and Metallographic Examinations of Alloy 600 and Alloy 82/182 from Field Components and Laboratory Materials Tested in PWR Environments

Many important reactor internal components are fabricated from nickel alloys (Alloy 600 & Alloy 690). These materials are joined using nickel base welding alloys (Alloys 82/182 & Alloys 52/152). Components fabricated from these materials can be susceptible to primary water stress corrosion cracking (PWSCC) to varying degrees, as evidenced by circumferential cracking in control rod drive mechanisms (CRDM) nozzle penetrations at Oconee and cracking in pipe butt welds at V.C. Summer and overseas plants. The NRC sponsored a research program on environmentally-assisted cracking in Light Water Reactors (LWRs) at the Argonne National Laboratory (ANL). The primary objective of task 4 of this project was to provide the NRC with technical data and analytical methods to independently estimate crack growth rates (CGRs) in nickel-alloy components and weldments caused by PWSCC. Such data and methods are used for regulatory determinations of residual life, inspection intervals, repair criteria, and effective countermeasures for reactor internal components. The statement of the work (SOW) identified needs for:

1. a summary of available crack growth data as well as an assessment of the data's usefulness,
2. reduction in CGR measurement uncertainty due to variations in test methods to facilitate an evaluation of industry generic analyses,
3. investigation of the influences of variables such as alloy composition, microstructure, temperature, and water chemistry on CGRs, and
4. identification of a test method that appropriately represents service conditions, and accurately measures CGRs with sufficient precision to minimize the imposition of regulatory conservatism.

The results of this study are documented in NUREG/CR-6964, ANL 07/12, "Crack Growth Rates and Metallographic Examinations of Alloy 600 and Alloy 82/182 from Field Components and Laboratory Materials Tested in PWR Environments" [10]. The scope of the present quality review is limited to this report.

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

This report is overly broad in scope. It includes newly generated data, as well as data from prior research conducted at Argonne National Laboratory and other laboratories. The new experimental work focused on the measurement of PWSCC crack growth rates (CGRs), as influenced by temperature, material composition, microstructure and mechanical loading variables. In addition, the researchers investigated the influence of these variables on the PWSCC fracture surfaces to gain a better understanding of the mechanisms of crack growth. The report addresses a number of other issues including:

- CGRs in Alloy 600 base metal
- Influence of microstructural variables and weld orientation on CGRs
- CGRs in laboratory fabricated weldments and field weldments from nuclear power plants

Table 2. Summary Results of ACRS Assessment of the Quality of the Project "Crack Growth Rates and Metallographic Examinations of Alloy 600 and Alloy 82/182 from Field Components and Laboratory Materials Tested in PWR Environments" (NUREG/CR-6964)

| **Performance Measures** | **Consensus Scores** | **Weights** | **Weighted Scores** |
|---|---|---|---|
| Clarity of presentation | 4.0 | 0.16 | 0.64 |
| Identification of major assumptions | 3.8 | 0.09 | 0.35 |
| Justification of major assumptions | 4.0 | 0.12 | 0.48 |
| Soundness of technical approach/results | 3.8 | 0.52 | 1.99 |
| Treatment of uncertainties/sensitivities | 3.8 | 0.11 | 0.42 |
| | | **Overall Score** | **3.88** |

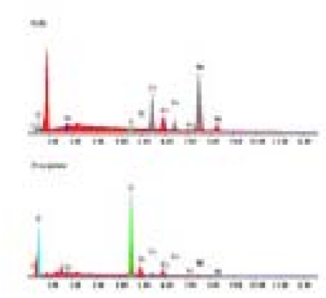
The research presented in NUREG/CR-6964 partially met the identified needs in the SOW. The consensus scores for this project are shown in Table 2. The score for the overall assessment of the work was found to be 3.88, i.e., it is of marginal quality. Documentation and strategy of this project were found to be of marginal quality. Methods used in the research were acceptable. The results marginally satisfy the research objectives. Comments and conclusions within the evaluation categories are provided below.

**Clarity of Presentation** (Consensus Score = 4.0)

The report is difficult to follow, perhaps because of its overly broad scope. It is not always clear when data discussed in the report are from new tests, or prior tests. It would have been better for readers, if the authors had issued one report presenting the new experimental findings on the A182/A82 welds, and a separate literature review and analysis focused on the broader objective of assuring that the current disposition curves used by the NRC for Inconel 600 base metal and A82/A182 weldments are adequate for their intended purpose.

The Abstract, Forward, and Executive Summary are poorly written. They do not clearly articulate the objectives of the work, or delineate the major findings and conclusions and whether such findings meet the objectives and needs stated in the SOW. They also do not clearly specify or distinguish between new experimental findings and data extracted from either earlier ANL studies or the literature.

While the main body of the report is generally well written, there are other deficiencies in the report presentation.  For example, Figure 13-b (see Figure 2) in the report is impossible to read.  Many other figures such as Figure 29-b (see Figure 2) are overloaded with excessive and cryptic information which makes their review and evaluation needlessly laborious for the reader.  The report also contains obvious errors which detract the reader from the main subject of the report (e.g. error on page 2 regarding the size of the Davis-Besse cavity being 50 x 70 inches!!).



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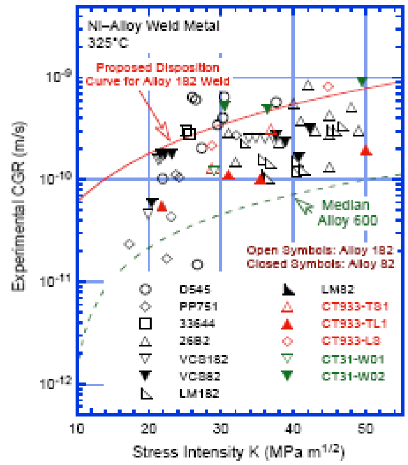


(b)

Unreadable Figure 13-b                                         Overly busy Figure 29-b

Figure 2. Examples of unreadable or overly busy Figures in NUREG/CR-6964 report

**Identification of Major Assumptions** (Consensus Score – 3.8)

The authors did not explicitly identify the major assumptions involved in the experimental measurements and analyses presented in the report.  There were numerous implicit assumptions, which should have been identified and justified.  Among these are:

- Test procedures and test variables utilized in the research  have been demonstrated to yield reproducible crack growth rates with acceptable uncertainty bands (addressing needs 2 and 4 in the SOW)
- Correction factors used to normalize results from 1T, ½T and ¼ T test specimens are sufficiently proven to justify the use of more than one test specimen geometry.
- Nickel base alloy welds fabricated under laboratory conditions using different filler materials, and different welding procedures can reasonably be expected to be comparable to field welded materials.
- Single test specimens can be used to generate environmental fatigue data without affecting subsequent PWSCC crack growth rates.
- Water chemistry conditions used in all experiments (2 ppm Li as LiOH and 1000 ppm B as $HBO_3$) are expected to yield prototypical or conservative data.

**Justification of Major Assumptions** (Consensus Score – 4.0)

No explicit or systematic justifications of major assumptions were provided in the report.

**Soundness of Technical Approach and Results** (Consensus Score – 3.8)

There are many examples of excellent research practices in this work. Sophisticated chemical and electrochemical methods were used to control the test environment chemistry and mechanical loading systems, and to measure extremely slow crack growth rates. Identical test methods were applied in the three separate test rigs used for this research. Thus the test procedures and controls used should provide reasonable assurance that results are reproducible. The authors however did not state whether earlier experiments had demonstrated that this is indeed the case.

Although the test systems and procedures used were carefully controlled to limit experimental variability, the researchers unnecessarily introduced many variables into the test program. The report does not state why these variables were needed or whether the variables were expected to affect the test results. This deficiency is particularly troubling in the three tests used to determine the activation energies (influence of test environment temperature on the CGRs) of laboratory fabricated A82/182 weldments. This problem is best illustrated by considering the variables addressed with only three tests specimens:

- Specimens were fabricated from two different laboratory weldments. One was a double-J weld joining two Inconel 600 plates. The weld procedure used 5 passes of A82 filler and 43 passes of A182 filler. The second weld was fabricated by filling a deep groove in a single Inconel 600 plate with several (number not stated) passes of A182 filler.
- Different A182 filler compositions were used for the two different welds. One A182 filler was nearly out of spec on iron content (6.005% vs. 6.10% specified) while the other was well within the specified ranges for all elements. No reason was provided why this filler metal variable was necessary or justified.
- Two test specimen configurations (full thickness 1T and half thickness ½ T) were used. The thicker 1T specimen is generally preferred for fracture mechanics testing of ductile materials. No justification was provided for the use of the ½ T specimens. Perhaps the smaller specimens were necessary due to limitations of the three autoclave systems used, but this was not stated in the report.
- Each specimen was tested in a different autoclave using different chemical control systems and mechanical loading fixtures. No discussion was offered as to why it was necessary or prudent to use a different test facility for each specimen.

Each specimen was used to measure both environmental fatigue crack growth rates under cycling loading conditions, prior to measuring PWSCC crack growth rates under constant load. The cyclic loading variables used for each specimen varied considerably. These included different combinations of waveforms, load ratios, rise times, down times, and test durations.

One of the major objectives of the new tests was to measure the influence of temperature on crack growth rates of A182 welds. The results of the tests are shown graphically in Figure 36 of the report, and reproduced here for discussion (See Figure 3). As displayed, the various intended and unintended) variables used in these experiments make the evaluation of the results laborious. The red symbols represent test specimens taken from the deep groove weld, and the blue from the double-J weld. The open symbols represent CGRs from 1T specimens and the filled symbols (red or blue) represent CGRs from ½ T specimens. Finally, the shapes of the symbols (triangles, squares, diamonds or rectangles) represent the four specimens in the test program. Consequently, one symbol on the graph represents four intended or unintended test variables.

For comparison, data from a similar study by Westinghouse requires only one symbol perhaps because the test variables were limited only to those necessary to determine the CGR of one type of weld, of one composition and one specimen geometry over the temperature range of interest.

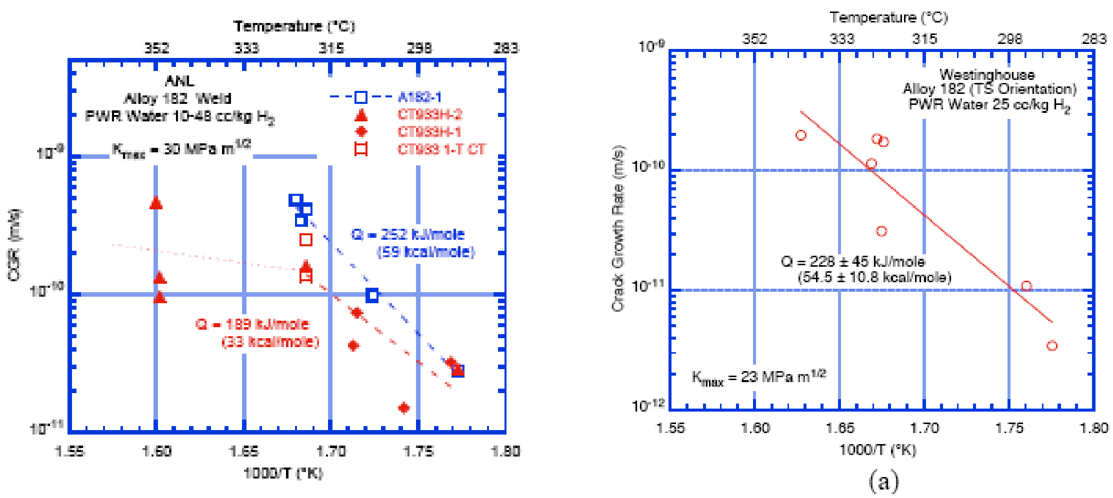


Figure 3. Comparison of Figures 35a and 36 from NUREG/CR-6964 report

The conclusions drawn from the ANL data plotted in Figure 36 are not particularly enlightening. While the activation energy for PWSCC crack growth in A182 double-J groove welds was in reasonably good agreement with other data in the literature, the CGRs determined from the tests of the deep groove weld, ½ T specimens exhibited considerable scatter. The CGRs from identical specimens (CT933H-1 and CT933H-2) tested over a 290°C to 320°C temperature range were inconsistent with the CGRs measured at the highest temperatures (352°C). No discussion was given as to the cause or significance of the large scatter in the CGRs at the highest temperature (352°C; see Figure 36), which were measured on the same sample (CT933H-2), at the same test conditions and in the same test facility. The CGRs determined in the highest temperature tests were excluded from the calculation of the activation energy. The authors contended the exclusion was justified because the data "suggest a plateau in CGR at temperatures above 320°C." No further justification was provided for the unusual temperature dependence of this series of tests. The lack of agreement with the 1T double-J weld results, combined with the scatter in the data, and the unusual temperature dependence suggests that the entire set of ½ T deep groove CGRs should be considered suspect pending further analysis of the influence of the many variables involved.

The reported results do not fully meet the broad objectives stated in the SOW. It is not clear how the NRC or the licensees can use the results presented in this report. Of primary concern is the fact that the results of laboratory experiments are counter to field observations which indicate that Alloy 600 base metal is more susceptible to cracking than weldments. While the hypothesis offered in the report to explain this discrepancy, viz. significantly higher degree of structural constraint is generally imposed on field welds during the welding process, seems plausible, no discussion is offered on how this hypothesis can be verified or how the welding procedures for laboratory samples can be modified to match field conditions. This brings into question the applicability and significance of all laboratory results on weld behavior, inasmuch as they do not appropriately represent service conditions (counter to the stated need in the SOW). The report correctly states that heats of Alloy 600 show a wide variability of their susceptibility to PWSCC. However, no discussion was offered as to the possible root cause(s) of such variability. Additionally, no discussion is offered as to why it is appropriate to use the 75$^{th}$ percentile data for the disposition curve given the large variability in the susceptibility of different heats to PWSCC. Hence, the results of this work do not eliminate or minimize the need for imposition of regulatory conservatism, again, counter to the stated need in the SOW.

**Treatment of Uncertainties/Sensitivities** (Consensus Score – 3.8)

It is not clear that a systematic treatment of uncertainties and sensitivities is possible in view of the large number of intended and unintended variables used in the CGR tests and the relatively small number of test specimens. Nevertheless, no discussion is offered as to the consistency or repeatability of the data (e.g. large difference in measured CGR values during test periods 6, 9, and 10 for CT933H-2 at the highest test temperature as shown in Table 6 and Figure 36 of the NUREG/CR-6964 report.

Weibull plots have been used extensively in the analysis of the data presented in the report. Even when test specimens seem to exhibit quite different CGRs, the Weibull analyses indicate that they are statistically in the same population. For example there seems to be a significant difference in the crack growth rates of laboratory fabricated and field fabricated A82/A182 weldments tested at ANL under identical conditions. The authors state that the differences in the crack growth rates are not statistically different, but suggest that field welds may be more susceptible due to material variability or mechanical restraints imposed during field welding. Thus, the question of the acceptability of using laboratory welded specimens to produce disposition curves for field welds remains an open issue.

## 3.2 Diversity Strategies for Nuclear Power Plant Instrumentation and Control Systems

The NRC has established regulatory guidance for assessing the diversity and defense-in-depth provided by the instrumentation and control (I&C) system architecture at a nuclear power plant. Guidance for performing diversity and defense-in-depth analyses of reactor protection systems to identify appropriate diverse systems and defense-in-depth approaches is provided in NUREG/CR-6303, *Method for Performing Diversity and Defense-in-Depth Analyses of Reactor Protection Systems* [11], as well as Branch Technical Position (BTP) 7-19, "Guidance on Evaluation of Defense-in-Depth and Diversity in Digital Computer-Based Instrumentation and Control Systems" [Chapter 7, "Instrumentation and Controls," of NUREG-0800, *Standard Review Plan for Review of Safety Analysis Reports for Nuclear Power Plants*]. However, there is currently no definitive guidance specifying how much diversity is sufficient to mitigate common cause failure (CCF) vulnerabilities that may arise from digital safety system designs.

The NRC sponsored a research project at Oak Ridge National Laboratory (ORNL) to develop a technical basis for establishing acceptable mitigating strategies that address the potential for digital CCF vulnerabilities. The specific objective of this research effort was to identify and develop diversity strategies, which consist of combinations of diversity attributes and their associated criteria, by leveraging the experience and practices of other industries and the international nuclear power community.

The results of this study are documented in NUREG/CR-XXXX, ORNL/TM-2008/XX, "Diversity Strategies for Nuclear Power Plant Instrumentation and Control Systems" [12]. The scope of the present quality review is limited to this report.

**General Observations**

In general, the investigators did a thorough job. They have identified and developed diversity strategies, which consist of combinations of diversity attributes and their associated criteria. Technology, which corresponds to design diversity, is chosen as the principal system characteristic by which diversity criteria are grouped to form strategies. The rationale for this classification framework involves consideration of the profound impact that technology-focused design diversity provides. Consequently, the diversity usage classification scheme involves three families of strategies: (1) different technologies, (2) different approaches within the same technology, and (3) different architectures within the same technology. The grouping of diversity criteria combinations according to these three families of strategies establishes baseline diversity usage and facilitates a systematic organization of strategic approaches for coping with CCF vulnerabilities.

The consensus scores for this project are shown in Table 3. The score for the overall assessment of the work was found to be 5.29, i.e., it is of professional quality. The results meet the research objectives.

Table 3. Summary Results of ACRS Assessment of the Quality of the Project on Diversity Strategies for Nuclear Power Plant Instrumentation and Control Systems (NUREG/CR-XXXX, ORNL/TM-2008/XX)

| Performance Measures | Consensus Scores | Weights | Weighted Scores |
|---|---|---|---|
| Clarity of presentation | 4.0 | 0.16 | 0.64 |
| Identification of major assumptions | 6.5 | 0.09 | 0.59 |
| Justification of major assumptions | 6.0 | 0.12 | 0.72 |
| Soundness of technical approach/results | 6.0 | 0.52 | 3.12 |
| Treatment of uncertainties/sensitivities | 2.0 | 0.11 | 0.22 |
| | | **Overall Score** | **5.29** |

Comments and conclusions within the evaluation categories are:

**Clarity of Presentation** (Consensus Score = 4.0)

Although the report is thorough and comprehensive in its exposition, it is difficult to determine the major point or points within each section due to the verbose, rambling, and repetitive presentation.

While assumptions are identified throughout the report, they are not organized and presented in a manner to allow them to be easily assimilated. In addition, there are three other important basic assumptions not explicitly stated but that could be derived from the discussions throughout the main body of the report. They are:

1. That qualitative judgments, in the absence of a means to quantify effectiveness, are valid in determining effective diversity attributes from best to least (see page 5-8, first whole paragraph and Section 6).

2. That technology employed could be used as the starting point or entry condition for the overall assessment. The only apparent basis given was that it is listed first in NUREG/CR-6303. NUREG/CR- 6303 did not provide a basis for it being a starting point.

3. That independence of some of the closely coupled approaches must be maintained for the conclusions to be valid. The authors do not address how that is ensured (see page 5-8, first whole paragraph).

**Identification of Major Assumptions** (Consensus Score = 6.5)

Good consideration was given to the development of major assumptions in the conduct and documentation of the research. As stated before, the major criticism is that assumptions are not organized and presented in a manner to allow them to be easily assimilated.

**Justification of Major Assumptions** (Consensus Score = 6.0)

The justifications were largely qualitative. They were based on usage, assessments of usage, and the judged effectiveness of the usage. Appendix A is more definitive in stating the basis for the assumptions.

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

The main body of the report that reviews and evaluates existing approaches is technically sound. However, Appendix A is problematic. The various weights are assigned using formulas that are of doubtful value. For example, the criteria under each attribute (Table A.3) are simply given "ranks" 1, 2, 3 or 1, 2, 3, 4 depending on whether the total number of criteria is 3 or 4. These ranks are then used in a formula to produce the criteria weights as follows:

$$W_{Cij} = \frac{(N_{cj} - M_{cij} + 1)}{\sum_{i=1}^{N_{cj}} M_{cij}}$$

where

$\boldsymbol{W_{cij}}$ = DCE weight of criterion *i* in attribute *j*
$\boldsymbol{N_{cj}}$ = number of criteria in attribute *j*
$\boldsymbol{M_{cij}}$ = rank of criterion *i* in attribute *j*

The Diversity Attribute Effectiveness Weights are also produced using a formula.

These weights should be produced by capturing the judgment of experienced people and not mechanically. The experts, for example, may assign different weights to the criteria under each attribute depending on their relative importance. This is an inherently subjective evaluation that cannot be based on formulas.

**Treatment of Uncertainties/Sensitivities** (Consensus Score =2.0)

There is neither discussion of the uncertainties in the evaluations nor guidance to be used as to what the calculated scores mean. The only references to uncertainty are general in the main body of the report.

# 4. REFERENCES


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