January 31, 2000

MEMORANDUM TO: Samuel J. Collins, Director
Office of Nuclear Reactor Regulation

FROM: Ashok C. Thadani, Director /RA/
Office of Nuclear Regulatory Research

SUBJECT: NRR USER NEED REQUEST FOR SUPPORT OF RESOLVING MATERIAL ISSUES RELATED TO AGE RELATED DEGRADATION OF REACTOR VESSEL INTERNAL COMPONENTS

By memorandum dated August 30, 1999, you requested that we expand the scope of our research effort on environmentally assisted cracking (EAC) to include:

(a) evaluation of the effects of high fluence on crack growth rates of austenitic materials;
(b) evaluation of the causes and mechanisms for irradiation assisted stress corrosion cracking (IASCC) in austenitic materials;
(c) assessment of the effectiveness of mitigative water chemistry measures;
(d) continued support to NRR as needed for review and evaluation of issues related to EAC;
(e) support for reviews with regard to extended licensing period applications.

In our initial response to you, dated November 2, 1999, we noted that our overall approach to accommodating your needs would involve meetings with your staff to identify and prioritize the short-term and long-term issues that need to be addressed, followed by a meeting with the research contractors and the public to solicit their respective views. We had also committed to delivering a revised detailed plan of EAC research to you by January 31, 2000. In this regard, we met with your staff on November 29, 1999, and subsequently with your staff and researchers from the Argonne National Laboratory, on January 6, 2000. In our interactions with your staff, we also became aware of additional EAC topics that NRR would like RES to address:

(a) evaluation of the causes and mechanisms for IASCC in PWR internals, with consideration of current understanding of mechanisms for BWR internals and environmental differences between PWRs and BWRs;
(b) void swelling in austenitic stainless steels;
(c) neutron irradiation embrittlement (e.g., loss of fracture toughness) of wrought austenitic stainless steel;
(d) synergistic embrittlement of cast austenitic stainless steel from concurrent exposure to high temperature and neutron irradiation.

We are also aware that your staff is preparing a revised summary user request to address all of the above considerations. However, since we were aware of these needs in advance, we wanted to deliver the research plan to you per the previous commitment. Our knowledge of your

overall research needs, coupled with the discussion from meetings with your staff, are reflected in the attached detailed research plan which we are hereby forwarding for your consideration. A draft version of this plan has been previously shared with your staff. Upon receipt and review of your revised summary user request, we will make any necessary changes to the research plans.

We look forward to your comments on the plan and to further interactions with your staff. It is also our intent to schedule a public workshop with the industry to discuss the plan after we have received and incorporated your comments. If you have any questions or comments, please contact Edwin Hackett at 415-5650 or Michael McNeil at 415-6794.

Attachment: As stated

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Attachment: As stated

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DATE	01/21/00		01/21/00		01/28/00		01/31/00			

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Attachment

EAC of Reactor Internals
Detailed Schedule

TASK 1: Environmental Effects on Fatigue Crack Initiation

The research undertaken will focus on (a) synergistic effects of surface finish and environment on fatigue life, (b) combined effects of loading sequence and environment, and (c) fatigue crack initiation in sensitized SS. The tests on surface finish effects will be initiated. A comprehensive evaluation of SS fatigue test specimens will be performed to explain why environmental effects are more pronounced in low–DO than high–DO water. The contractor will provide reviews and evaluation of issues related to environmental effects on fatigue as required by NRC.

FY 2000 (FIN W6610) (1.0 MY)

1. Complete tests to establish saturation strain rate for low–alloy steels (12/99).

2. Initiate metallographic evaluation of SS specimens to help explain why environmental effects are more pronounced in low–DO than in high–DO water (1/00).

3. Conduct fatigue tests on austenitic SS in high–DO water at 288EC to confirm that environmental effects on fatigue life are moderate and independent of strain rate (6/00).

4. Initiate fatigue tests at 288°C on low–alloy steel and austenitic SS specimens with different surface finish, in air and LWR environments (8/00).

FY 2001 (1.0 MY)

1. Complete metallographic evaluation of SS specimens to understand the mechanism of fatigue crack initiation in austenitic SS in LWR environments.

2. Complete fatigue tests at 288°C on low–alloy steel and austenitic SS specimens with different surface finish, in air and LWR environments.

FY 2002 (1.0 MY)

1. Initiate fatigue tests on low–alloy steels in high–DO water to study the combined effects of loading sequence and environment on fatigue life.

2. Initiate fatigue tests on sensitized Type 304 SS.

FY 2003 (1.0 MY)

1. Complete fatigue tests to study the effects of loading sequence.

2. Complete fatigue tests on sensitized SSs.

3. Update damage rules and design guidance for application of fatigue design curves for complex loading histories to take account of environmental effects.

TASK 2: IASCC and Other Irradiation Effects

A. Evaluation of the causes and mechanisms for IASCC of austenitic SSs in BWRs

This program will evaluate the susceptibility of austenitic SS to IASCC as a function of the fluence level, water chemistry, material chemistry, welding process, and fabrication history, and provide data and technical support required to address inspection-interval and CGR decisions and to help NRC address various issues arising in license renewal or from other licensee submittals. Crack growth rate (CGR) tests and slow strain rate tests (SSRTs) will be conducted on high–fluence model SSs from Halden Phase–I irradiations (carried out under NRC FIN W6610) to investigate the effects of material chemistry and irradiation level on the susceptibility of SSs to IASCC. CGR tests will be conducted on SS welds to establish the effects of fluence level, material chemistry, and welding process on IASCC. Also, SSRTs and CGR tests will be carried out on grain boundary engineered (GBE) model SS alloys to study the effect of grain boundary geometry on IASCC and investigate the prospect of using GBE as a mitigative measure. Models and codes developed under CIR and from industry sources will be benchmarked and used in conjunction with this work.

Compact tension (CT) specimens of submerged arc (SA) and shielded metal arc (SMA) welds of Types 304 and 304L SS in the as–welded condition and after low–temperature heat–treatment will be irradiated up to 1.2 x 10^{21} n/cm^2 in the Halden reactor. CT and tensile specimens of GBE Types 304, 304L, 316, and 316L SS will also be included in the irradiation experiments. The details of the Halden-II test matrix are included in the overall research-strategy analysis attached.

FY 2000 (FIN W6610) (2.3 MY)

1. Complete SSRT tests on Halden medium fluence specimens (6/00).

2. Initiate SSRT tests on Halden high fluence specimens (7/00).

3. Complete J–R tests on Halden high fluence specimens (8/00).

4. Initiate CGR tests on medium and high fluence specimens (9/00).

(TASK 2 contd.)

5. Begin Phase-II irradiation experiment at Halden Reactor to determine CGRs in irradiated welds and examine candidate IASCC resistant materials (5/00).

6. Continue analytical electron microscopy studies internal grain-boundary oxidation, grain-boundary microchemistry, and cracking behavior.

<u>FY 2001 (2.3 MY)</u>

1. Complete CGR and SSRT tests on high–fluence model SSs from Halden Phase–I irradiations to investigate the effects of material chemistry and irradiation level on the susceptibility of SS to IASCC.

2. Obtain CT specimens of SS welds irradiated to 0.6 x 10^{21} fast n/cm^2 in the Halden Phase–II experiment.

3. Initiate CGR tests on the Halden Phase–II weld specimens.

4. Characterize oxygen, helium, and fluorine distributions in field-cracked Type 304 and 304L SS core shroud welds by hot secondary ion mass spectroscopy (Paul Scherrer Institute of Switzerland).

5. Models and codes developed under CIR and from industry sources will be benchmarked and used in conjunction with this work.

<u>FY 2002 (1.8 MY)</u>

1. Continue CGR tests on the Halden Phase–II weld specimens.

2. Obtain CT specimens of SS welds and CT and SSRT specimens of GBE materials irradiated to 1.2 x 10^{21} fast n/cm^2 in the Halden Phase–II experiment.

3. Initiate SSRT on the Halden Phase–II GBE specimens.

<u>FY 2003 (1.8 MY)</u>

1. Complete CGR tests on select weld and GBE specimens from Halden Phase–II irradiation. Make detailed comparisons between neutron-irradiated and proton- irradiated results to permit cost-effective projections on effects of high fluence in LWRs with more than
40-years of operating experience.

2. Complete SSRTs on select GBE specimens from Halden Phase–II irradiation.

(TASK 2 contd.)

3. Tests on synergistic embrittlement of cast stainless steel by irradiation at high temperature will be conducted.

B. <u>Evaluation of the causes and mechanisms for IASCC of austenitic SSs in PWRs</u>

The program will focus on (a) evaluate the effects of very high fluence on crack growth rates, (b) neutron irradiation embrittlement,(e.g., loss of fracture toughness), and (c) void swelling behavior in austenitic SSs. Material will be procured from the EBR–II reactor hex cans and from cracked and sound baffle bolts of PWRs (procurement under NRC FIN W6610).

<u>FY 2000 (FIN W6610) (0.5 MY)</u>

1. Obtain specimens from EBR-II reactor hex cans (3/00).

2. Perform SSRT tests and transmission electron microscopy to provide a better understanding of IASCC behavior at very high fluence. Determine swelling behavior through density measurements. Work with PNNL and SKI (Sweden) to learn more about swelling issues (9/00).

3. Obtain cracked and intact baffle bolts of pressurized water reactors (PWRs) (9/00).

<u>FY 2001 (0.5 MY)</u>

1. Perform microstructural studies on the baffle bolt specimens and on materials from the EBR-II reactor to provide a better understanding of IASCC behavior at very high fluence.

2. Determine swelling behavior through density measurements; cooperate with PNNL and SKI on swelling issues.

<u>FY 2002 (1.0 MY)</u>

1. Conduct CGR tests on baffle bolt specimens and on materials from EBR-II reactor. Make detailed comparisons between neutron-irradiated and proton-irradiated results to permit cost-effective projections on effects of high fluence in LWRs with more than 40-years of operating experience.

2. Complete fracture toughness J–R curve tests on the baffle bolt material.

(c) Make detailed comparisons between neutron-irradiation and proton-irradiation effects to permit extrapolation of IASCC results into license-renewal space.

FY 2003 (1.0 MY)

1. Complete CGR tests on very high–fluence materials.

2. Prepare detailed analysis of methods for projecting CGRs and fracture toughness for PWR components in license-extension space.

TASK 3: Cracking of Nickel Alloys and Weldments

Evaluate the dependence of SCC and corrosion fatigue of Ni alloys and welds on alloy composition, cold work, and water chemistry. Conduct CGR tests on Inconel 82, 182, 52, and 152 weld metals and on cold–worked (CW) Alloy 600 in LWR environments.

FY 2000 (FIN W6610) (0.7 MY)

1. Complete CGR tests on mill–annealed and 30% cold–worked (CW) Alloy 600 and Inconel 82/182 weld metals in simulated BWR and PWR water. Coordinate work with SKI test programs (9/00).

FY 2001 (0.5 MY)

1. Complete CGR tests on Alloy 690, and In 52/152 weld metal in LWR environments.

2. Issue a topical report on the subject.

FY 2002 (0.3MY)

Perform analyses of microchemistry and grain-boundary effects on 600 and possibly other Ni alloys.

TASK 4: Assessment of Industry Crack–Growth Models – Analysis and Testing

Determine the effects of Cr level in the steel and cold work on CGRs in austenitic SSs in LWR environments. Procure material and fabricate CT specimens from model SS alloys with lower Cr contents and cold–worked (CW) Types 304L and 304 SS (to be carried out under NRC FIN W6610). Also, assessment of the effectiveness of the mitigative water chemistry measures,
e.g., hydrogen water chemistry or noble metal additions, will be performed.

(TASK 4 contd.)

FY 2000 (FIN W6610) (0.3 MY)

1. Procure model SS alloys with lower Cr contents fabricate CT specimens (7/00).

2. Fabricate CT specimens of cold–worked (CW) Type 304L and 304 SS (5/00).

3. Initiate CGR tests on furnace sensitized materials and lower chromium SSs to determine the effect of chromium levels on growth rates, and on CW Type 304L to determine the effect of higher yield strengths on growth rates (8/00).

FY 2001 (0.5 MY)

1. Complete CGR tests on CT specimens of CW SSs in LWR environments.

2. Complete an assessment of the effectiveness of mitigative water chemistry measures.

FY 2002 (1.0 MY)

1. Complete CGR tests on the low–Cr model alloys in LWR environments.

Topical Reports/Milestones

- 7/00 Topical Report on IASCC of Medium-Fluence Specimens from Halden-I Experiment
- 9/00 Topical Report on Loading and Environmental Effects on SS S-N Curves
- 3/01 Topical Report on Corrosion-Fatigue Properties of Ni Alloys
- 3/02 Topical Report on Field-Cracked Shroud Welds
- 9/02 Topical Report on Predicting CGRs in LWR Environments

- 5/03 Topical Report on Loading Sequence Effects on Fatigue in LWR Environments
- 9/03 Topical Report on Long-Term Projections of IASCC in LWR Environments
- 11/03Topical Report on Fatigue Damage Accumulation Rules

ROUTING AND TRANSMITTAL SLIP	DATE: October 27, 2004

TO:	INITIALS	DATE
1. M. McNEIL, MEB/DET/RES		
2. E. HACKETT, ABC/MEB/DET/RES		
3. M. MAYFIELD, AD/DET/RES		
4. A. THADANI, D/RES		
5. R. Lambert/dispatch		
6.		
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10.		
11.		
12.		

	Action		*File*		*Note and Return*
	Approval		*For Clearance*		*Per Conversation*
	As Requested		*For Correction*		*Prepare Reply*
	Circulate		*For Your Info*		*See Me*
	Comment		*Investigate*	*X*	*Signature*
	Coordination		*Justify*	*X*	*Concurrence*

REMARKS MEMO TO S. COLLINS, FROM A. THADANI - **RES No. 990207**

NRR USER NEED REQUEST FOR SUPPORT OF RESOLVING MATERIAL ISSUES RELATED TO AGE RELATED DEGRADATION OF REACTOR VESSEL INTERNAL COMPONENTS

FROM: JEAN GARLAND	Room No.-Bldg. T-10-E4 Phone No. 6983