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OAK RIDGE NATIONAL LABORATORYOPERATED BY MARTIN MARIETTA ENERGY SYSTEMS, INC.
POST OFFICE BOX 2008, OAK RIDGE, TENNESSEE 37831-6205**ORNL****FOREIGN TRIP REPORT**

ORNL/FTR-3738

DATE: October 1, 1990

SUBJECT: Report of Foreign Travel of B. R. Bass, Engineering Technology Division

TO: Alvin W. Trivelpiece

FROM: B. R. Bass

Purpose: Detailed discussions with Japanese researchers concerning (1) the Elastic-Plastic Fracture Mechanics in Inhomogeneous Materials and Structures (EPI) Program and (2) ongoing large-scale pressurized-thermal-shock (PTS) experiments in Japan. At the request of the host organizations, a review of ongoing Heavy-Section Steel Technology (HSST) Program work on reactor pressure vessel fracture-prevention issues was included in the discussions.

Sites Visited:	9/5/90	University of Tokyo	Tokyo, Japan	G. Yagawa
	9/6/90	Komae Laboratory, Central Research Institute of Electric Power Industry	Tokyo, Japan	K. Kashima
	9/7/90	Tokyo Institute of Technology	Tokyo, Japan	S. Aoki
	9/10/90	Kobe University of Mercantile Marine	Kobe, Japan	T. Nishioka
	9/11/90	Takasago R&D Center, Mitsubishi Heavy Industries	Takasago, Japan	Y. Urabe
	9/12/90	Toyohashi Institute of Technology	Toyohashi, Japan	H. Homma
	9/14/90	Kyushu Institute of Technology	Iizuka-City, Japan	M. Nakagaki

Abstract: Discussions were held with Japanese researchers concerning (1) the Elastic-Plastic Fracture Mechanics in Inhomogeneous Materials and Structures (EPI) Program, and (2) ongoing large-scale pressurized-thermal-shock (PTS) experiments in Japan. In the EPI Program, major activities in the current fiscal year include round-robin analyses of measured data from inhomogeneous base metal/weld metal compact-tension (CT) specimens fabricated from welded plates of A533 grade B class 1 steel. The round-robin task involves participants from nine research organizations in Japan and is scheduled for completion by the end of 1990. Additional experiments will be performed on crack growth in inhomogeneous CT specimens and three-point bend (3PB) specimens 10 mm thick. The data will be compared with that generated previously from 19-mm-thick-specimens. A new type of inhomogeneous surface-cracked specimen will be tested this year, with ratio of crack depth to surface length (a/c) satisfying $0.2 \leq (a/c) \leq 0.8$ and using a 3PB type of applied load. Plans are under way to fabricate a new welded plate of A533 grade B class 1 steel (from a different heat than that currently being tested) in order to provide an expanded fracture-toughness data base.

Discussions concerning the Japanese PTS-integrity studies focused on the recently completed Step-C test and a planned series of tests addressing the effects of warm-prestressing (WPS). The Step-C test, completed in March 1990, was designed to investigate crack behavior in materials with a fracture-toughness gradient. In the test, a semielliptical surface flaw in a plate with three layers of toughness was subjected to thermal-shock loading. The flaw initiated in cleavage immediately became a long flaw and arrested at an interface between materials of differing fracture toughness. The next series of PTS tests addressing WPS effects will utilize both intermediate and large-scale specimens. Intermediate-scale tests of 6T-CT specimens will be subjected to four types of WPS-loading cycles. Verification of the WPS model will be carried out through testing of five large-scale, flat-plate specimens with surface flaws subjected to different postulated PTS transients.

Other topics concerning fracture-prevention issues in reactor pressure vessels were discussed with each of the host organizations, including an overview of ongoing work in the Heavy-Section Steel Technology (HSST) Program.

1. INTRODUCTION

The primary objective of this trip was to hold detailed discussions with Japanese researchers concerning (1) the Elastic-Plastic Fracture Mechanics in Inhomogeneous Materials and Structures (EPI) Program and (2) ongoing large-scale pressurized-thermal-shock (PTS) experiments in Japan. At the request of the host organizations, a review of ongoing HSST Program work on reactor pressure vessel (RPV) fracture-prevention issues was also included in the discussions.

The principal objective of the EPI Program is to investigate elastic-plastic crack growth phenomena in inhomogeneous materials and structures, aiming at the development of estimation schemes of fracture resistance applicable to inhomogeneous structures. The Japanese consortium responsible for the EPI Program was organized in July 1988 as a

subcommittee of the Nuclear Engineering Research Committee of the Japan Welding Engineering Society (JWES). The EPI subcommittee in Japan consists of nine universities, three research institutes, and 21 companies. The HSST Program, on behalf of the U.S. Nuclear Regulatory Commission, is the sole U.S. participant in the EPI Program. The EPI Program is scheduled to be completed in August 1992.

Three working groups (WG), Theoretical WG, Experimental WG, and Estimation Scheme WG, have been set up under the EPI subcommittee to carry out the objectives of the program. The Experimental WG generates experimental data on crack-growth behavior in inhomogeneous specimens to be used in evaluating the applicability of various fracture models to inhomogeneous materials. The Theoretical WG analyzes the experimental results using numerical and analytical methods to understand crack growth phenomena in inhomogeneous materials and to provide the fracture models necessary for the development of engineering estimation schemes. The Estimation Scheme WG is responsible for the development of engineering schemes to determine crack-growth resistance based on experimental and analytical results. During this trip, discussions were held with the chairman of the EPI subcommittee and with the task leaders of the three working groups in the EPI Program.

The Japanese PTS-integrity studies were initiated in FY 1983 as a national project by Japan Power Engineering and Inspection Corporation (JAPEIC) under contract with the Ministry of International Trade and Industry (MITI). During the period of these studies, there have occurred a number of interactions between the JAPEIC participants and the HSST Program staff concerning PTS experiments in the respective countries. In the most recent of these interchanges, JAPEIC provided the HSST Program with a problem statement on the Japanese Step-B PTS experiment for inclusion in the recently completed CSNI Project FALSIRE. The problem statement included a detailed description of the test, data, material properties, and results of analyses. As described in the following section, discussions during this trip focused on the recent Step-C PTS experiment and on an upcoming series of intermediate and large-scale warm-prestressing experiments to be carried out by JAPEIC.

In the next section, a summary of the discussions held at each of the visited institutions is presented. While the primary emphasis was on the two topics described above, other topics related to experimental and analytical fracture mechanics developments in Japan and in the HSST Program were also discussed.

2. SUMMARY OF DISCUSSIONS

2.1 Department of Nuclear Engineering, University of Tokyo

Professor G. Yagawa, chairman of the EPI subcommittee, and Professor S. Yoshimura, task leader of the Estimation Scheme WG, provided an overview of current and future efforts in the EPI Program, with an emphasis on the near-term experimental and numerical tasks. The major computational/analytical task of the current fiscal year (which runs to the end of March 1991) will be a round-robin analysis based on measured data from selected CT-specimen tests. The round-robin task is scheduled to be completed by the end of calendar year 1990 and will involve participants from five universities and four industrial organizations in Japan. According to the round-robin problem statement, participants are requested to perform generation-phase, crack-growth analyses based on crack growth (Δa) vs load-line displacement (δ) relations measured in the experiments. The side-grooved CT specimens (19 mm in thickness) used in these experiments consist of four different configurations: (1) homogeneous base metal, (2) base metal/weld metal with the crack tip in

the heat-affected-zone (HAZ), (3) base metal/weld metal with the crack tip on the fusion line, and (4) base metal/weld metal with the crack tip in the weld metal. The problem statement includes the necessary information for each specimen concerning geometry, material properties, measured load (P) vs δ curves, and measured relations among P , δ , and Δa . Participants are requested to provide calculated results for applied load per unit thickness, J_{PATH} calculated on integral paths, J_{MC} , J_D and J_M obtained with conventional estimation formulas (that is, Merkle-Corten, ASTM E-813, and modified Ernst, respectively), as well as crack-tip opening angle (CTOA) and displacement (CTOD). The analysis matrix is designed such that at least two analyses will be carried out for each test by different participating organizations. The round-robin exercise is expected to provide important input for the development of effective engineering estimation schemes for inhomogeneous structures.

Several different tasks are scheduled to be performed by the members of the Experimental Working Group in 1990. Additional residual stress measurements are to be performed on a portion of a welded plate of A533 grade B class 1 steel that was fabricated and tested in 1989 under the EPI Program (see Ref. 1). These measurements will be conducted on an "as-welded" segment (i.e., not stress relieved by heat treatment) by Prof. H. Kobayashi of the Tokyo Institute of Technology using an acousto-elastic technique. Similar measurements on stress-relieved welded segments from the same plate were previously performed by Prof. Kobayashi for the EPI Program and by Prof. E. Rybicki of the University of Tulsa for the HSST Program; Professor Rybicki utilized a destructive strain-gage technique for his measurements. A segment of the as-welded plate will also be provided to the HSST Program for possible testing. Additional experiments on crack growth in CT specimens and three-point bend (3PB) specimens are planned using specimens of 10 mm thickness, with the testing to be conducted by Nippon Steel and Kawasaki Steel. These data will be compared with data generated previously using specimens of 19-mm thickness in order to study size effects. Another type of specimen being utilized this year focuses on the growth of surface cracks in welded plates. Professor Kikuchi of the Science University of Tokyo is testing surface-cracked specimens with ratios of crack depth to surface length (a/c) satisfying $0.2 \leq (a/c) \leq 0.8$, using a 3PB type of applied load. In each case, the crack plane is perpendicular to the weld direction, with the fusion line coinciding with the minor axis of the semielliptical crack. At the University of Tokyo, Profs. Yagawa and Yoshimura are analyzing large-scale growth in welded CT specimens using computer-image processing. Measurements of nonlinear fracture-mechanics parameters using caustic techniques are being conducted by Prof. T. Nishioka at Kobe University. Finally, fracture tests under nonisothermal conditions are being used by Prof. H. Homma at Toyohashi Institute of Technology to study the effects of thermal gradients on the fracture-initiation process.

Professor Yagawa indicated that plans are under way to fabricate a new welded plate similar to that tested in 1989 by the EPI Program. The plate will be constructed by Kawasaki Steel from a different heat of A533 grade B class 1 steel and will be utilized in a testing program to augment the data compiled from the first plate.

Other points of discussion included a demonstration by Professor S. Sakai of an interactive image-processing system for analyzing the three-dimensional structure of a scanning electron microscope (SEM) picture. Finally, Professor Machida provided an overview of his considerable body of work, both experimental and analytical, in dynamic fracture and crack arrest.

2.2 Komae Research Laboratory, Central Research Institute of Electric Power Industry (CRIEPI)

Technical discussions concerning fracture-mechanics studies at CRIEPI covered topics related to light water reactor and fast breeder reactor programs. In light water reactor research, a probabilistic approach to PTS assessment is being evaluated using the PFM computer program under development at CRIEPI. In the LEFM-based PFM code, results from thermal and stress analyses based on the finite-element method provide input for fracture analyses of cracks subjected to PTS loading. Probabilistic aspects are based on Monte-Carlo simulation techniques. Probabilistic variables in the PFM code incorporate the Marshall distribution for crack depth and normal distributions for Cu, Ni content, initial RTNDT, Δ RTNDT, neutron fluence, and fracture toughness. Fracture phenomena considered are crack initiation, crack arrest, and warm-prestress effects. The PFM code has been used to perform sensitivity analyses of RPV fracture probability due to PTS events.

The program for PTS studies at CRIEPI included participation in the CSNI Project FALSIRE, which was completed in May 1990. Analyses were performed for three PTS experiments, the ORNL/HSST PTSE-2 test and the first and second United Kingdom Atomic Energy Authority (UKAEA) spinning-cylinder tests. Results of these analyses were presented by Dr. Kashima at the Project FALSIRE Workshop held in Boston, Mass., May 8-10, 1990.

The discussions also provided a brief overview of the CRIEPI/EPRI Joint Program on RPV Embrittlement. The objective of the Program, which runs through 1992, is to provide analytical bases for quantitative estimation of safety margins and prediction of plant life. Evidently, part of this program includes the development of an RPV materials data base that will eventually reside at CRIEPI.

The review of structural-integrity studies for light water reactors included results from leak-before-break (LBB) evaluations of carbon-steel piping. Applications of three analytical approaches to predicting failure of carbon-steel pipes were described: finite-element method, two-criteria approach, and G-factor approach. The analysis results were compared with results from pipe tests conducted at Nuclear Power Engineering Test Center (NUPEC) and in the International Piping Integrity Research Group (IPIRG) Program. Evaluations of LBB for carbon-steel pipes based on probabilistic fracture mechanics were also presented. In the latter studies, the effects of factors such as frequency of inspection and leak-monitor sensitivity were discussed.

A tour of the material test facilities in the Materials Section focused on testing capabilities for fast-breeder reactor developments. The experimental equipment included a 1000-ton fatigue machine which is being used for LBB tests of large stainless steel wide plates at 550°C. Also on display was a 100-ton fatigue machine being used for vessel model tests under transient-thermal conditions, performed to demonstrate the validity of inelastic analysis. Additional testing facilities included approximately 30 conventional fatigue machines with capacity up to 10 tons and temperature of 1000°C, approximately 30 creep machines for temperature up to 1000°C, and two tensile-test machines.

2.3 Department of Mechanical Engineering Sciences, Tokyo Institute of Technology

Discussions concerning the EPI Program focused primarily on computational studies of interfacial crack models and on acoustic techniques for nondestructive measurements of residual stresses in welds. Professor S. Aoki, task leader of the Theoretical Working Group in the EPI Program, is leading a study to develop a fracture model for cracks at the interface between two dissimilar materials in structures having welded or adhesive joints. The large-strain finite-element model utilizes Gurson's constitutive relation for porous, plastic solids to incorporate the effects of microvoid nucleation and growth on near crack-tip fields. Presently, this model is being developed to predict combinations of material properties that lead to so-called "strong" or "weak" bonds at the interface between "hard" and "soft" materials. In particular, it is desirable to predict whether the interface crack will extend along the interface (weak bond) or extend into the softer material (strong bond). Professor Luo Xuefu from Tsinghua University is in residence at the Institute for one year to work with Professor Aoki on this problem.

Professors H. Kobayashi and Y. Arai have developed and employed acousto-elastic techniques for nondestructive measurement of residual stresses. Recently, these techniques were applied to the determination of residual stresses in segments of the welded plate of A533 grade B class 1 steel tested in the EPI Program and reported in Ref. 1. The technique is based on the principle that, in a state of plane stress, differences in principal stress and principal directions of stress can be measured from the relative differences in the velocities and the principal directions of ultrasonic shear waves. In recent studies, they evaluated the influence of material anisotropy on the measured acousto-elastic effect and applied these techniques to welded plates. Results of their studies will be compared with the recently completed measurements of residual stresses in welded segments from the same plate performed by Professor Rybicki for the HSST Program using destructive strain-gage techniques.

2.4 Department of Ocean Mechanical Engineering, Kobe University of Mercantile Marine

A hybrid numerical-experimental method has been developed by Professor T. Nishioka to measure mode I and mixed-mode fracture parameters using a laser-caustic (shadow pattern) method. The method of caustics is an optical technique that has been used to measure stress intensity factors in both static and dynamic fracture mechanics problems. In applications of this method, high-speed photographs of the reflected caustic patterns around the crack tip are taken using a laser-generated light source. Professor Nishioka has developed a finite-element technique aided by computerized symbolic manipulation for simulating the formation process of caustic patterns in elastoplastic materials. The simulated and actual caustic patterns can then be compared and the relation between computed-fracture parameters, such as the T^* -integral, and the size of the caustic pattern can be obtained for various optical arrangements. This technique is being applied at Kobe in support of the testing program of the Experimental Working Group in the EPI Program. Applications have been to quasi-static CT-specimen tests and to dynamic tear tests of steels.

Professor Nishioka provided a tour of his laboratory facilities in the Department of Mechanical Engineering and described the experimental setup for high-speed laser-caustic photography used in conjunction with a tensile testing machine. Current capabilities limit camera speed to a maximum of 1×10^5 frames/s for photographing the caustic patterns. However, in November 1990, Kobe is scheduled to take delivery of a new camera that will significantly improve high-speed photographic capabilities. The new camera, a Cordin

Model 330, has a maximum speed of 2×10^6 frames/s with a storage capacity of 80 frames. Evidently, the latter will be one of only three cameras of this model being used in Japan.

Near-term contributions to the EPI Program by Professor Nishioka will be concerned primarily with additional measurements of nonlinear-fracture parameters (i.e., T^* -integral) in CT specimens of RPV steels using the laser caustic technique. He is also participating in the 1990 Round-Robin Analysis of the EPI Program, performing analyses of two base metal/weld metal CT specimens with the crack tip located in the HAZ and on the fusion line.

2.5 Takasago R&D Center, Mitsubishi Heavy Industries

Discussions with Dr. Y. Urabe and his staff concentrated on recent developments in the Japanese PTS-integrity studies, including the current status of the testing program being carried out at the Takasago R&D Center. The stated objectives of the PTS-integrity studies in Japan are to gain public acceptance for RPV integrity against PTS events and to develop a data base for life extension. To meet these objectives, a research program involving both experimental and analytical studies has been developed. The experimental program for investigating crack behavior under PTS conditions features a large-scale, flat-plate specimen with a thickness approximating that of an RPV. A special PTS test facility has been constructed at Takasago to apply thermo-mechanical loading to the flat plate to approximate PTS-loading conditions. The facility contains a horizontal testing machine with a capacity of 2,000 tons in tension and 500 tons in bending. A large-scale thermal-hydraulic loop with a flow-rate capacity of $10 \text{ m}^3/\text{s}$ and bulk-coolant temperature of -32°C is used to thermally shock the flawed surface of the plate. Surface flaws are generated in the plate by electro-discharge machining followed by fatigue-sharpening with a cyclic-bending load.

Large-scale PTS tests completed at the Takasago facility include (a) a preliminary verification test involving brittle crack initiation, (b) Step-A test for verification of no crack initiation under PTS conditions at end of design life, (c) Step-B test investigating crack behavior for upper-shelf conditions, and (d) Step-C test investigating crack behavior in material with a toughness gradient.

Details of each test through Step B had previously been reported to the HSST Program. Consequently, the focus of the discussions was on the results of Step C, which have not been reported in the open literature. The Step-C test, completed in March 1990, utilized a beam with a semielliptical surface flaw of depth $a = 16.9 \text{ mm}$ and length $c = 119.9 \text{ mm}$. The dimensions of the beam are $170 \times 75 \text{ mm}$ in cross-section, with a cooled length of 3 m ; the beam is welded into a test structure 6.9 m in length. The beam consists of a specially heat-treated A533 grade B class 1 steel with three layers (thickness of layers: $t_1 = 32 \text{ mm}$, $t_2 = 90 \text{ mm}$, $t_3 = 70 \text{ mm}$) of increasing fracture toughness. The surface flaw was located in the 32-mm-thick layer having the lowest toughness and an RTNDT $\sim 150^\circ\text{C}$. Initial temperature of the beam was $T_0 = 263^\circ\text{C}$. The beam was subjected to thermal-shock-only loading, i.e., shocking of the flawed surface with the coolant at 0°C and coordinated application of a monotonic-bending load; there was no tensile load on the beam. Initiation of the flaw reportedly took place near the K_{Ic} curve constructed from small-specimen data. The short flaw immediately became a long flaw with an approximate depth of 19 mm . Following four subsequent jumps, which were nonuniform along the length of the flaw, the crack finally arrested at the interface between the first and second layers of toughness at a depth of $\sim 32 \text{ mm}$. The crack also had several branches out of the plane of the original flaw. An inspection of the fracture surface revealed that, in the band from 19 to 32 mm in

depth, there were apparently many remaining ligaments. The arrested crack extended almost the entire width of the plate, except for a remaining ligament on one side of approximately 62 mm. Based on the substantial differences in toughness, it was predictable that the crack would arrest at the interface between layers 1 and 2 of the beam (the third layer was conceded to be irrelevant to the test). Dr. Urabe indicated that the data and analysis results from the Step-C test were preliminary and proprietary to MITI and could not be released without the latter's approval. This position is consistent with our previous experiences with JAPEIC and is related to the well-known political sensitivity associated with the interpretations of these PTS tests in Japan.

The next series of PTS tests at Takasago are designed to study and validate the effects of warm-prestressing (WPS). Both intermediate-scale basic tests and large-scale model tests will be performed. The intermediate-scale tests will utilize 6T-CT specimens and will be conducted on a 1000-ton tensile machine. Four types of WPS loading will be considered: (1) load, cool at constant load, load to failure (LCF); (2) load, cool with partial unloading, load to failure (LPCF); (3) load, unload, cool, load to failure (LUCF); and (4) NO WPS. Verification of the WPS model will be carried out through tests of five large-scale, flat-plate specimens. Tests 1 and 2 will consist of NO WPS and LPCF loadings, respectively. Tests 3-5 will utilize loadings that simulate differing postulated PTS transients. The surface flaws employed in these tests will be of the 6/1 ratio type, with a flaw depth of 10 or 20 mm. The test material will be an A533 grade B class 1 material with special chemistry and heat treatment having an RTNDT $\sim 130^{\circ}\text{C}$ and upper-shelf energy $\sim 70\text{ J}$. The first test (NO WPS loading) will have an initial temperature of 200°C , bulk coolant temperature of -32°C , and PTS loading (that is, coordinated tension, bending, thermal shock). The test specimen is currently being flawed and is scheduled for testing at the end of 1990. The five large-scale tests in this series are expected to be completed in two years.

2.6 Department of Energy Engineering Toyohashi Institute of Technology

The testing program organized by the Experimental WG of the EPI Program was the primary subject of discussion with Professor Homma, who serves as task leader of that group. Because the details of the overall test schedule had already been covered by Professor Yagawa at the University of Tokyo, Professor Homma concentrated on the experimental work currently under way at Toyohashi. The objective of one of his studies is to determine whether there is a thermal gradient effect on cleavage initiation in pressure vessel steels. In other words, he seeks to determine whether cleavage initiation is a function of temperature "pointwise" or does it extend over a finite region in front of the crack tip. In the first phase of these studies, he is performing tests on PMMA to validate techniques. Small cracked specimens, with dimensions $20 \times 80\text{ mm}$ and $80 \times 80\text{ mm}$, are being used in experiments where the thermal gradient in front of the crack tip is varied to determine the effect on initiation toughness. By the end of 1990, it is anticipated that the program will progress to testing of A533 grade B class 1 steel obtained from the EPI Program.

Results from these studies of thermal-gradient effects could have some impact on interpreting the WP-1 series of large-scale, wide-plate tests conducted by the HSST Program. The WP-1 specimens were subjected to a relatively severe linear, thermal gradient, and experienced cleavage initiation at K_I/K_{Ic} ratios that varied in the range of 2 to 4. Questions have been raised about a possible relationship between thermal-gradient effects and this apparent elevation in toughness. However, recent studies [2] in the HSST Program have demonstrated some success in correlating cleavage initiation in the wide-plate and CT specimens using a criterion based on a maximum principal stress theory.

A tour of the laboratory facilities at Toyohashi included a demonstration of the computer-assisted instrumented Charpy-impact-testing system developed under the direction of Professor Niinomi. The system incorporates four Charpy machines, the largest of which has a 50-kg-m capacity. The laboratory also included one 50-ton tensile machine, a one-ton tensile machine, and several fatigue-testing machines. Various programs utilize the machines for testing of ferritic steels, aluminum alloys, plastics, ceramics, and composites.

2.7 Department of Mechanical System Engineering Kyushu Institute of Technology

Recent computational developments by Professor Nakagaki for fracture-mechanics analysis have focused on integral parameters for thermal-fracture applications. In these studies, he has examined the utility and the limitations of several different integral parameters (T^* , $\hat{J}$, J' , etc.) for characterizing the crack-driving force in thermal problems. Important issues examined in these studies include the effect of material-property variation with temperature on the accuracy and the path independence of these parameters. Thus far, the emphasis in his studies has been on fracture models utilizing thermoelastic constitutive formulations. In the near future, Professor Nakagaki plans to extend his work to thermo-elastic-plastic constitutive models. In discussions of these issues at Kyushu, it was agreed that material and experimental data from the second HSST pressurized-thermal-shock experiment, PTSE-2, would be an appropriate and challenging experiment for evaluating these parameters in the context of thermal and inelastic effects.

Participation by Kyushu in the 1990 Round-Robin Analysis of the EPI Program will include two analyses of base metal/weld metal CT specimens with the crack tip located in the weld and in the fusion line, respectively. These analyses will be performed using the T^* -integral as the fracture characterizing parameter.

A tour of the Kyushu facilities revealed that the only testing equipment is one 10-ton tensile machine. This is consistent with the mission of the Institute as a computer science facility, concentrating on artificial intelligence, robotics, "fuzzy" computing, and other advanced developments. One interesting feature is that the five divisions of the Institute each have approximately 40-50 computer workstations for instructional and research purposes.

REFERENCES

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2. J. Keeney-Walker, B. R. Bass, and J. D. Landes, "An Investigation of Crack-Tip Stress Field Criteria for Predicting Cleavage-Crack Initiation," presented at 22nd National Symposium on Fracture Mechanics, Atlanta, Ga., June 25-28, 1990 (to be published by ASTM).

APPENDIX A

Itinerary

Traveler: B. R. Bass

August 31	Travel	Knoxville, Tenn. to Honolulu, Hawaii
Sept. 1-2	Weekend	(All expenses of stopover in Honolulu borne by traveler)
Sept. 3-4	Travel	Honolulu, Hawaii, to Tokyo, Japan
Sept. 5	Meeting	University of Tokyo
Sept. 6	Meeting	Komae Laboratory, Central Research Institute of Electric Power Industry
Sept. 7	Meeting	Tokyo Institute of Technology
Sept. 8-9	Weekend	
Sept. 10	Meeting	Kobe University of Mercantile Marine
Sept. 11	Meeting	Takasago R&D Center, Mitsubishi Heavy Industries
Sept. 12	Meeting	Toyohashi Institute of Technology
Sept. 13	Travel	Toyohashi, Japan, to Iizuka, Japan
Sept. 14	Meeting	Kyushu Institute of Technology
Sept. 15-16	Travel	Iizuka-City, Japan, to Knoxville, Tenn.

APPENDIX B

List of Attendees

Date and Location of Meetings	Names and Affiliations of Attendees
9/5/90 Dept. of Nuclear Engineering, University of Tokyo (UT), Tokyo, Japan	G. Yagawa (UT) S. Yoshimura (UT) S. Machida (UT) S. Sakai (UT) T. Takano (UT) T. Shimakawa, Kawasaki Heavy Industries
9/6/90 Komae Research Laboratory, Central Research Institute of Electric Power Industry (CRIEPI), Tokyo, Japan	K. Kashima T. Fujioka M. Matsubara N. Miura A. Nitto Y. Takahashi T. Onchi N. Soneda
9/7/90 Dept. of Mechanical Engineering Science, Tokyo Institute of Technology (TIT) Tokyo, Japan	S. Aoki (TIT) H. Kobayashi (TIT) H. Nakamura (TIT) Y. Arai, Saitama Univ., Japan X. Luo, Tsinghua Univ., P. R. China
9/10/90 Dept. of Ocean Mechanical Engineering, Kobe University of Mercantile Marine, Kobe, Japan	T. Nishioka
9/11/90 Takasago Research and Development Center, Mitsubishi Heavy Industries, Takasago, Japan	Y. Urabe K. Hojo M. Tomimatsu
9/12/90 Dept. of Energy Engineering Toyohashi University of Technology, Toyohashi, Japan	H. Homma Y. Kanto K. Tao M. Niinomi H. Shah
9/14/90 Dept. of Mechanical System Engineering, Kyushu Institute of Technology, Iizuka-City, Japan	M. Nakagaki T. Horie

APPENDIX C

Literature Received

1. G. Yagawa and Y. Yoshimura, *Problem Statement for Round-Robin Analysis of Large-Scale Crack Growth in CT Specimens.*, EPI Program, 1990.
2. M. Matsubara and H. Okamura, "An Integrity Evaluation Method of the Pressure Vessel of Nuclear Reactors Under Pressurized-Thermal-Shock," *JSME International Journal, Series I*, Vol. 31, No. 4, pp. 732-737 (1988).
3. T. Takano, H. Sumiyoshi, and C. Masuda, "Algorithm for Three-Dimensional Analysis of Cleavage Facet and Its Application for Brittle Fracture Surface of Steels," *ISIJ, International*, Vol. 30, No. 7, pp. 552-558 (1990).
4. S. Machida and H. Yoshimuri, "Some Recent Experimental Work in Japan on Fast Fracture and Crack Arrest," *Engineering Fracture Mechanics*, Vol. 23, No. 1, pp. 251-264 (1986).
5. K. Kashima, M. Matsubara, and N. Miura, "Prediction of the Failure Stress from Japanese Carbon Steel Pipe Fracture Experiments," presented at ASME PV&P Conference, Nashville, TN, June 17-21 (1990).
6. T. Fujioka, K. Kashima, and Y. Takahashi, "Leak-Before-Break Evaluation of Carbon Steel Pipes Based on Probabilistic Fracture Mechanics," (to be published).
7. Slides on following presentation: Y. Takahashi, "Results of Collaboration Study on High-Temperature Flaw Assessment Procedure".
8. Slides on following presentation: N. Soneda, "Sensitivity Analysis of RPV Failure Probability Due to PTS Event".
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