UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

October 31, 2000

MEMORANDUM FOR: William H. Bateman, Chief
Materials and Chemical Engineering Branch
Division of Engineering

THRU: Keith R. Wichman, Chief
Component Integrity Section
Materials and Chemical Engineering Branch
Division of Engineering

FROM: William H. Koo, Sr. Materials Engineer
Component Integrity Section
Materials and Chemical Engineering Branch
Division of Engineering

SUBJECT: REPORT ON TRIP TO IAEA WORKING GROUP 2 ON COMPREHENSIVE INTEGRITY ASSESSMENT TECHNIQUES FOR MITIGATION OF IGSCC IN RBMK REACTORS

I participated in the first meeting of Working Group 2 (WG-2) on Comprehensive Assessment Techniques which was held September 7-8, 2000, at Ignalina Nuclear Power Plant (INPP), Visaginas, Lithuania. The objective of WG-2 is to develop a break preclusion methodology for assessment of structural integrity of the 300 mm stainless steel piping used in RBMK reactors. The Working Group meeting was sponsored by the IAEA Extra Budgetary Programme on Mitigation of Intergranular Stress Corrosion Cracking in RBMK Reactors.

Intergranular stress corrosion cracking (IGSCC) is a relatively new issue in RBMK reactors. IGSCC was first detected in 1997 in the heat affected zone (HAZ) of austenitic stainless steel piping welds in several RBMK NPPs. An IAEA sponsored workshop was held in Slavutych, Ukraine June 22-26, 1998, to exchange information on experience with IGSCC in austenitic piping in BWR and RBMK plants. A follow-up workshop meeting was held at IAEA in Vienna, October 27-30, 1998, to develop detailed outlines for several follow-on projects based on the conclusion and recommendations made by the Slavutych Workshop. The IAEA Programme's First Steering Committee meeting was held in Vienna, May 16-19, 2000, which established priorities in several technical areas that needed to be addressed for IGSCC issues in RBMK reactors. Four working groups were formed to focus on the established priorities in the technical areas of improvements in ISI performance and qualification, comprehensive assessment techniques, qualification of repair techniques and decontamination techniques, respectively.

CONTACT: W. H. Koo, EMCB/DE
415-2706

William H. Bateman

The meeting was attended by 22 experts from Germany, Japan, Lithuania, Russia, Sweden, United Kingdom, Ukraine, USA and the IAEA (Attachment 1). The WG-2 leader is Mr. Bjorn Brickstad and the Secretary is Mr. Adam Letzter. Both are experts from Sweden.

The major activities accomplished during the first WG-2 meeting are summarized below:

(1) The Working Group leader led the review and discussion of the WG-2 objectives and its four tasks: (1) Damage Data Base, (2) Break Preclusion Methodology, (3) Root Causes of IGSCC in RBMK Plants, and (4), Risk Based Inspection RBI Pilot Study for Ignalina NPP. The Russian representatives agreed with to further understand the IGSCC mechanism in RBMK reactors it is important to collect the damage data base and will support the activity, however, this activity is very sensitive to the plant owners. Therefore, in requesting the release of such data from the plant owners, detailed justification should be provided. The WG-2 objectives and tasks (Attachment 2) were approved by the participants and will be presented to the next steering committee meeting.

(2) The RBMK plant representatives briefly described their plant-specific actions being taken to address and mitigate the IGSCC issue.

(3) The western experts from Sweden, Finland and USA presented their experience or program in mitigating IGSCC. I presented a summary (Attachment 3) of the program implemented in the USA to mitigate the IGSCC in BWRs. In the USA, the IGSCC mitigation program is based on NUREG 0313, Revision 2 and is implemented through the issuance of Generic Letter 88-01.

(4) A German expert (Mrs. Renate Kilian) from Siemens Nuclear Power presented German experience pertaining to stress corrosion cracking (SCC) in stabilized stainless steel. Cracking was found in material with low stabilizing ratio (<4). IGSCC was found in base metal with no sensitization when severely cold worked. The crevice condition at weld root would promote crack initiation. The IGSCC mechanism is not fully understood at this time, since IGSCC is a function of many variables such as EPR (degree of sensitization), stress, strain, K (stress intensity factor), T (temperature), sulfate content, flow rate, oxygen and hydrogen peroxide content, cold deformation, crevice condition and many other parameters. Siemens Nuclear Power Plant has collected about 20 welds in the damage data base.

(5) The participants were divided into four task groups to discuss and develop its respective work plan. The leader and co-leader of each task group were selected. I am the leader of task 2 for development of break preclusion methodology. The co-leader of Task 2 is Mr. Alexey Arzhaev from Russia (NIKIET/RDIPE).

(6) For each task, the subtasks, actions, and deliverables as well as the milestones and estimated completion dates were developed (Attachment 4).

(7) The participants agreed to have three more WG-2 meetings (tentatively scheduled for March 5-7, 2001, September 5-7, 2001, and March 2002) to finalize and deliver the technology transfer products based on the framework developed by the first Steering Committee (SC) meeting.

The first Working Group 2 meeting is considered to be a success because the goals set forth for this meeting are all achieved. Each participant is enthusiastic in providing input and sharing experience regarding the mitigation of IGSCC. In the meeting the Russian representatives and RBMK plant representatives have shown their support of the work plan designed to transfer the western technology to assist the RBMK plant owners to resolve the IGSCC issue in their plants. For the work plan outlined for Working Group 2, the task of collecting damage data from RBMK plants is very important toward our effort to determine the root cause of the cracking and understand the mechanism of IGSCC. Furthermore, the understanding of the basic IGSCC mechanism would provide important input for the completion of the remaining WG-2 tasks. One important element in the development of comprehensive integrity assessment techniques is to determine a crack growth equation for representative RBMK environment. In flaw evaluation, this equation would be used to calculate the potential crack growth in the affected component. However, this crack growth equation needs to be supported by a good crack growth data base. At this time, such data for the materials used in RBMK reactors are very limited and require an extensive effort to locate. In the next several months, as a leader of Task 2, I will be working extensively on the assignments for which I am responsible and will coordinate with other task members to ensure that all Task 2 assignments will be completed in accordance with the proposed milestones and schedules.

ATTACHMENT 1

First Working Group 2 Meeting
Comprehensive Integrity Assessment Techniques
List of Participants

SWEDEN

Mr. Bjorn Brickstad — *WG-2 Leader & Task 4 Leader*
Det Norske Veritas (DNV)
Technical Consulting
Box 30234
SE-104 25 Stockholm
Sweden
Tel.: +46 8 587 940 57
Fax: +46 8 651 70 43
E-mail: bjorn.brickstad@dnv.com

Mr. Adam Letzter — *WG-2 Secretary & Task 1 Leader*
Det Norske Veritas (DNV)
Nuclear Technology
Box 30234
SE-104 25 Stockholm
Sweden
Tel.: +46 8 587 94 281
Fax: +46 8 651 70 43
E-mail: adam.letzter@dnv.com

Mr. Ervin Liszka — *Observer*
Swedish International Project Nuclear Safety
Box 70283
SE-107 22 STOCKHOLM
Sweden
Tel.: +46 8 698 30 82
Fax: +46 8 20 98 95
E-mail: elk@sip.se

GERMANY

Ms. Renate Kilian — *Task 3 Leader (provisional)*
SIEMENS AG
Energieerzeugung KWU NT12
Freyeslebenstrasse 1
3220
Erlangen
D-91050 Germany
Tel.: +49 9131 18 7363, +49 911 75 9738
Fax: +49 9131 18 5395
E-mail: Renate.Kilian@erl11.siemens.de

Mr. Hermann Schaefer — *Task 2*
Gesellschaft fuer Anlagen- und Reaktorsicherheit (GRS) mbH
Forschungsgelaende
Garching
85748 Germany
Tel.: +49 89 32004 483
Fax: +49 89 32004 306
E-mail: scm@grs.de

JAPAN

Mr. Yoshitsugu Morishita *Task 2*
International Cooperation and Technology Development Center, ICTDC / JNC
1 Shiraki, Tsuruga-shi
Fukui
Japan
Tel.: +81 770 39 1031
Fax: +81 770 39 9228
E-mail: morie@t-hq.jnc.go.jp

USA

Mr. William H. Koo *Task 2 Leader*
U.S. Nuclear Regulatory Commission NRC NRR/DE
11555 Rockville Pike
Mail Stop O-9H4
Washington
DC 20555-0001 USA
Tel.: +1 301 415-2706
Fax: +1 301 415-2444
E-mail: WHK@nrc.gov

UNITED KINGDOM

Mr. Laurence Poulter *Task 2*
AEATechnology AEAT
RD3 Risley, Warrington
Cheshire
WA3 6AT United Kingdom
Tel.: +44 1925 254255
Fax: +44 1925 254629
E-mail: laurence.poulter@aeat.co.uk

LITHUANIA

Mr. Juri Saburov *Task 1 Co-leader & Task 4 Co-Leader*
Ignalina NPP, INPP
4761 Visaginas
Lithuania
Tel.: +370 66 286 68
Fax: +370 66 29350, 3706628818 or 2
E-mail: saburov@mail.iae.lt

Mr. Arturas Klimasauskas *Task 2 and 4*

Lithuanian Energy Institute
3 Breslaujos Str.
3035 Kaunas
Lithuania
Tel.: +370 7 45 13 22
Tel.: +370 87 70 724 (cellular)
Fax: +370 7 35 12 71
E-mail: arturas@isag.lei.lt

Mr. Alexander Alejev *Observer*
VATESI
Sermuksniu 3
LT-2600 Vilnius
Lithuania
Tel.: +370 2 614 427
Fax: +370 2 614 487
E-mail: alejev@vatesi.lt

RUSSIA

Mr. Alexander M. Parshin *Task 1*
Smolensk NPP
Smolensk region
Desnogorsk
216532 Russia
Tel.: +7 08153 7 93 14
Fax: +7 08153 7 47 69
E-mail: snpp@deol.ru

Mr. Sergei A. Polyanskikh *Task 1*
Kursk NPP
Kursk region
Kurchatov
307239 Russia
Tel.: +7 0731 5 33 25
Fax: +7 07131 4 18 19; +7 07131 5 31 90
E-mail:

Mr. Alexey I. Arzhaev *Task 2 Co-Leader*
NIKIET / RDIPE
P.O.Box 788
Moscow
101000 Russia
Tel.: +7 095 263 74 51
Fax: +7 095 264 40 10
E-mail: arjaev@enter.ru

Mr. N. Karpunin *Task 2*
Gosatomnadzor NRS (NTC / GAN)
Taganskaya st.. 34
Moscow
109147 Russia
Tel.: +7 095 912 7986
Fax: +7 095 912 40 41, +7 095 275 55 48
E-mail: sec@ntc.asvt.ru

Mr. Vitaly A Kiselyov *Task 2*
ENES, NIKIET / RDIPE
P.O.Box 788
Moscow
101000 Russia
Tel.: +7 095 263 74 49
Fax: +7 095 264 79 34
E-mail: kis@entek.ru

Mr. Alexander Tereschenko *Task 3 Co-Leader*
PROMETEY
49 Shpalernaya Str.
St Petersburg 193015
Russia
Tel.: +7 812 274 1134
Fax.: +7 812 274 1707
E-mail: mail@karprometey2.spb.su

RUSSIA

Mr. Vladimir V. Aladinsky *Absent at the 1st WG-2 meeting*
Task 3
INSC / RINSC
P.O.Box 837
Moscow
101000 Russia
Tel.: +7 095 263 73 51
Fax: +7 095 264 40 10
E-mail: rinsc@insc.ru

Mr. Anatoly A. Petrov *Task 1*
Leningrad NPP
Leningrad region
Sosnovy Bor
188537 Russia
Tel.: +7 81269 6 12 07
Fax: +7 81269 6 25 18
E-mail:

UKRAINE

Mr. V. Chugunov *Task 1*
Chernobyl NPP (ChNPP)
Slavutych. Kiev. Obl.
255190 Ukraine
Tel.: +38 044 93 43343
Fax: +38 044 79 25943
E-mail: gis@chnpp.atom.gov.ua

Mr. Vasyl Torop *Task 2*
Institute for Problems of Strength of Ukrainian Academy of Science
IPP-Centre Ltd
2. Timityazevskaja str
Kiev
01014 Ukraine
Tel.: +38044 296 3957
Fax: +38044 296 3957
E-mail: tor@ipp.adam.kiev.ua

FINLAND

Mr. Rauli Keskinen *Task 1*
Finnish Centre for Radiation and Nuclear Safety
Department of Nuclear Safety
P.O.Box 268
SF-00101 Helsinki, Finland
Tel.: +358 0 7082341
Fax: +358 0 7082392
E-mail: Rauli.Keskinen@stuk.fi

IAEA

Mr. Radim Havel *IAEA Representative*
IAEA
P.O. Box 100
A-1400 Vienna
Austria
Tel.: +43 1 2600 2213
Fax: +43 1 26007
E-mail: R.Havel@iaea.org

ATTACHMENT 2

Work plan for WG-2, Comprehensive Integrity Assessment Techniques

Objectives

1. To recommend a break preclusion procedure that based on ISI results, can form the basis for decisions for safe operation until the next inspection.

2. To recommend target sizes for flaws that need to be detected during ISI depending on the inspection interval.

3. To improve the understanding of the root cause and cracking mechanisms of IGSCC in RBMK plants.

4. To exchange and transfer knowledge on Risk Based Inspection procedures that can be relevant for RBMK plants.

Task 1, Damage data base

Collection of data of occurred damages shall be performed that can guide the inspection locations and help understand under what circumstances IGSCC is occurring in RBMK plants.

Task 2, Break preclusion methodology

A procedure shall be defined to assist the decisions to be made when an actual defect is detected. The procedure shall give guidance when a repair/replacement is recommendable and when the flaw can be left for continued safe operation. The procedure shall in this case give guidance on the inspection interval. The procedure shall also be able to set the target flaw size coupled with the inspection interval for an inspection program for potential sites of IGSCC.

Task 3, Root causes of IGSCC in RBMK plants

Information shall be collected in order to find out the cracking mechanisms during both initiation and propagation of stress corrosion cracks in stabilised stainless steels. The understanding of root cause of the IGSCC in RBMK plants will help to decide upon cost effective mitigation activities. If possible, this task shall give guidance to Task 2 and Task 4 about the crack growth rate that can be used to predict the extension of future cracking. The outcome of Task 3 will help to clarify whether it is meaningful to investigate the Leak Before Break LBB behaviour of the IGSCC in the relevant RBMK piping systems.

Task 4, Risk Based Inspection RBI pilot study for Ignalina NPP, unit 2.

This task will use modern RBI technology to perform a pilot study for INPP, unit 2 for IGSCC-susceptible locations in stainless steel piping systems. The outcome of the pilot study will be a recommendation of a new inspection programme where more inspection efforts are

directed to components having higher risk for core damage. The pilot study is part of an ongoing contract between DNV Sweden and INPP.

ATTACHMENT 3

IGSCC MITIGATION PROGRAM FOR U.S. BWRs

- Implemented by Generic Letter 88-01

  "NRC Position on Intergranular Stress Corrosion Cracking (IGSCC) in BWR Austenitic Stainless Steel Piping"

  (dated January 25, 1988, and supplement 1, dated February 4, 1992)

- Technical Bases Provided in NUREG 0313, Revision 2

PURPOSE & SCOPE OF PROGRAM

- Purpose
  - -To Provide Assurance of Continued Long Term Piping Integrity and Reliability.

- Scope
  - - Applies to all BWR Piping Containing Reactor Coolant Including Reactor Vessel Attachments & Appurtenances,
  - - 4 Inches or Larger in Nominal Diameter
  - - At a Service Temperature above 200°F
  - - Made of Austenitic Stainless Steel and Nickel Based Alloys (Such as Alloy 600 and Alloy 182).

MAJOR PROGRAM ELEMENTS

- INSPECTION
- MITIGATION
- REPAIR
- FLAW EVALUATION
- LEAK DETECTION

IGSCC INSPECTION

- Ultrasonic Testing Is Primary Inspection Method
- Using Qualified Inspection Methods And Personnel
  (Demonstration of ability to detect and size IGSCC)
- Inspection Extent And Schedules
  (7 IGSCC Categories depending on IGSCC susceptiblity and mitigation)
- Sample Expansion
  (If detection of new flaw or significant flaw growth)

INSPECTION SCHEDULES FOR BWR PIPING WELDMENTS

(For details see Generic Letter 88-01 and its supplement)

IGSCC Category	Description of Weldments	Inspection Extent & Schedule
A	Resistant Materials	25% Every 10 Years
B	Non-resistant Materials Stress Improved (SI) Within 2 Years of Operation	50% Every 10 Years
C	Non-resistant Materials SI After 2 Yrs of Operation	100% Every 10 Years
D	Non-resistant Materials	All Every 2 Refueling Cycles

(Continue Inspection Schedules)

IGSCC Category	Description of Weldments	Inspection Extent &Schedule
E	Cracked Reinforced by Weld Overlay or Mitigated by SI	All Every 2 Refueling Cycles
F	Cracked Inadequate or No Repair	All Every Refueling Outage
G	Non-resistant Materials Not Inspected	All next Refueling Outage

MITIGATION

- Materials
  - Replacing Components with IGSCC Resistant Materials
    Wrought Condition: $\leq$0.35%Carbon,304L,304NG,316NG...
    Casting & Welds: $\leq$0.35% Carbon & Ferrite $\geq$ 7.5%

- Water Chemistry Control
  - EPRI Guidelines, Monitoring Conductivity, Chloride & Sulfate With 3 Action Levels
  - Hydrogen Water Chemistry: Addition of Hydrogen to Reduce the Dissolved Oxygen Content in Reactor Coolant.

- Stress Improvement
  To Introduce Compressive Stresses on Piping/Weld Inside Diameter Surface.
  - Induction Heating Stress Improvement
  - Mechanical Stress Improvement Process

REPAIR METHODS

- Piping Replacement- Using IGSCC Resistant Materials

- Weld Overlay
  - Using IGSCC Resistant Materials to Reinforce the Cracked Piping Welds.
  - Designed Using Limit Load Evaluation Per ASME Code
  - Full or Engineering Design

- - Stress Improvement
  - Induction Heating Stress Improvement
  - Mechanical stress improvement Process
  - Only for Minor Flaws

- - Approved Clamping Devices

FLAW EVALUATION METHODS

(To Assess the Structural Integrity of Cracked Piping Welds.)

- Flaw Growth Calculation
  - Operating stresses Taken from Piping Stress Analysis Report.
  - Use a Lab Measured Residual Stress Through-Wall Distribution for Large Diameter Piping (≥ 12 inches nominal diameter).
  - Use a Crack Growth Rate Curve which is an Upper Bound for Weld Sensitized Material in Simulated BWR Environment (for Crack Depth Calculation).
  - The Aspect Ratio (Length vs. Depth) Is Assumed to Increase the Same Factor that Depth is Increased (Limited to 20 to 1 Ratio). For Axial Crack, the Length is Limited to 1.5 times the Thickness of the Pipe.
  - Guidelines Provided for Multiple & Complex Crack Charact'rztn.
  - UT Sizing Uncertainties are not Considered in the Calculations. If Inspected by Non-Qualified Personnel or Inspection Limitation Exists, Assume Crack Depth to Be 75% Through-Wall.
  - Add Crack Growth due to Fatigue, if Any.

(Flaw Evaluation Methods Continue)

- Flaw Acceptance Criteria
  - Based on Limit Load Analysis per ASME Code, Section XI, IWB-3640.
  - For Gas Tungsten-ARC and Gas Metal-Arc Welds (GTAW and GMAW) the Maximum Allowable Crack Depth Limit is 75% of Wall Thickness, and for Shielded Metal-Arc and Sub-Merged Arc welds (SMAW and SAW) the Limit is 60% of Wall Thickness.
  - For SMAW and SAW welds, a Correction Factor is Applied in the Analysis to Account for Low Fracture Toughness.
  - Apply a Safety Factor of 2.77 to Load for Normal Operating Conditions Including Up-Set and Test Conditions.
  - Apply a Safety Factor of 1.39 to Load for Emergency and Faulted Conditions.

LEAKAGE DETECTION

- Unidentifed Leakage Limits
  - Maximum Leakage Rate not to Exceed 5 GPM or
  - No More Than 2 GPM Increase in 24 Hours

- Monitoring Frequency
  - Sump Level Monitored at Approximately 4 hours Intervals or Less.
  - Inoperable Leakage Measurement Instruments not to Exceed 24 Hours.

- Capability of Leakage Detection Systems
  - Conforming to Position in Regulatory Guide 1.45 "Reactor Coolant Pressure Boundary Leakage Detection Systems"

CONCLUSIONS

- The Implementation of the Aggressive Inspection Program and the IGSCC Mitigation in the U.S. BWRs is Continuing. The Program does not Consider Leak-Before-Break (LBB) and Risk-Based-Inspection Methodology (RBI).

- In Recent Years, There are Very Few Reports of New Cracking or Significant Growth of Old Cracks.

- This Could be Attributed to the Industry efforts in Mitigating the IGSCC Susceptible Components and Improving the Quality of the Reactor Coolant Water Chemistry.

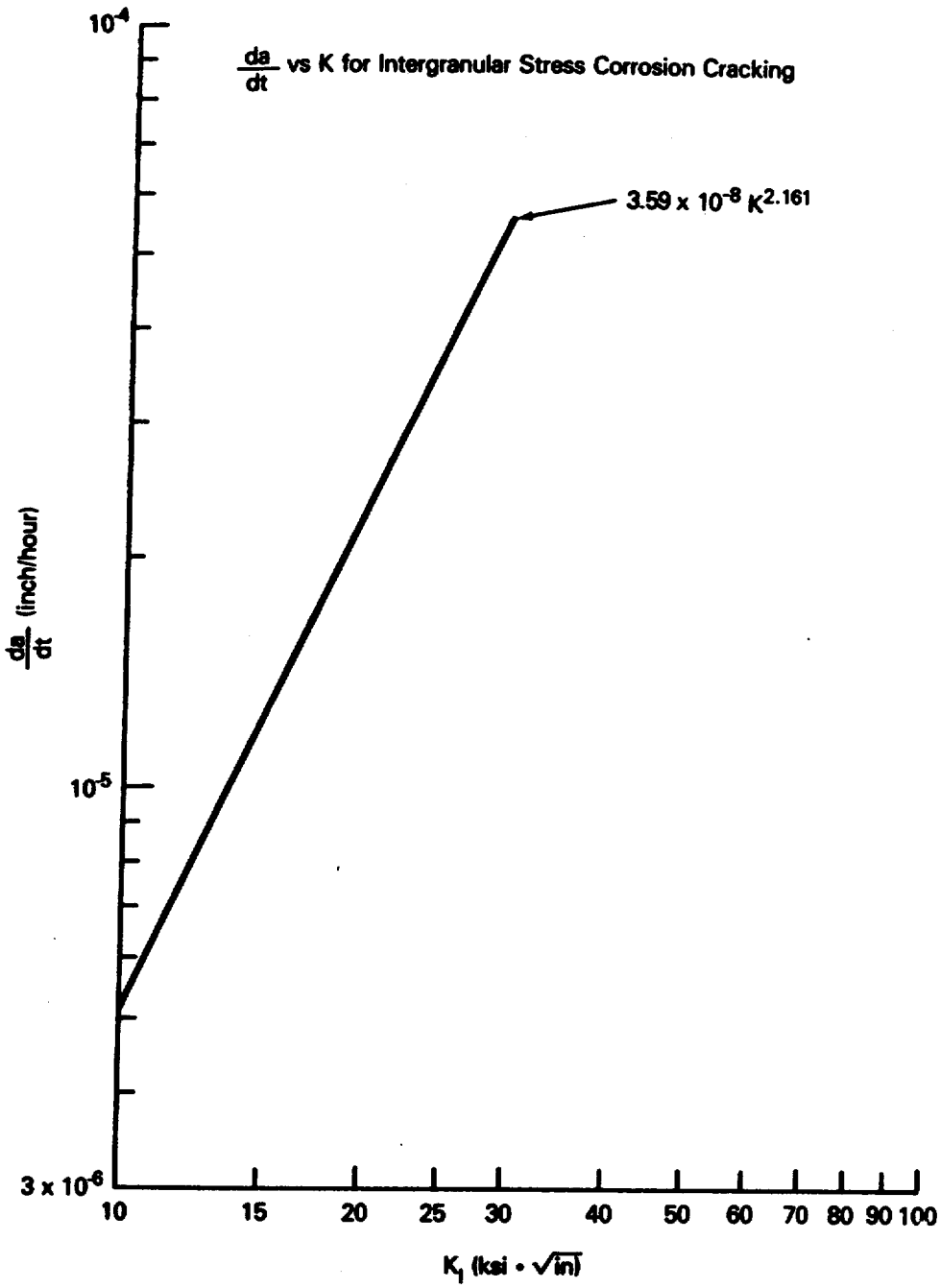

Figure 2
$\frac{da}{dt}$ vs K for Intergranular Stress Corrosion Cracking

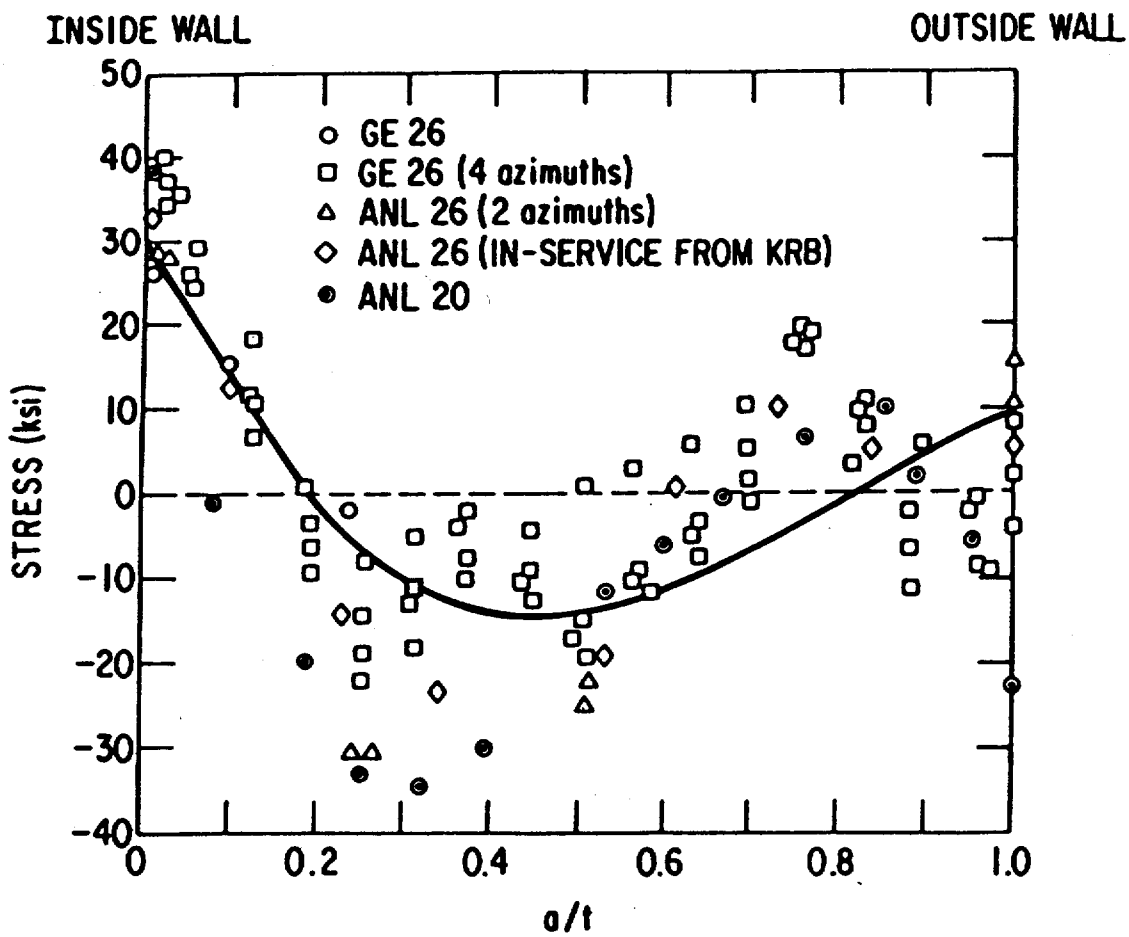

Figure 3
Through-wall Distribution of Axial Residual Stress in Large-Diameter Pipes ($t \geq 1$ in.)

ATTACHMENT 4

Task 2, Development of Break Preclusion Methodology

Objectives

A procedure shall be defined to assist the decisions to be made when an actual defect is detected. The procedure shall give guidance when a repair/replacement is recommendable and when the flaw can be left for continued safe operation.

The procedure shall define the requirements for inspection capability. Recommendations will also be made for inspection intervals. This will be done separately both for welds where existing flaws are being monitored and also for welds where defects have not been detected during previous inspections.

Subtasks

Subtask 1 Description/rationale of flaw size assessment procedure (based on Russian regulatory requirements). Explanation of repair size criterion.
Deliverable: Report (Mr. A. Arzhaev and Russian members) December 2000.

Subtask 2 Review of national practices for Break Preclusion (Integrity Assessment) of NPP austenitic stainless steel components (USA, Japan, Germany, UK, Sweden etc).
Deliverable: Reports (Messrs. Koo, Poulter, Morishita, Schaefer, Torop)December 2000.

Subtask 3 Comparison of different practices. Recommendations for improvements to reference methodology (see Subtask 1). Provision of improved procedure (including worked example)
Responsible: Messrs. Koo and Arzhaev
Deliverable: Report May 2001

Subtask 4 Review of existing data on stabilised stainless steel (08Kh18N10T, A321 etc). (mechanical properties, crack growth rate data etc).
Deliverable: 1) List sources of data. 2) Obtain data. 3) Peer review report
Responsible: Messrs. Koo and Arzhaev
February 2001

Subtask 5 Consideration of applicability of LBB arguments to RBMK dia.300 mm piping. Interaction with TG3 of WG2
Deliverable: Report
April 2001

Subtask 6 Determination of inspection requirements (flaw size detection limits, sizing accuracy). Interaction with WG1.
Deliverable: 1)Initial contact with WG1 (report). 2)Report following TG2 activities
October 2000, May 2001.

Inputs from other WGs for Task 2 of WG-2:

WG-2 Task 3: -estimates of crack growth rates for stabilised SS piping;
-collection of data on stabilised steels (08Kh18N10T, A321).

WG-1: -information on maximum flaw size, which could be missed during ISI and UT uncertainties with flaw, sizing (length, depth)

Actions

Contact WG1 to determine capabilities of ISI techniques and discuss requirements of crack assessment methodology (LP)

Identify if available information on material properties is adequate. Possibly contact RBMK utilities to obtain further data on material properties (particularly results of tests on aged specimens) (Messrs. A Arzhaev, A Klimasauskas, V Torop) If necessary, RH will make formal request on behalf of IAEA.