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COVER SHEET
FOR TRIP REPORTS SUBMITTED TO THE OFFICE OF ENERGY RESEARCH

Destination(s) and Dates for Which Trip Report Being Submitted: Japan, November 28-December 8, 1990

Name of Traveler: Timothy D. Burchell

Joint Trip Report ☐ Yes ☒ No

If so, Name of Other Traveler(s): _____

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FOREIGN TRIP REPORT

ORNL/FTR-3853

DATE: January 4, 1991

SUBJECT: Report of Foreign Travel by Timothy D. Burchell, Development Staff Member, Metals and Ceramics Division

TO: Alvin W. Trivelpiece

FROM: Timothy D. Burchell

PURPOSE: To participate and present a paper in the United States-Japan Fusion Energy Workshop P-165 on "Critical Topics of Plasma Facing Materials/Plasma Facing Component Data for the Next Step Fusion Devices," at Nagoya, Japan, December 3-6, 1990, and to visit the JT-60U tokamak at the Japan Atomic Energy Research Institute (JAERI) to discuss the application of carbon-carbon composites as plasma facing materials (PFM's).

SITES VISITED: 1990

12/3-6/90	Workshop	National Institute for Fusion Science (NIFS), Nagoya, Japan	Prof. A. Miyahara
12/7/90	JAERI	Tokai and Naka, Japan	Dr. M. Seki

ABSTRACT: The United States-Japan Workshop P-165 brought together approximately 60 scientists and engineers to discuss critical topics of plasma facing materials and components for the next-step fusion device. In addition to the United States and Japanese participants, there were several guest attendees from Europe. The international makeup of the participants greatly enhanced the success of the workshop. The author jointly chaired a workshop session entitled "Impact of Neutron Effects to Plasma Facing Materials and Plasma Facing Component (PFC) Feasibilities for the International Thermonuclear Experimental Reactor (ITER)," and presented an overview paper on neutron effects and materials selection for the next-step plasma facing devices. The author presented his work on the effects of neutron irradiation on graphites and carbon-carbon (c/c) composite materials, which are strong candidate materials for PFC's in ITER. The workshop addressed many issues of current concern to the PFC/PFM community including: plasma erosion of PFM's; trapping/detrapping of hydrogen isotopes; large machine operating experience; and extent of the materials database.

Two JAERI sites were visited after the Nagoya workshop. At Naka, the author toured the JT-60U tokamak and discussed upgrade details. The extensive use of c/c composites as a PFM was of particular interest. At the Tokai site the author visited Tritium Laboratory.

The author's participation in the workshop and subsequent visits and discussions with Japanese colleagues at JAERI were beneficial to the United States Fusion Energy Program.

COMPREHENSIVE TRIP REPORT

1. Introduction

The next generation of fusion energy reactors, e.g., the Compact Ignition Tokamak (CIT) and the International Thermonuclear Experimental Reactor (ITER), will place increasingly stringent demands on existing materials. This concern is most acute in the field of plasma facing components (first wall armor, limiters and diverters), where the selected material must be able to withstand severe thermal fluxes, neutron damage, and very high surface temperatures. Graphite has been utilized in the past for plasma facing components for several reasons: (1) it does not melt, (2) its low atomic number minimizes radiative heat losses from the plasma, and (3) it has good resistance to thermal shock. However, the use of graphite has not been without problems, notably the phenomena of radiation-enhanced sublimation (RES). This and other concerns (i.e., the degradation of thermophysical properties by neutron damage, tritium retention, and the irradiation lifetime and behavior of carbon/carbon composites) have led materials scientists worldwide to consider other candidate materials.

For ITER and CIT, graphite and c/c composites remain the first-choice material for the PFC's; however, beryllium, some high Z materials such as molybdenum and tungsten, and ceramics such as silicon carbide are being considered as options for ITER. The workshop considered all candidate plasma facing materials and directly addressed the issues for the next generation of tokamak devices. A summary of the meeting is reported here, and the agenda is appended. Discussions with JAERI personnel are reported. Conclusion and recommendations regarding the future direction of the U.S. graphite and carbon composite PFC program are given.

2. Detailed Report of Traveler's Activities

2.1 Workshop P-165 - Critical Topics of PFM/PFC Data for The Next Step (TNS) Fusion Devices

A total of 62 scientists and engineers participated in this workshop. A complete list of participants with their affiliations is appended. Details of the session chaired by the traveler are summarized below. Summaries of other sessions will be published by the workshop organizers in due course.

2.1.1 Session 3. Impact of Neutron Effects on PFM and PFC Feasibility for ITER

Four contributions were heard in this session. In his overview of neutron effects and materials selection for TNS devices, Burchell briefly discussed available high and low Z materials options for plasma facing applications. A detailed summary of the effects of neutron damage on the physical and mechanical properties of graphites was followed by a review of the neutron irradiation induced structural changes occurring in c/c composites. Materials model were described which allowed interpretation of available data on dimensional changes in carbon fibers, cloths and c/c composites. Data from a recent Fast Flux Test Facility (FFTF) Materials Open Test Assembly (MOTA) experiment were reviewed. Tentative recommendations for optimization of c/c composite materials for neutron resistance were presented.

Changes in the thermal properties of graphite and c/c composites were discussed in a presentation by Maruyama. Data showing the reduction of thermal conductivity of graphite grades IG-110, EPT-10 and c/c composite CX-2002U after a neutron irradiation to 0.1 dpa were reported. The thermal conductivities of the materials studied were reduced to 10 to 20% of their unirradiated value after neutron irradiation. A model to describe the reduction of thermal conductivity was presented. The conductivity was related to the phonon mean free path (mfp) through the Debye theory of conductivity, and estimates of the effect of neutron damage on the phonon mfp obtained from the irradiation-induced swelling. Maruyama also reported thermal conductivity data for boron-doped graphites. The undoped graphite had a room-temperature thermal conductivity of 82.6 W/m•K, which was reduced to approximately 18 W/m•K and 13 W/m•K in the parallel- and perpendicular-to-forming direction cases respectively for a 30% boron content.

Oku reported a novel technique utilizing microhardness measurements. Initial work has confirmed a relationship between strength and elastic modulus, and the microhardness for metals. This technique will be extended to study c/c composite materials to study fiber, impregnant and interface properties. Tanabe reported a reduction of L_a, the graphite crystallite size, after ion beam irradiation. The ordered crystallographic structure was disrupted and an amorphous structure developed. Tanabe postulated the formation of covalent bond between the graphitic layers during the radiation damage induced amorphization.

In summary, the appreciable neutron irradiation induced degradation of graphite and c/c thermal conductivity does not allow a diverter plate design that will comply with the ITER guidelines for maximum permissible surface temperature and component lifetime. Newly developed c/c composite materials with thermal conductivities >300 W/m•K should be available for diverter and first-wall applications, and will allow TNS devices to initially operate. However, their conductivity will be reduced, typically to <40 W/m•K after 0.1 dpa at the coolant side of the diverter. The reduction of thermal conductivity with continuing neutron irradiation would cause an increase in the diverter surface temperature above the design limit. Boron additions reduce the thermal conductivity significantly, i.e., 3% boron appears to reduce room-temperature conductivity by as much as 50%. This appears to limit the application of boronated materials to the first wall where the requirements for thermal conductivity are more moderate and where the boron additions will be beneficial in suppressing chemical oxidation.

2.1.2 P-165 Executive Summary

The following executive summary and recommendations was provided by Prof. A. Miyahara (NIFS), P-165 Chairman.

It was clearly recognized that development of plasma facing components and materials are critical path to ITER engineering design. Before construction of ITER, we have to have several candidate concepts for selection and optimization; however, at present we have no realistic solution. In order to overcome this difficult situation, the workshop participants agreed to recommend the following procedure. We must implement this process formally with world-wide coordination in the near future.

1. Continue the material development following defined process at the United States-Japan Workshop Q-52 at Livermore in 1985.

2. Identify procedures of screening test for simulation and machine experiments.

3. Establish an international panel to review the materials evaluation testing and make recommendations for further development.

2.2 Visit to JAERI

The traveler visited the JT-60U facility. The tokamak was in the final stages of reassembly after an extensive upgrade and period of renovation. The machine is very impressive, giving the impression of having been extremely well designed and engineered! Of particular interest to the traveler was the replacement of certain parts of the graphite wall armor with c/c composites.

The Japanese, in the usual manner, had sought the participation of all domestic vendors of c/c composite materials and, consequently, had utilized several different materials. These will be evaluated during the first year of operation of JT-60U. Samples of the materials were shown to the traveler and were found to be largely of the 2D type. One of the c/c composites being used is Mitsubishi's MKC-1PH material which is being considered for the CIT.

While at JT-60U, the author viewed a video film shot prior to the replacement of the first wall. It showed the damage that had been sustained on the protective graphite tiles, caused by thermal shock and plasma erosion. Much of the damage was attributed to local heating on tile edges due to misalignment. The use of c/c composites in the worst areas and profiling of the first wall prior to operation is expected to eliminate this problem.

In the JT-60U modification, the original poloidal field (PF) coils, support structures, and the vacuum vessel are superseded by new ones to allow single-null, open-diverter plasmas with plasma current of up to 6 mA. The existing toroidal field (TF) coils and their support fixtures will be used after reinforcement. The existing high power heating and power supply system will be also used after minor modification. Neutron shields for deuterium operation are being prepared. The design of JT-60U was initiated in 1987 and fabrication of the new PF coil system and vacuum vessel started at the end of 1988. JT-60U starts

operating in 1991. The device will run the plasma in a single null diverter configuration. A high conductivity (>300 W/m•K) c/c composite material is being used for the diverter material. The plasma current in JT-60U is expected to be twice that previously attained in JT-60. Considerable improvement in plasma confinement is thus anticipated.

The traveler also visited the Tritium Laboratory with Dr. K. Wilson (Sandia National Laboratory, Livermore, California). The experimental facilities were impressive. Much of the work in progress was aimed at understanding the processes controlling the adsorption and transport of tritium in materials.

3. Conclusions and Recommendations

The traveler gained a great deal of useful experience and knowledge from the P-165 Workshop. A familiarity with overseas research programs, particularly the Japanese, was acquired through discussions with contacts made at the workshop and during the subsequent visits to JAERI. The following areas remain major concerns for carbon-based materials as PFC's:

- radiation enhanced sublimation (RES),
- degradation of thermophysical properties due to neutron damage, and
- tritium retention.

Research activities are ongoing in these areas in the United States. However, it is recommended that further cooperation with international partners be sought. This could be particularly beneficial (both technically and financially) in the neutron irradiation field, where experimental costs are high. Another area where cooperation is actively sought by the Japanese is the postirradiation high heat flux testing of c/c composites and graphites included in the United States/Japan FFTF MOTA experiments. It is recommended that the United States further explore these areas for collaboration, perhaps through the ITER program.

APPENDIX A

ITINERARY

1990

11/28	Travel from Oak Ridge, Tennessee, to Osaka, Japan, via plane
11/30	Renew H7 visa, U.S. Consulate Office, Osaka, Japan
12/1-2	Weekend, travel from Osaka, Japan, to NIFS, Nagoya
12/3-6	Workshop P-165, NIFS, Nagoya, Japan
12/6	Travel to Katsuta, Japan
12/7	Visit to JAERI, Naka and Tokai sites, Japan
12/8	Travel from Katsuta, Japan, to Tokyo, Japan, to Oak Ridge, Tennessee, via plane

APPENDIX B

PERSONS CONTACTED

Prof. A. Miyahara, Chairman, Workshop P-165

Prof. N. Noda, National Institute for Fusion Science, Nagoya, Japan

Prof. T. Oku, University of Iberaki (at P-165)

Prof. T. Tanabe, Osaka University (at P-165)

Dr. M. Seki, Japan Atomic Energy Research Institute, Naka, Japan

APPENDIX C

BIBLIOGRAPHY

P-165 Workshop Agenda

Tentative
1990. 11. 28

J-US Workshop P-165
on
"Critical Topics of PFM/PFC Data
for the Next Step Fusion Devices"

Date & Term: December 3 - 6, 1990
Place: NIFS - Nagoya 464-01, Japan

Aim & Scope:

To address and discuss topics which are critical for to design and construct TNS Devices as ITER (International), LHD&FER (Japan), CIT & Steady State Exp (US) and NET (EC), with reference to the present days' large machine experiments.

As conclusion, we should identify the most critical topics for TNS PFM/PFC especially ITER as reference and establish mechanism or organization to carry out more tight and effective international collaboration.

Tentative Agenda

Dec. 3 (Mon)

[I] Welcome and Opening Address / O. Motojima (NIFS) 9:15 - 9:45

(1) Welcome / A. Iiyoshi (NIFS)
(2) Opening Talk: Definitions of Comprehensive Requirements of PFM/PFC Data for TNS Fusion Devices
A. Miyahara (NIFS)

Coffee Break 9:45 - 10:00

[II] Plenary Session / A. Miyahara (NIFS) 10:00 - 12:00

(1) Overview of PFM/PFC Research in US
W. B. Gauster (SNLA)
(2) Report from the 4th Carbon Workshop in Jülich
H. Conrads (KFA Jülich)

Luncheon 12:00 - 13:00

[III] Topics Session
Topics 1: 13:00 - 15:00
How to Bridge Present Large Machines' Experiences to the Design Activities of the Next Step Devices? / R. Behrisch (MPI Garching) & S.I. Itoh (NIFS)
1. Review and Problem Definition R. Behrisch (MPI)

P-165 Workshop Agenda
(continued)

2. Comment from JET K. J. Dietz (JET)
3. Comment from JT-60 T. Ando (JAERI)
4. Comment from TFTR W. B. Gauster (SNLA)
   Discussion and Summary Guided by Chairperson

Coffee Break 15:00 - 15:15

Topics 2: 15:15 - 17:30
Problem Area of PFC Aspects / W. B. Gauster (SNLA) & N. Noda (NIFS)
1. Overview: Limitation of Heat Exhaust of Present PFC Design and Future Innovative Directions to Improvement W. Gauster (SNLA)
2. Comment on Heat Exhaust of PFC M. Seki (JAERI)
3. Gaseous Divertor Experiment by PISCES-A-an Innovative Direction of Heat Exhaust Y. Hirooka (UCLA)

Discussions and Summary N. Noda & W. B. Gauster

Reception 17:30 - 19:00

Dec. 4 (Tue)

Topics 3: 9:00 - 11:00
Impact of Neutron Effects to PFM and PFC Feasibilities for ITER / T. Burchell (ORNL) & T. Tanabe (Osaka Univ.)
1. Overview: Neutron Effects and Material Selection for TNS Plasma Facing Materials T. Burchell
2. Change of Thermal Properties of Graphite by Neutron Irradiations T. Maruyama (PNC)
3. How to Correlate the Change of Micro Structure and Material Properties? T. Oku (Ibaraki Univ.)
4. How to Establish the Data Base without 14MeV INS? T. Tanabe (Osaka Univ.)

Discussions and Summary T. Tanabe & T. Burchell

Topics 4: 11:00 - 15:00 (Incl. Luncheon 12:00 - 13:00)
Trapping and Detrapping of Implanted Hydrogen Isotopes / K. L. Wilson (SNLL) & K. Watanabe (Toyama Univ.)
1. Overview: Definition of Unsolved Problems and Survey of Present Status K. L. Wilson (SNLL)
2. Compensation Effects on the Diffusion Constants of Hydrogen Isotopes in Materials K. Watanabe & K. Ashida (Toyama Univ.)
3. Thermal Desorption Spectra of Hydrogen from Graphite Implanted with Hydrogen Ions M. Yamawaki (Univ. Tokyo)
4. Ion-Induced and Thermal Release of Hydrogen Isotopes from Graphite K. Morita (Nagoya Univ.)
5. Hydrogen Solubility in Neutron Irradiated Graphite H. Atsumi (Kinki Univ.)

P-165 Workshop Agenda
(continued)

6. Hydrogen Behavior in Mo and W T. Tanabe (Osaka Univ.)
Discussions and Summary: K. Watanabe & K. L. Wilson

Coffee Break 15:00 - 15:15

Topics 5: 15:15 - 18:15
Erosion of Plasma Facing Materials under Off-Normal Operating Conditions / J. Linke (KFA Jülich) & M. Seki (JAERI)
1. Overview: Simulation of Disruptions in Different HHF Test Facilities J. Linke (KFA Jülich)
2. Detail Evaluation Process of the Thermal Erosion during Disruptions for ITER H. Bolt (Univ. Tokyo)
3. Requirements from NET Design J. G. van der Laan (NET)
4. Efforts towards Runaway Electron Damage Data Base Establishment H. Bolt (Univ. Tokyo)
Discussion and Summary: M. Seki & J. Linke

Banquet 19:00 - 21:00

Dec. 5 (Wed)

Topics 6: 9:00 - 12:00
Erosion of Plasma Facing Materials under Normal Operating Conditions / A. A. Haasz (Univ.of Toronto) & Y. Hirooka (UCLA)
1. Overview: Erosion of Plasma Facing Materials under Normal Operating Condition A. A. Haasz (Toronto)
2. Recent Results of PISCES Experiments Y. Hirooka (UCLA)
3. Comment on Erosion/Redeposion in the DIII-D Divertor K. L. Wilson (SNLL)
4. Data from MPI Garching R. Behrisch (MPI-Garching)
Discussions and Summary: A. A. Haasz & Y. Hirooka

Luncheon 12:00 - 13:00

Topics 7: 13:00 - 15:00
Present Status of Material Data Base
T. Hino (Hokkaido Univ.) & H. Bolt (Univ. Tokyo)
1. Overview of Present Status: Requirements from Users H. Bolt (Univ. Tokyo)
2. Oxidation Properties of Metal Mixed Graphites and RES Data for Several Isotropic Graphites T. Hino (Hokkaido Univ.)
3. Manufactures' and Fabricators' Opinion (J, US, EC)
Discussions and Summary: T. Hino & H. Bolt

Coffee Break 15:00 - 15:15

P-165 Workshop Agenda
(continued)

Topics 8: 15:15 - 17:15
Possibilities of Medium- and High-Z Plasma Facing Materials for Future Large Machines / H. Conrads (IPP-Jülich) & K. Itoh (NIFS)
1. Overview: Possible Plasma Scenario Compatible with High Z Plasma Facing Material K. Itoh (NIFS)
2. Operation Experiences of Ultra Long Pulse TRIAM Mo-Limiter Discharge N. Yoshida (Kyushu Univ.)
3. Scenario to Apply Metal Mixed Graphite as First Wall Material and Possibility to Use High Z Plasma Facing Material T. Hino (Hokkaido Univ.)

Discussions and Summary Guided by Chairman

Dec. 6 (Thu)

[IV] Summary & Conclusion 9:30 - 12:00

Luncheon 12:00 - 13:00

How to Read Agenda?

Next to the topics number and alloted time, title of the topics followed by name of the chairman are indicated. Then talk number 1 is overview or reporter presentation, while talks number 2, 3, 4 ··· will be either prepared commentators talks or poster presentation. It depends on chairperson's guidance.

Notices: For quick publication of the workshop document, we would like to ask you to prepare one copy of your manuscript and transparencies with the cover sheet noted title, name, affiliation and abstract.

APPENDIX D

Participants for United States-Japan Workshop P-165

R. Bahrisch, MPI Garching
T. D. Burchell, Oak Ridge National Laboratory
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A. A. Haasz, University of Toronto
Y. Hirooka, UCLA
W. Kohlaas, IPP-KFA Jülich
J. G. van der Laan, NET
J. Linke, IRW-KFA Jülich
H. M. Saad, NCRRT
K. L. Wilson, SNLL

K. Aehida, Toyama University
T. Ando, JAERI
S. Ishihara, Mitsubishi
N. Ogiwara, JAERI
T. Oku, Ibaraki University
Y. Sawada, Toshiba
K. Shimizu, Mitsubishi
M. Seki, JAERI
T. Sogabe, Toyo Tanso
T. Tanabe, Osaka University
H. Nakamura, JAERI
H. Nariai, Tsukuba University
T. Hino, Hokkaido University
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C. Maruyama, PNO
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S. Yamazaki, Kawasaki
N. Yoshida, Kyushu University
H. Bolt, University of Tokyo

H. Ateumi, Kinki University
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M. Iseki, Nagoya University
K. Okada, Mitsubishi
S. Gotoh, Hitachi
M. Shibui, Toshiba
R. Jinbo, JAERI
S. Soma, Toyo Tanso
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END

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