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"TRITIUM RETENTION IN FUSION REACTOR PLASMA FACING COMPONENTS"

Summary Report of an IAEA Specialists' Meeting held in IAEA Headquarters
Vienna, Austria, 17 - 18 June 1993

Prepared by R.A. Langley

December 1993

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

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Abstract

This Report contains the summary of the IAEA Specialists' Meeting on "Tritium Retention in Fusion Reactor Plasma Facing Components" which was organized by the IAEA Atomic and Molecular Data Unit and held on June 17-18, 1993 in Vienna, Austria. The meeting proceedings are summarized and 1) a list of additional information required on tritium retention was prepared by the specialists as well as 2) formulation of the scope of a proposed co-ordinated research program dealing with the meeting topic. There were 13 Specialists, 2 Observers, and 3 representatives of the IAEA in attendance.

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I. Introduction

With the advent of the ITER EDA, the choices for the plasma facing component materials must be made in a timely fashion consistent with the known requirements. Many of these requirements have not needed to be addressed until this point in time, and as such, it is necessary that accurate information be provided to the machine designers so that judicious choices may be made for these materials. It was one of the purposes of this IAEA Specialists' Meeting on "Tritium Retention in Fusion Reactor Plasma Facing Components" to define the pertinent physical material parameters and potential materials for use as plasma facing components (PFC).

Tritium retention and release data are needed for: 1) recycling models, 2) tritium inventory estimates, 3) tritium permeation calculations, and 4) hydrogen embrittlement characterization. In addition to strongly influencing plasma operations,these data are pertinent to reactor safety and loss of radioactive material to the environment.

Of particular interest for this meeting was the consideration of the plasma erosion products of the plasma facing components since a Research Coordination Meeting (RCM) on Erosion of Plasma Facing Components preceded this meeting; much of the in-vessel tritium inventory is thought to be contained in the redeposited layer of the erosion products. This is especially true if carbon materials, e.g. graphite, doped graphites, and carbon fiber composites, are used as the PFC material.

The ultimate aim of a Co-ordinated Research Program (CRP) dealing with this topic would be to provide reactor designers models for tritium retention and release based on evaluated experimental and theoretical data. To achieve this end, the meeting participants gave presentations on their work, including work of their colleagues, and discussed the data needed to validate the models required by the reactor designers. In addition, the scope of the proposed CRP was addressed.

The next section summarizes each of the presentations given, and where applicable, addresses areas where the individual presenter thinks data are needed. The remaining two sections describe results of a discussion by the participants on additional data required, and finally, addresses the need for and the scope of the proposed CRP. The Meeting was attended by 13 specialists, 2 observers and 3 representatives of the IAEA (see Appendix 1).

II. Meeting Proceedings

The meeting was opened by Dr. Iyer, Director of the IAEA Division of Physical and Chemical Sciences, who expressed the Agency's interest in this area of fusion research and development and, on behalf of the IAEA, thanked the participants for their willingness to contribute to the meeting. He pointed out the main objectives for the meeting were: 1) review of the existing information relevant to tritium retention and release, 2) identify areas where information is lacking, and finally, 3) formulation of the scope of the co-ordinated research program to involve both experimentalists and modelists in improving the data base for tritium retention in fusion relevant materials, and for advancing the predictive power of the modeling codes. Following Dr. Iyer's presentation the participants adopted the Meeting Agenda (see Appendix 2), which was divided into five sessions. The first three of these were devoted to presentations by the participants addressing their work completed and planned in the areas of interest of the meeting. The two remaining sessions addressed the identification of additional information required on tritium retention and release and on the formulation of the scope of the proposed co-ordinated research programme.

The first session, chaired by Dr. R. Causey of Sandia National Laboratories/USA, dealt with tritium inventory in components and component materials. Dr. P. Wienhold of the Forschungszentrum Juelich GmbH/Germany addressed hydrogen permeation and tritium inventory in metallic components of tokamaks. He reviewed the use of the modeling code PERI, its past applications and explained its intended uses. In particular, he addressed the permeation of tritium through the plasma facing components and vacuum vessel wall into the blanket and cooling medium. Dr. Perujo, of the ISPRA Institute for Safety Technology/CEC, gave an overview of hydrogen transport parameters in fusion materials. He noted that four numerical codes had been used to model tritium migration in materials. He outlined the main facets of the codes and presented a review of experimental data for diffusivity, solubility, recombination rates, and heat of transport for various materials of interest. He pointed out that a theoretical study showed that trapping and surface processes strongly affected tritium recycling, inventory and permeation and recommended that a better knowledge of these processes was necessary in order to understand and correctly model tritium transport. Dr. B. Scherzer, of the MPI fuer Plasmaphysik/Germany, presented a paper on the dynamic hydrogen inventory in graphite. He demonstrated with experimental results how the inventory can change with different experimental conditions and with time. Concluding this session, Dr. A. Haasz, of the University of Toronto/Canada, gave results of their experimental studies on hydrogen retention and reemission

from graphite. They did studies using graphites of varying porosity in an attempt to determine if previous results reported by Dr. Langley of ORNL/USA concerning migration of atomic hydrogen into the graphite bulk could be substantiated. His results appeared to confirm the earlier results. Using a dual-beam ion accelerator, the Toronto group found evidence that suggests that hydrogen moves in form of atoms in the implantation zone, whereas methane formed at the end of ion range and moved in the form of molecules. In addition Dr. Haasz reported on other work in Canada (McMaster University) concerning tritium inventory in beryllium, beryllium carbide and vanadium. The later two involved mainly a survey of the literature which showed the lack of available data.

The second session was chaired by Dr. A. Haasz and addressed retention in graphites, carbon based materials and retention in plasma devices. Dr. B. Emmoth, of the Manne Siegbahn Institute of Physics/Sweden, gave the first presentation of the session and presented results of experimental studies performed at their institute. They have extensive experimental capabilities which they have used to study tritium retention in various graphites, carbons and silicon coatings. The carbons consisted of silicon doped and fiber components They studied both thermal release and ion induced release using numerous analytical techniques. Dr. K. Morita, of Nagoya University/Japan, addressed the issue of isotope effects in the ion-induced and thermal re-emission of hydrogen from graphite. He presented experimental data which showed that isotope effects using hydrogen and deuterium can be used to predict tritium retention and release. Dr. Scherzer presented the second of two papers on low energy hydrogen reflection from graphite. The recent work was performed by Dr. M. Mayer and consisted of measuring the angular dependence of the reflection coefficient of deuterium at energies below 50 eV from different types of graphites and comparing the results with the TRIM code calculations. They studied reflection as a function of incident angle and for different incident particle energies. Dr. Causey presented data on the retention of hydrogen in graphite, beryllium, vanadium and tungsten. The main conclusion with regards to using graphite was that damage created in the bulk graphite via neutrons or ions increased retention substantially. Another concern is the retention in the eroded material. Although the data were scant some were presented for retention in beryllium, vanadium and tungsten. Drs. M. Guseva and Y. Martynenko presented similar data for boron doped graphite. They found a substantial reduction in the tritium retention for boron doped graphite. They postulate that the boron is trapped at the same sites where hydrogen is trapped. Experiments appear to substantiate this. They performed the study for graphites with differing porosity, with different amounts of boron doping and for different temperatures and other experimental parameters. The final presentation of the session was made

by Dr. P. LaMarche of Princeton University/USA. His talk addressed the pertinent issues of hydrogen retention in the plasma experiment TFTR and the proposed experiment TPX and put many of the experimental issues in perspective in regards to tritium use in fusion reactors. He pointed out the possible problems created by hydrogen retention, namely embrittlement, permeation and recycling. He also noted the major problem of codeposition but pointed out that attempts to control this effect have been made by keeping the plasma edge temperature low. In conclusion, he feels that some limited success has been obtained in manipulating the plasma edge without affecting the plasma center but that edge parameters end up being key to the overall plasma performance.

The final session for the presentations concentrated on retention in graphite and high Z materials and retention issues in the JET device. Dr. P. LaMarche chaired the session. Dr. T. Tanabe, of Osaka University/Japan, presented the first presentation of the session which dealt with hydrogen retention in graphite at high temperature and in high Z materials. He addressed the effect of high temperature on hydrogen solubility and the effect of neutron irradiation in graphite. He also pointed out the possible effects of neutron damage trapping of hydrogen. In addition, he addressed the retention in high Z materials stating that there were two types of retention effects depending on whether the material was an exo or endothermic hydrogen occluder. He presented numerous data for the diffusivity, solubility and permeability for unirradiated materials but pointed out that little reliable data exist for irradiated materials, and that the values for these materials could be significantly different. He also presented a few comments on the recombination coefficient for Mo and W stating that little experimental data exist. Dr. E. Vietzke, of the Forschungszentrum Juelich GmbH/Germany, reported on joint work with Dr. Peter Franzen, of Max-Planck-Institute for Plasmaphysik in Garching, and Dr. A. A. Haasz, of the University of Toronto, addressing the atomic and molecular hydrogen re-emission from carbon and boron doped carbon for temperatures to 1700 K. Below 1000 K he found that hydrogen was reemitted as molecules, whereas above 1000 K hydrogen was reemitted as a mixture of atomic and molecular species. He concludes that the atomic release of hydrogen from carbon is a thermal effect. He also found that annealing depleted the doped graphite of boron in the surface region. In addition, he presented results of a code, entitled EIRENE, which accounts for the atomic and molecular emission. Dr. C. Wu, of the NET Team/Germany, discussed a model, TIPO, which the NET team has used to predict the tritium transport and inventory in porous materials, namely graphite and doped graphites. He discussed what effects the carbon properties and neutron induced damage had on tritium retention. He pointed out the importance of assessing the predictive capabilities of the model, to gain an understanding of the

influence of the variables which affect the kinetics of release and to define the confidence level of the code predictions. Dr. Andrew, of the JET Team/UK, presented results on retention and release of tritium in the JET plasma facing components. As JET contains significant amounts of beryllium, it is unique in its problems relating to tritium retention. He pointed out that JET is in reality a mixed material machine, i.e. beryllium and carbon. He presented experimental data which showed there was a dynamic situation with regard to tritium retention and release. The conclusion drawn following introduction of beryllium into JET was that the tritium retention could still be described in terms of known responses of graphite.

III. Identification of Additional Information Required on Tritium Retention

The meeting participants discussed data needs regarding tritium retention and release as ascertained from their collective knowledge. The participants discussed the importance of the proposed CRP with respect to ITER and agreed that the most important materials to include were materials under consideration for ITER but that the list should not be constricted to those of only ITER consideration, e.g. graphites, doped graphites and carbon fiber composites. The participants felt that probably the largest potential effect which had not been studied in detail was the effect of vacancy formation on tritium retention. It was thought that this will significantly alter the tritium retention and subsequent material degradation.

The following table, **Table 1**, represents the participants' best estimate of the availability of experimental and theoretical data.

Included in the material list are materials which have been considered during the ITER EDA and are currently being considered for ITER EDA and other fusion experiments operating or in the design phase. Included in the physical property list are those properties which are thought to influence the retention and release of tritium. Not included in the physical properties list is porosity, which is especially important for graphite and plasma sprayed metals. We have chosen to refer to porosity as a material property and not to include it in the Table.

In only one area in the above table was the availability of data rated high and this was for reflection from medium and high Z materials. For two areas there are essentially no data and for the remaining areas the available data are limited.

It should be noted that for compound materials, e.g. SiC or B_4C, even less information is usually available. It should be noted that even for one material, there are many techniques for

Table 1. Availability of Experimental and Theoretical Data

Physical Property	Material: Beryllium	Material: Carbon	Material: Medium and High Z material (Ti, V, Mo, Nb, W)
Diffusivity	L	M	M
Solubility	L	M	M
Recombination rate coefficient	L	M[a]	L
Trapping	L	M	M
n-generated	L	M	d
He effects	L	d	M
Reflection	L[b]	M[c]	H

Degree of data availability
H = high
M = medium
L = low

a) limited to graphite
b) only calculations
c) extensive for some graphites
d) unknown

producing the final product and each technique can result in different physical properties and material properties which could affect tritium retention.

IV. Scope and Objectives of Proposed CRP

The meeting participants first discussed whether a CRP was needed and if it could serve a useful purpose. The consensus was that the experimental and theoretical data which would be obtained during the CRP are essential for reactor designers. They concluded that a CRP would be highly useful and would allow the participants better communication amongst themselves and could serve as a mechanism to inform the machine designers and the funding agencies of the perceived problems so that financial support could be obtained for performing the needed experiments. In addition, they thought that the A+M Data Unit could serve a very useful service in collecting the data in the ALADDIN database and, where possible (e.g. through consultants' services), evaluating the data.

The scope of the proposed program was laid out along the lines of Table 1 and the various participants discussed areas of interest, concerning both material and physical properties in which

they would be interested to contribute to the CRP. The one area where little work is planned is neutron damage induced trapping. This was the area discussed in the previous section where there is the biggest gap in existing data. This situation was thought to be severely disturbing and should be addressed by the meeting participants with their individual funding agencies as well as support from the A+M Data Unit on elucidating this problem.

Objectives of the CRP are to collect and evaluate the relevant data for use by fusion reactor designers especially in regard to the ITER activity.

LIST OF PARTICIPANTS

CANADA

Dr. A.A. Haasz	Institute for Aerospace Studies, University of Toronto, 4925 Dufferin St., North York, Ontario, M3H 5T6

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CEC - COMMISSION OF THE EUROPEAN COMMUNITIES

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MEETING AGENDA

Thursday, June 17

09:30 - 09:45 - Opening **(Janev, Iyer)** **Room: C-07-IV**
- Adoption of Agenda **(Langley)**

Session I **Chairman:** **Causey**

09:45 - 10:15	**Wienhold**	H Permeation and T Inventory in Metallic Components of Tokamaks
10:15 - 10:45	**Perujo**	H Isotopes Transport Parameters in Fusion Reactor Materials: An Overview
10:45 - 11:00	**Coffee break**	
11:00 - 11:30	**Scherzer**	Dynamic H Inventory in Graphite
11:30 - 12:00	**Haasz**	H Retention and Re-emission from Graphite
12:00 - 14:00	**Lunch**	

Session II **Chairman:** **Haasz**

14:00 - 14:30	**Emmoth**	PFC's and T Retention: Report on Retention in Silicon-doped Graphites, CFC and Vacuum Plasma Sprayed Layers
14:30 - 15:00	**Morita**	Isotope Effects in the Ion-induced and Thermal Re-emission of H from Graphite
15:00 - 15:30	**Scherzer**	Low-Energy H Reflection from Graphite
15:30 - 16:00	**Coffee break**	
16:00 - 16:30	**Causey**	Modeling of T Retention in Tokamak PFC's
16:30 - 17:00	**Guseva & Martynenko**	Retention of Implanted H in Graphites
17:00 - 17:30	**LaMarche**	Issues on Hydrogen Isotope Retention in TFTR and TPX

Friday, June 18

Session III **Chairman:** **LaMarche**

09:00 - 09:30	**Tanabe**	H Retention in Graphite at High Temp. and in High Z Materials
09:30 - 10:00	**Scherzer**	High-Temp. H Re-emission from C and Doped Graphite
10:00 - 10:30	**Vietzke**	Atomic Re-emission of H from C and B Doped C Above 1000°K

10:30 - 11:00	**Coffee break**	
11:00 - 11:30	**Wu**	Tritium Retention in Carbon Materials used as Fusion Plasma Facing Components
11:30 - 12:00	**Andrew/Pick**	Retention and Outgassing of Tritium in the JET First Wall
12:00 - 14:00	**Lunch**	
Session IV	**Chairman: Langley**	
14:00 - 15:30		Identifying Additional Information Required on T-Retention
15:30 - 16:00	**Coffee break**	
Session V	**Chairman: Langley**	
16:00 - 18:00		Formulation of the Scope of the Co-ordinated Research Programme