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1st IAEA Research Coordination Meeting on

"TRITIUM RETENTION IN FUSION REACTOR PLASMA FACING COMPONENTS"

October 5 - 6, 1995, Vienna, Austria

SUMMARY REPORT

Prepared by R.A. Langley

December 1995

IAEA NUCLEAR DATA SECTION, WAGRAMERSTRASSE 5, A-1400 VIENNA

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ABSTRACT

The proceedings and results of the 1st IAEA research Coordination Meeting on "Tritium Retention in Fusion Reactor Plasma Facing Components" held on October 5 and 6, 1995 at the IAEA Headquarters in Vienna are briefly described. This report includes a summary of presentations made by the meeting participants, the results of a data survey and needs assessment for the retention, release and removal of tritium from plasma facing components, a summary of data evaluation, and recommendations regarding future work.

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1. INTRODUCTION

The 1st Research Co-ordination Meeting (RCM) on "Tritium Retention in Fusion Reactor Plasma Facing Components" (October 5 and 6, 1995 at the IAEA Headquarters in Vienna) was organized as part of the activity within the IAEA Co-ordinated Research Programme (CRP) on the same subject. The objectives of the Meeting were:

a) to review the tritium retention and release requirements for plasma facing components in fusion reactors (including internal vessel structural materials and coating materials);
b) to review the available data which the meeting participants had measured/collected;
c) to encourage the early measurement of properties which are deemed most necessary.

These objectives were reached either in total or in part during the meeting.

The meeting was attended by five of the chief scientific investigators of the CRP or their representative, three observers, and the staff of the IAEA Atomic and Molecular (A+M) Data Unit. The List of Meeting Participants is given in Appendix 1.

After opening remarks and adoption of the proposed Agenda the Meeting proceeded with presentations by each of the participants on experimental results pertinent to the CRP subject. One potential member of the CRP, Dr. Perujo of ISPRA, could not attend because his Institution had sent the Agreement to the EU in Brussels a few months ago for signature and it has never been signed due to bureaucratic problems. One meeting participant came as an observer because he presented his signed Agreement only after arriving at the meeting.

2. BRIEF MEETING PROCEEDINGS

The first day was spent reviewing work preformed by the CRP participants since the beginning of the CRP. After opening remarks, **Dr. Ryon Causey** of Sandia National Laboratory/Livermore chaired the first scientific session. **Dr. Tanabe** of Nagoya University discussed work performed in cooperation with Dr. Kizu of Osaka University on "Hydrogen Behavior in Beryllium and Tungsten". Their motivation for performing the work was to explain results which had been obtained in an operating fusion reactor experiment, namely JET. These results included high tritium retention in the beryllium tiles and the effect of oxygen impurity in the grain and along the grain boundary of the beryllium. In addition they reported new data

on tungsten. The beryllium sample used for the experiment had a BeO content of about 1 wt% with zinc impurity segregated to the surface. They measured permeability, diffusivity, and solubility in two thicknesses of beryllium and in tungsten and compared their results with previous experimental results. **Dr. Gorodetsky** of The Institute of Physical Chemistry of the Russian Academy of Sciences presented work done with Drs. Kanashenko and Zakharov on hydrogen retention in beryllium. They investigated re-emission, bubble formation, surface evolution and the type of trap created during bombardment with 3 keV and 10 keV deuterium ions. The type of beryllium studied was TIP-30 which had 2.2 wt% BeO. They found that most of the precipitates were BeO located on grain boundaries. They observed bubble formation at fluences as low as 3×10^{16} D/cm^2. They have proposed that deuterium retention and re-emission occurs during irradiation in three separate stages; in the first the concentration of mobile deuterium increases and re-emission appears, in the second stage the deuterium concentration reaches some critical value and the formation of bubbles begin. Both the deuterium concentration and re-emission change only slightly during this stage. The third stage occurs when the bubble concentration reaches a critical value and the bubbles start to burst leading to significant deuterium release and increase of the external surface area. This process continues until the re-emission flux becomes equal to the implant flux. In addition they studied the characteristics of the bubbles formed on irradiation and solubility and recombination of hydrogen in/on beryllium. For Be a recombination coefficient, K_r, of 2.6×10^{-21} $e^{(-0.54eV/kT)}$ cm^4/s was obtained and for BeO $K_r=1.6X10^{-24}$ $e^{(-0.58eV/kT)}$ cm^4/s was obtained. The main conclusion drawn from the work was that hydrogen was mainly contained in bubbles in beryllium and formation of these bubbles was enhanced by radiation defects and ion implantation. The last presentation of the morning session was given by **Dr. Guseva** of the Kurchatov Institute of the RF. Her colleagues in this study were Drs. Martynenko and Kalikaukas. They studied the peculiarities of hydrogen accumulation in beryllium at high irradiation doses. The beryllium samples used contained less than 2 wt% BeO. The major portion of the study was conducted using the SAPPHIRE device which provided a continuous ion flux, up to 10^{18} cm^{-2} s^{-1} and particle energies up to 10 keV. The main conclusions drawn from the work were: at low doses hydrogen exists in Be in solution and diffuses into the sample while at doses of about 10^{18} cm^{-2} hydrogen bubbles form and coalesce. The coalescing bubbles produce channels through which hydrogen escapes. At a dose of about 5×10^{18} cm^{-2} small blisters appear on the surface and at doses greater than 10^{19} cm^{-2} the blisters disappear and texturing of the surface occurs. As the

dose increases the hydrogen concentration decreases and a shift of the hydrogen profile towards the surface occurs. At high dose approximately 98% of the trapped hydrogen is located within bubbles and only 2% is in solution. Cone formation was observed at this high dose as well as enhanced hydrogen release.

The second session was chaired by **Dr. Guseva**. **Dr. Haasz** of the University of Toronto presented work done with Dr. Davis on hydrogen interaction with pure/doped graphites and metals. The objectives of the project were to assess the effect of dopants on H re-emission and H-retention in graphite and to study H re-emission and H-retention in metals. The pure graphites studied were HPG99 and EK98 and the doped graphites had high density, i.e. 2.06 g/m^3 and were anisotropic. The dopants used were B, Si, T, Ni, Al, and W. The metals studied were W, Mo, and Ta. Re-emission using line of sight QMS, quadruple (quantitative) mass spectrometry, showed that D_2 was emitted to about 1600 K and D re-emission started at a temperature of about 800K. Retention was also studied and saturation was observed for increasing fluence for fully dense material while retention continually increased for graphites of less than full density. Thermal desorption spectroscopy was performed on pure graphite and D, D_2, and CD_4 were observed. Dr. Haasz summarized their major results as follows: 1) for B and Ti doped graphites D atom re-emission occurs at a temperature somewhat higher than that seen for pure graphite; 2) for retention, B-doped graphite was similar to undoped graphite while Ti-doped graphite had somewhat higher retention; 3) Si- and W-doped graphite had considerably higher retention; 4) for the metals studied, W, Mo, Ta, D re-emission, using line of sight QMS, was observed at T>1200 K; and 5) in the case of Ta, emission of both D and D_2 were observed from the back surface. **Dr. Vietzke** of KFA/Juelich presented work accomplished with Drs. Philipps, Pospieszczyk, Esser, and Winter on atomic re-emission of H from graphite at high fluxes and experiments on H removal from co-deposited layers. The pure graphite EK98 and the doped graphite USB15 (15% B in C) were studied experimentally to measure the re-emission as a function of temperature from 200 to 2200 K. H_2 re-emission dominated from low temperature to temperatures around 1000 K and H re-emission dominated at temperatures above 1200 K. A model was presented for the re-emission which coincided with experiment fairly well for fluxes to a few 10^{15} H/cm^2 s. The main question is does atomic re-emission still exist at high fluxes, especially in the diverter region of ITER. Experiments have been designed to study this question in the TEXTOR tokamak in the coming months. In addition, experiments are planned on H removal from co-deposited layers. These experiments include the reaction of

O_2 and D_2O with a-C:H films and with the use of other gases including air. The next presentation was made by **Dr. Causey** of Sandia National Laboratories and addressed tritium retention in plasma facing materials. He explained that the work is being performed solely for the ITER project and consists of research on tritium migration and retention in unirradiated and irradiated samples of carbon, beryllium, and tungsten. He stated that his lab was moved from SLL to LASL this past year and had been inoperative for many months due to the move but would be operable within the next few weeks. The experiments on tritium retention in neutron irradiated materials using tritium gas exposure has already begun and tritium retention in beryllium will begin by mid November 1995 and will be extended to tungsten materials within the next 18 months. The next presentation was given by **Dr. Morita** of Nagoya University; the work was done in collaboration with Dr. Tsuchiya. He described work done on isotope difference in the hydrogen retention in graphite under simultaneous H and D irradiation which is important in the understanding of the recycling of hydrogen isotopes from PFC's and to predict the transient recycling fluxes of D and T during D-T burning discharges in order to control the D/T ratio in the plasma fuel. They performed experiments using simultaneous H and D beams and observed that the D/H ratio of retained concentration at steady state is 1.8±0.2. They proposed mass balance equations to describe the dynamic behavior of hydrogen in graphite which includes diffusion, sputtering, trapping, thermal and ion-induced detrapping, recombination, and hydrocarbon molecule formation. They obtained for the detrapping cross sections for H-D:2.5×10^{-18} cm^2, D-H:3.3×10^{-18} cm^2, H-H=D-D:2.9×10^{-18} cm^2. They have shown that the D/H ratio calculated is 1.6±0.2 using experimental data. In addition they reported initial measurements on the retention and re-emission of hydrogen in beryllium as studied by the ERD technique. They reported the thermal desorption of implanted deuterium during isochronal annealing and observed a continuous decline with increasing anneal time and also a continuous decline with increasing temperature reaching zero concentration at 500 C. They have shown that there are apparently two re-emission stages, the lower at 90 C and a broad second stage at 300±100 C. The lower stage corresponds to re-emission of D retained around the projected range in the bulk and the higher broad stage is composed of two stages, a lower temperature one corresponding to re-emission from the oxidized surface layers and a higher temperature one from the bulk. The final presentation was given by **Dr. Behrisch** of IPP/MPI Garching. Collaborators for this work included Drs. Martinelli, Mayer, Naujoks, Roth, Scherzer, Coad and Garcia-Rosales. Dr. Behrisch reported on both laboratory and fusion device

measurements. The fusion device results were reported at the EPS/95 meeting and will be published in the proceedings of that meeting. A summary of those results follows: even though Be is evaporated on the internal surfaces of the device, JET, the composition of the deposited layer was about 70% Be, 15% C, and 15% O. The concentration of the metals Ni, Cr, and Fe in the deposited layer was about 1% and other elements were only detected in trace amounts. The amount of deuterium implanted on the inner wall was about 1×10^{17} cm^{-2} and on the outer wall $2\text{-}6\times10^{17}$ cm^{-2}. The deuterium was distributed throughout the whole of the deposited layer to a concentration of a few percent. Hydrogen concentration was compatible to the deuterium concentration. They also investigated the co-deposition of hydrogen with carbon, beryllium and tungsten in laboratory experiments. The measured co-deposited deuterium to substrate atom ratio was 0.41 for carbon and 0.38 for beryllium whereas for tungsten the deuterium amount retained remained constant at about 10^{17} cm^2. This work has been submitted to J. Nucl. Mater. for publication.

3. DATA STATUS AND NEEDS

It was recognized by the meeting participants that in order to do definitive experiments and to obtain meaningful results that for the material studied it was very important to specify in as detailed a manner as possible the characteristics of the material since many of the properties needed are very dependent on the specifics of the material such as method of formation, initial starting material, impurity content, grain size, density (porosity), anneal temperature and other possible factors. In order to provide as useful results as possible it is especially pertinent to identify the ITER reference materials. A session was had to discuss the status of the available data. Three basic materials were considered beryllium, carbon and tungsten. Each of these materials was addressed separately. The parameters of major interest are recombination coefficient, K_r, diffusion coefficient, D, solubility coefficient, S, reflection coefficient, R, and trapping coefficient for various fluence, flux, temperature, and damage. For beryllium, data for four different types were assessed; these were monocrystal beryllium, and the engineering materials: BWS-65, TIP-30 and plasma sprayed. In addition since beryllium readily oxidizes to form BeO the above parameters are also needed for this compound and the effect of its interface with beryllium needs to be known. In Table 1 the data assessment for beryllium is given; the parameter of interest is shown in the first column, available data is shown in the second column, and needed data is shown in the third column. The assessment of data for

carbon based materials is given in Table 2. The materials which need to be considered are pyrolytic graphite, nuclear grade graphite, doped graphites, 2 and 3 dimensional carbons and redeposited carbon. Table 3 presents the data assessment for tungsten. There is the need to identify the ITER reference material and to study plasma-sprayed tungsten. Table 4 presents an assessment for other materials of interest. These consist mainly of titanium, vanadium alloys, stainless steel, and coatings. The vanadium alloy VCr5Ti5 is of particular interest since it is being considered as an in-vessel structural material.

4. CONCLUSIONS AND RECOMMENDATIONS

This Research Coordination Meeting provided the opportunity for the participants to collectively assess the status of data dealing with tritium retention and release in fusion reactor plasma facing materials. In addition ancillary topics were addressed, e.g. tritium removal techniques, which are very important in the operation of fusion reactors. The participants concluded that considerable data was available for specific materials under specific conditions but that for many of the conditions which will probably be encountered in ITER and other devices, e.g. the diverter chamber, little experimental data exists and theoretical approaches are not, at present, valid to the low energies required. The CRP members agreed to continue experimental measurements and theoretical calculations on the idems listed in Tables 1-4 as "Needed Data".

It is recommended that the CRP be continued so that the participants can address the pertinent issues in a coordinated manner and that the next RCM be held in approximately 18 months. This will allow time for measurements in progress to come to fruition and for specific materials to be chosen for the various internal vessel components and future work can then be planned.

Appendix 1

IAEA Research Coordination Meeting on
"Tritium Retention in Fusion Reactor Plasma Facing Components"

October 5 - 6, 1995, IAEA Headquarters, Vienna, Austria

LIST OF PARTICIPANTS

Dr. A.A. Haasz	Institute for Aerospace Studies, University of Toronto, 4925 Dufferin St., Downsview, Ontario, CANADA, M3H 5T6
Dr. R. Behrisch (Observer)	Euratom Association, Max-Planck-Institut für Plasmaphysik, Boltzmann-strasse 2, D-85748, Garching bei München, GERMANY
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Dr. K. Morita (Observer)	Department of Crystaline Material Science, Faculty of Engineering, Nagoya University, Furo-cho, Chigusa-ku, Nagoya 464-01, JAPAN
Dr. T. Tanabe	Dept. of Nuclear Engineering, Faculty of Engineering, Osaka University, ?-1 Yamada-Oka, Sulta-shi, Osaka 565, JAPAN
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Appendix 2

IAEA Research Coordination Meeting on
"Tritium Retention in Fusion Reactor Plasma Facing Components"

October 5 - 6, 1995, IAEA Headquarters, Vienna, Austria

MEETING AGENDA

Thursday, October 5 1995 **Meeting Room: C07-43**

09:30 Opening Address
Adoption of Agenda

Session 1: Participant Presentations I

Chairman: Causey

10:00 - 10:30: Tanabe: Hydrogen in Be & W. Reflection of Energetic Hydrogen

10:30 - 11:00: Gorodetsky: Hydrogen Adsorption on and Solubility in Graphites

11:00 - 11:30: Coffee Break

11:30 - 12:00: Guseva: Peculiarities of Hydrogen Ion Accumulation in Beryllium at High Irradiation Doses

12:00 - 14:00 Lunch

Session 2: Participant Presentations II

Chairman: Guseva

14:00 - 14:30: Haasz: Hydrogen in Pure and Doped Graphites

14:30 - 15:00: Vietzke: Atomic Hydrogen Re-emission from Graphite by Ion Bombardment at High Fluxes

15:00 - 15:30: Causey: Tritium in Plasma Facing Materials

15:30 - 16:00: Coffee Break

16:00 - 16:30: Morita: Retention and Re-emission of Hydrogen in Beryllium Studied by the ERD Technique/Isotope Difference Between Hydrogen Inventories in Graphite under Simultaneous H^+ and D^+ Irradiation

16:30 - 17:00: Behrisch: Codeposition of Hydrogen with Be, C and W

Friday, October 6, 1995

Session 3: Discussion I

Chairman: Haasz

09:30 - 10:30: Discussion of Status of Tritium Retention/Release

10:30 - 11:00: Coffee Break

11:00 - 12:30: Discussion Continued

12:30 - 14:00: Lunch

Session 4: Discussion II

Chairman: Langley

14:00 - 15:30: Discussion of Future Data Needs

15:30 - 16:00: Coffee Break

16:00 - 17:30: Discussion of CRP Objectives

Adjournment of the meeting

Table 1: Data Assessment and Need/Beryllium

Parameter	Available data (sources)	Need*
K_T	(W. Hsu /SLL, JET)	T 500-1200K
D,S	sintered Be 400-800K (Tanabe) some old data	For all four types
R	Theory (Reasonable data for E > 50 eV)	Calculation, E<10eV
Trapping	Moderate amount known quite a few sources	Irradiation with n(<10 dpa) effect of He effect of BeO/Be interface bubble formation

* Data needed for four types of Be considered: monocrystal, BWS-65, TIP-30, and plasma sprayed

Table 2: Data Assessment and Need/Carbon based materials

Parameter	Available data	Need
K_T	Good database	*
D,S	Good database	*
R	Good database	*
Trapping	Good database	*

* Data needed for redeposited material (Jülich) and doped material (Ti, B, Si) and for effects of neutrons (radiation damage)

Table 3: Data Assessment and Need/Tungsten

Parameter	Available data	Need* (possible source)
K_r	Sparse	(Causey and JAERI)
D,S	New data from Tanabe	Important
R	Good database (theory)	Important
Trapping	Some data at low T	High T
n effects	Sparse, med T (INEL)	Important

* Need to identify ITER reference material and measure parameters for plasma-sprayed material.
+ The effect of C and O on the parameters needs to be investigated, but O is not expected to be important.

Table 4: Data Assessment and Need/Other materials medium and high Z

Material	Available data	Need
Ti	scarce	All parameters(TPX)
V-alloy (V Cr_5 T_5)	very scarce	glow discharge
316 SS	Good database for undamaged material	keV charge exchange neutrals effects of n damage
Coatings	scarce	need to select materials