International Atomic Energy Agency INDC(NDS)-442

INDC INTERNATIONAL NUCLEAR DATA COMMITTEE

First IAEA Research Co-ordination Meeting on "Tritium Inventory in Fusion Reactors"

4-6 November 2002, IAEA Headquarters
Vienna, Austria

SUMMARY REPORT

Prepared by: R.E.H. Clark

February 2003

IAEA NUCLEAR DATA SECTION, WAGRAMER STRASSE 5, A-1400 VIENNA

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Abstract

The proceedings and conclusions of the first Research Co-ordination Meeting on "Tritium Inventory in Fusion Reactors", held on November 4-6, 2002 at the IAEA Headquarters in Vienna are briefly described. This report includes a summary of the presentations made by the meeting participants and the specific goals set by the participants of the Co-ordinated Research Project (CRP).

Reproduced by the **IAEA** in Vienna, Austria
February 2003

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Appendices

1. INTRODUCTION

The first Research Co-ordination Meeting (RCM) of the participants of the IAEA Co-ordinated Research Project (CRP) on "Tritium Inventory in Fusion Reactors" was held on November 4-6, 2002, at the IAEA Headquarters in Vienna, Austria. The objectives of the meeting were:

1. To summarise the current research activities of the participants

2. To formulate specific objectives for the CRP

3. To form a work plan among the CRP participants to meet the specific objectives of the CRP

The meeting was attended by CRP participants A.A. Haasz (Canada), N. Bekris (Germany) J. Roth (Germany), T. Tanabe (Japan), V.Kh. Alimov (Russian Federation), A, Pisarev (Russian Federation), J.P. Coad (United Kingdom), R.A. Causey (United States), R. Doerner (United States) C.H. Skinner (United States) and S. Artemov (Uzbekistan) as well as observers G. Federici (ITER Garching) and M. Mayer (Germany). The Agency was represented by A. Nichols, R. Clark and D. Humbert. The list of meeting participants is attached as Appendix 1.

2. BRIEF MEETING PROCEEDINGS

The meeting began with a welcoming address by A. Nichols, Head of the Nuclear Data Section. The Meeting Agenda was adopted without change (see Appendix 2). The meeting then continued with seven sessions. The first five sessions were devoted to reports of the latest research from each individual participant. Very brief summaries of the presentations are included here. The full presentations are available on request. The fifth session was devoted to a summary of the current research activities. The sixth session included discussions and a formulation of data needs for tracking tritium inventory in fusion machines. The final session was devoted to formulating specific objectives and matching those objectives to the individual participants. These final three sessions resulted in a document identifying specific tasks to be performed by each participant for fulfilment of the overall objectives of the CRP. This is included in as Section 3 of this report. For reference, the background and overall objectives for the CRP are included in Appendix 3.

The first session of the meeting was chaired by C. Skinner and included presentations by G. Federici, R. Doerner and A. Pisarev.

The first speaker of the session, G. Federici, gave an overview of the problem of plasma facing materials (PFM) in ITER. He reviewed the desirable material properties of carbon and carbon's disadvantages due to its tritium retention properties. He pointed out that no engineering scale demonstration of tritium removal has been performed. He then reviewed other possible materials for use as PFMs in various regions of a fusion reactor and summarized the advantages and drawbacks. One problem with using different materials in different regions will be the formation of mixed materials. He also stressed the need for better modelling capability. He pointed out that current estimates are that the limit for

overall tritium in ITER could be reached in a few hundred pulses, which is unacceptable. He indicated that one strategy in ITER is to begin operation in the deuterium phase with carbon in the divertor. If it is found that this is a problem, there will be a plan to switch to tungsten.

The second talk of this session was given by R. Doerner on the topic of mixed materials including beryllium, carbon and tungsten. He summarized a number of research efforts being undertaken to examine the interactions of combinations of these elements. A United States-European Commission collaboration has begun on this issue. There will be a number of experiments as well as modelling using several tools at different institutions. A number of issues need to be examined such as temperature and fluence dependencies. Deuterium content in plasma exposed materials as well as redeposited materials will be examined. He pointed out that besides the safety issue in tritium retention, there is also an effect on the plasma behaviour. He gave a summary of the possibility of using liquid metals to be able to adjust the hydrogen recycling rate by adjusting the flow rate of the liquid.

The final talk of the first session was given by A. Pisarev on the topic of hydrogen ion trapping and release. He discussed the various aspects faced in modelling ion implantation and release, such as the shape of the thermal desorption, re-emission, positions and shapes of peaks in temperature dependence, etc. He then outlined a laboratory experiment with three stages: re-emission during ion implantation, decay of the release after termination of implantation, and thermal desorption during subsequent programmed heating. He outlined the diffusion equation and boundary conditions and explained the parameters in the model. He concluded that modelling can give a very good description of this problem but that there is still a lack of knowledge about real properties of the ion modified solid.

The second session was held in the afternoon of the first day and was chaired by R. Doerner. Reports were presented by N. Bekris, P. Coad, C. Skinner and R. Causey.

The first presentation of the second session was by N. Bekris on the topic of detritiation of JET tiles. He summarized methods including an argon plasma source, an open flame (nitrous oxide-acetylene) and radio frequency heating. The argon plasma reaches temperatures of 10000 K at the arc core. Experiments with the arc resulted in a detritiation factor of approximately 200. Baking of tiles achieved a factor of approximately 100. However, to reach the levels required in ITER a factor approaching 1000 will be needed. A large amount of tritium may be taken up in flakes. From an analysis of the tritium balance in JET it appears that close to a kilogram of flakes are in the machine with tritium concentration of 3.3 mg/gram. This amount of flakes is consistent with endoscopic inspection.

The second talk of the session was by P. Coad on the topic of tritium retention in JET and detritiation. He summarized the deposition at JET, which is asymmetric. There are pictures of flakes on the floor of JET. Ion beam analysis of wall tiles shows deposition. Some JET divertor tiles are to be analysed in December 2002. A laboratory has been equipped to handle beryllium and tritium contaminated samples from JET. Samples were taken from divertor tiles. These were analysed using secondary ion mass spectrometry. To look into migration of carbon, 1.3×10^{23} atoms of carbon 13 were injected and followed. They were found on the inner wall of the divertor, but not in the shadowed areas, nor in the outer divertor. It has been found that there are thick deposited films at the inner divertor wall with

beryllium and metal rich films with an overlayer containing carbon and deuterium. The shadowed areas show films containing almost exclusively carbon and some deuterium.

C. Skinner gave the third talk of the second session on the application of a scanning laser for tritium removal and heat transfer issues. He presented recent results on laser detritiation. He pointed out that for successful operation of ITER there is a need to either drastically reduce co-deposition of tritium with carbon or to demonstrate fast and efficient tritium removal. Current knowledge of tritium deposition is machine dependent. TFTR was a limiter machine with no divertor while JET is a divertor machine. The detritiation process in TFTR would be unacceptable for ITER. Heating for removal is impractical. There are now Nd:Yag laser systems commercially available with programmable scanning features. Experiments have been done with this system on TFTR and JET tiles with a release rate of up to 87%. The laser can be sent through optical fibres with 90% transmission and could be scanned using a remote arm. There is a proposal for using this on JET in 2004. Also, heating by scanning lasers mimics heat loads in slow transient off-normal events and gives a new technique for studying heat flux interactions.

R. Causey gave the fourth and final talk of the second session on the topic of deuterium uptake in co-deposited layers after flash heating in vacuum. During laser heating only the outer layers reach high temperatures. Apparently the carbon matrix is mostly left intact. The question arises as to the ability of this matrix to quickly reabsorb tritium. A graphite tile from TFTR prior to tritium operations was used as a source of co-deposited layers for a test of this process. Samples were heated to 150 C to remove water vapour then heated to 1000 C to release deuterium, which was measured. After exposure to atomic deuterium the procedure was repeated. The result was the co-deposited layer appears to provide very low recycling for several subsequent discharges. It appears that the depleted co-deposited layer is difficult to completely refill.

The third session was held on the morning of the second day and was chaired by P. Coad. V.Kh. Alimov, A.A. Haasz and J. Roth reported on their research.

V.Kh. Alimov gave a presentation on the topic of deuterium retention in tungsten carbide and tungsten trioxide. He described several different specimens including hot-rolled foils, chemically vapour deposited (CVD) coatings of cubic tungsten carbide and tungsten carbide layers formed by deposition of carbon on tungsten foil. It appeared that deuterium atoms in the tungsten and the CVD tungsten carbide diffuse into the bulk of the specimens and are captured by defects also. It appears that most of the deuterium in the tungsten foils is trapped in molecular form and that bubbles form, apparently on grain boundaries. For CVD coating the retention is in atomic form and the molecular component is absent. Tungsten carbide grown on the tungsten foil surface has higher deuterium retention. Further studies were performed using W-C and C deposited on silicon substrates in a D_2 atmosphere. Deuterium appears to be distributed homogeneously throughout the thickness. Further studies were undertaken on oxides of tungsten since tungsten has a strong affinity for oxygen.

A.A. Haasz gave the second talk of this session on the topic of hydrogen retention in tungsten. His objectives were to explore the affect of bulk and surface impurities on deuterium retention in single crystal tungsten (SCW), to examine the role impurities play in deuterium retention, investigate how repeated implantations effect deuterium retention and

to look for signs of bubble formation in SCW. He first gave some background information on retention data for tungsten. He then gave details of the experimental set-up and the samples used and summarized the ion implantation. He then presented results for a variety of materials on the effect of pre-implant annealing on oxygen and carbon impurities. He summarized the results for temperature and fluence dependence. He found some interesting differences in retention curves at 500 K. He reviewed some results from polycrystalline tungsten (PCW) to help in understanding the current results. He pointed out the effect of cumulative damage in a specimen leading to higher deuterium retention than in a freshly prepared sample, which was also seen with PCW. He hypothesised that initial trapping occurs at impurities and/or dislocations, initial trapping leads to formation of clusters which could grow to nano-bubbles, and the clusters and/or bubbles will create strain fields that will eventually interact limiting further cluster growth. He then summarized a next key experiment in which the background impurities during implantation should be reduced to reduce the adsorped impurities. Measurement of retention would then show the effect of the impurities on retention.

J. Roth gave the final talk of the session on the topic of deuterium retention in tungsten and its dependence on surface conditions. First he gave a summary of the mechanisms for deuterium behaviour in tungsten. He then presented an overview of the processes influencing hydrogen inventory and presented theory along with experimental parameters. He then presented results for retention under a variety of conditions and some comparisons of theory with experiment. He found that retention occurs in different trap sites with different energies and that theory explains this well. Depth profiling shows long range diffusion and a proportionality to the square root of the fluence. He found that sample preparation and surface treatment have a strong influence on retention and on trap densities. Both carbon implantation and surface oxidation increase retention. He pointed out a number of open questions related to annealing, blistering, molecule formation, neutron irradiation and pre-implantation of carbon and oxide films. He concluded by outlining future work to include making more precise measurements of parameters for D retention in tungsten, studies of D retention in doped graphites, and studies of D retention in ASDEX Upgrade.

The fourth session was held on the afternoon of the second day. R. Causey served as the chairman of the session. S. Artemov and T. Tanabe gave talks in this session. Tanabe included a presentation of the work of V. Philipps, who was invited as an observer but was unable to attend.

S. Artemov presented the first talk of this session. He reviewed the use of the neutron induced elastic recoil detection (NERD) method for tritium inventory purposes and the activities currently being taken to improve the method. He began by reviewing the theoretical basis of depth profiling of hydrogen isotopes and a summary of the NERD method. The main advantage of the method is the ability to give depth profiles for large depths. The shortcoming has been the limited depth resolution. However, the depth resolution can be improved by use of a Monte Carlo simulation of recoil energy spectrum. This has been implemented with a computer code called DRIN. Several results were presented. Future work will include increasing the sensitivity of the NERD method and decreasing the charged particle background, develop procedures for standardized measurements, and develop a database for cross sections to allow elimination of “alien” tritons from the measured spectra. It is planned to use the method on some specimens of interest in the framework of the CRP.

T. Tanabe gave the final presentation of this session. The first portion of his presentation summarized work from V. Philipps, who was unable to attend the meeting. This part of the talk focused on transport of carbon and fuel deposition in TEXTOR. TEXTOR has been completely opened and all tiles removed and assessed. Estimates were made of erosion and deposition rates and of D retention in deposited carbon. Overall retention was found to be quite high. If extrapolated to ITER, tritium retention would limit the lifetime to a few hundred shots, but it was pointed out that extrapolations are dangerous.

Tanabe then gave a presentation of his own current work on tritium retention on plasma facing materials determined with an imaging plate technique. After a brief description of the technique, an overview of carbon-hydrogen chemistry was given. Sources of tritium in a fusion reactor were enumerated. An overview of studies of several fusion machines was given, detailing studies of tritium retention in a variety of tiles. A Monte Carlo simulation code for following energetic tritons was described. Simulations from the code were used to predict tritium deposition and then compared with the imaging plate measurements.

The remaining sessions of the RCM were devoted to a summary of current research, data needs for fusion reactors, and formulation of a work plan for the CRP. There were wide ranging discussions in those sessions covering a number of topics of concern to tritium inventory in fusion reactors. A summary of the main outcomes of those discussions is presented in the next Section.

3. MEETING CONCLUSIONS AND WORK PLAN

During the course of the sessions on summarizing current research and formulating a list of data needs and a work plan, C. Skinner undertook the task of recording the outcomes on a laptop computer using an overhead projector so that the participants could comment on and suggest changes as the discussions unfolded. The resulting document was then distributed to the participants and revised as needed. This resulted in a summary of data needs as perceived by the participants and a list of specific tasks to be performed by the participants. This is included here as the work plan.

SUMMARY OF MEETING RECOMMENDATIONS

CARBON LEADING TO CODEPOSITION

General Comments:

It cannot be assumed that the first wall will be carbon free. There is a concern that there will be a 'memory' of the previous carbon phase if ITER later switches to tungsten. There is a question of carbon layers forming on long-term samples. The erosion sources are not known. The erosion of beryllium impacting on carbon should be looked into. Doped graphites should be kept in mind but the effect of the dopant disappears with high particle and heat load. There is room for improvement in the understanding of material properties. Carbon is needed only for ITER considerations; it will not be useful in a working reactor because of swelling.

Flux and fluence dependence of chemical erosion is important in modelling. The PSI facility in Holland may be able to help in this. C2 complexes are very flux dependent, but this may not be addressed in lab experiments. While valuable data can be gained in the next two years, tokamak experiments may not converge on a clear answer. There are some discrepancies between PISCES and Berlin PSI results. It is important to have measurements at high flux.

Kukushkin needs sputtering yield of 1-2% to radiate sufficient power and avoid high heat flux. Effect of ITER disruptions on 'grassy' surfaces found on PISCES.

There is still some question of erosion sources. Erosion source on wall in JET is not strong enough to explain deposition. Is there an additional carbon source? What is the contribution from start up and ramp down? Micro-hot spots have been seen in laser experiments.

Specific tasks identified for Carbon:

- *Monitor erosion program on DIII-D (R. Doerner).*
- *Identify sources & sinks in tokamaks: use C13 methane puffs in ASDEX and JET (M. Mayer and P. Coad to evaluate JET & ASDEX data; T, Haasz and R. Doerner to monitor porous plug in DIII-D.*
- *JT-60 RES experiments (T. Tanabe).*
- *Chemical erosion of carbon, Flux & Fluence dependence (J. Roth will evaluate flux dependence; R. Doerner will evaluate fluence dependence).*
- *Dopants: development of low erosion materials, measure erosion and H retention. (J. Roth).*
- *Hydrocarbon species generation.(T. Haasz with tritium)*
- *Hydrocarbon species transport.(M. Mayer and P. Coad will evaluate JET and ASDEX data).*

- *Change in erosion due to impurities e.g. Be, C. (R. Doerner).*
- *Temperature effects on species film formation; where does carbon go and in what form ? (J. Roth).*

MIXED MATERIALS

General Comments

Will chemical erosion be suppressed by Be? This will be investigated in PISCES. The effect of ELMS is important. Could ELMs remove a Be coating? The ELM question is still very much open. Will ELMs raise the surface temperature? Globules are seen in laser experiments on JET tile 3 with Be and C on the surface. For Be – W mixed materials there is essentially no data at all. Is there some prospect at TPE? Will anyone do modelling of oxygen? What about the erosion of Be/O? Modelling is still needed for JET and ASDEX.

Specific tasks identified for mixed materials:

- *Further QMBs on JET, evaluation of distribution to other machines (P. Coad)?*
- *Long term samples on other machines (M. Mayer at ASDEX, P. Coad at JET, C. Skinner at NSTX, T. Tanabe on JT-60).*
- *NERD profiles of JET samples (S. Artemov and P. Coad).*
  (S. Artemovi to contact knox@physics.isu.edu (John M. Knox) (R. Causey)
- *Contact John Sharpe in regard to dust sampling in JT60 (SHARJP@inel.gov) (T. Tanabe).*
- *Be seeded plasma interactions with C (R. Doerner)*
- Gas Balance

DEPOSITION AND CODEPOSITION

General Comments:

A minimum temperature is needed to prevent the formation of films, 200C (manageable) or 600C. Jacob is working on this and it appears the answer is 570 K. Could there be technology transfer of deposition monitors to DIII-D ?(P. Coad/Dennis Whyte). There was little dust found on JT60, is it due to high wall temperature? TEXTOR also operates hot but finds lots of flakes.

For tritium and codeposit removal, laser scanning may work. We need to evaluate the redeposition question. We could consider oxidation if desperate. Nicolas finds he needs 100 deg higher temperature than Tony. Does oxidation work on mixed materials ? Some data on Be/C tile 3 heating and oxidation are available

Specific tasks identified for deposition, codeposition, and removal:

- *Further QMBs on JET, evaluation of possible supply of QMBs to other machines (p. Coad)*
- *Look at removal techniques and reabsorption (C. Skinner (if funded) and R. Causey)*
- *In-vessel testing (C. Skinner and P. Coad in JET).*

- *Looking for new proposals (N. Bekris: plasma arc).*
- *Effect of metals on thermal oxidation (T. Haasz).*
- *Electron stimulated desorption (T. Tanabe).*
- *HeO glow discharge (summary of Cowgill's results) (R. Causey (note: 5mg/hr in TFTR)).*
- *Clarify BET specific surface area of JET flakes (P. Coad and N. Bekris).*
- *Investigate co-deposition of mixed materials (R. Doerner)*

ALL METAL OPTION

General Comments:

There is a need to consider pure metals, mixed materials, and alloys. For pure tungsten there is the evolution of microstructure, and trapping. Radiation induced trapping can eventually be a problem, but is unlikely to be a tritium inventory problem. There is the need to distinguish the low and high flux cases. This is important for polycrystalline materials. Experiments at room temperature are worth doing using sprayed tungsten samples. Understanding comes when collating data from different experiments. It is important to learn about grades of plasma spray W available. There is the question of obtaining samples. T retention is still an open question if C on W poisons recombination at surface. We cannot explain 1% retention data at low fluence. Is there a possibility of edge nano-bubbles? This is possibly not an issue at high fluence. Do we only need to consider plasma simulators/tokamaks? The previous problem with extrapolation from ion beam experiments: was the model wrong? Ion beam data also illuminate fundamental physics. Retention in clean W is negligible, if 'dirty' W then the answer is not clear. Plasma spray on carbon is successful at high heat flux. ITER Spec is 10 mm thick Be on Cu, 1 m2, 5 tons.

Specific tasks identified for all metal option:

- *T retention on clean W at high flux (exchange samples with Garching) (R. Causey and R. Doerner).*
- *Retention measurements with sprayed W (G. Federici will provide spec. T. Haasz/J. Roth/S. Artemov/ R. Causey will do experiments if material available).*
- *Database of H in W (R. Causey and A. Pisarev).*
- *Modeling of H retention, as in TMAP (A. Pisarev).*
- *Be and C seeded plasma interactions with W (R. Doerner)*

Mixed materials involving tungsten:

General Comments:

What about W with O and C layers? O is unlikely on W: will react with Be instead. An all tungsten machine would still need to have a getter to remove oxygen. Could boron be used? But would it co-deposit? This would also bring up the need to use an impurity for radiative cooling. Tungsten also acts as a getter for O. But JT60 operated without boronization (hot walls). There is the issue of migration of Be into W. What is the effect of tokamak radiation? Early work suggests this is not important.

Specific tasks identified for mixed materials involving tungsten:

- *The effect of O, C layers on W on H retention (J. Roth; T. Haasz simultaneous C/H).*
- *Diffusion of Be in W as a function of temperature (J. Roth).*
- *Future TPE work at INEEL, inject Be into plasma, study retention on W substrate (R. Causey).*
- *Generate H retention and diffusion data in WC (S. Artemov).*

Summary of Action Items

1. *Monitor erosion program on DIII-D (R. Doerner).*
2. *Identify sources & sinks in tokamaks: use C13 methane puffs in Asdex (M. Mayer and P. Coad to evaluate JET & Asdex data; T, Haasz and R. Doerner to monitor porous plug in DIII-D.*
3. *JT-60 RES experiments (T. Tanabe).*
4. *Chemical erosion of carbon, Flux & Fluence dependence (J. Roth will evaluate flux dependence; R. DOerner will evaluate fluence dependence).*
5. *Dopants: development of low erosion materials, measure erosion and H retention. (J. Roth).*
6. *Hydrocarbon species generation.(T. Haasz with tritium)*
7. *Hydrocarbon species transport.(M. Mayer and P. Coad will evaluate JET and ASDERX data).*
8. *Change in erosion due to impurities e.g. Be + W on C. (R. Doerner).*
9. *Temperature effects on species film formation; where does carbon go and in what form ? (J. Roth).*
10. *Further QMBs on JET, evaluation of distribution to other machines (P. Coad)?*
11. *Long term samples on other machines (M. Mayer at ASDEX, P. Coad at JET, C. Skinner at NSTX, T. Tanabe on JT-60).*
12. *NERD profiles of JET samples (S. Artemov and P. Coad).*
13. *(S. Artemov to contact knox@physics.isu.edu (John M. Knox) (R. Causey)*
14. *Contact John Sharpe in regard to dust sampling in JT60 (SHARJP@inel.gov) (T. Tanabe).*
15. *Look at removal techniques and reabsorption (C. Skinner (if funded) and R. Causey)*
16. *In-vessel testing (C. Skinner and P. Coad in JET).*
17. *Looking for new proposals (N. Bekris: plasma arc).*
18. *Effect of metals on thermal oxidation (T. Haasz).*
19. *Electron stimulated desorption (T. Tanabe).*
20. *HeO glow discharge (summary of Cowgill's results) (R. Causey (note: 5mg/hr in TFTR)).*
21. *Clarify BET specific surface area of JET flakes (P. Coad and N. Bekris).*
22. *T retention on clean W at high flux (exchange samples with Garching) (R. Causey and R. Doerner).*
23. *Retention measurements with sprayed W (G. Federici will provide spec. T. Haasz/J. Roth/S. Artimov/R. Causey will do experiments if material available).*
24. *Database of H in W (R. Causey and A. Pisarev).*
25. *Modeling of H retention, as in TMAP (A. Pisarev).*
26. *The effect of O, C layers on W on H retention (J. Roth; T. Haasz simultaneous C/H).*
27. *Diffusion of Be in W as a function of temperature (J. Roth).*
28. *Future TPE work at INEEL, inject Be into plasma, study retention on W substrate (R. Causey).*
29. *Generate H retention and diffusion data in WC (S. Artemov).*

Additional Activities Related to CRP

R. Doerner:	H retention and release in liquid metals
R. Causey:	H/He retention and release in liquid metals H retention in SiC
T. Haasz:	H retention in W under simultaneous H+ He impact
N. Yoshida:	He effect on H retention in PFC materials: W, Mo, V.
T. Tanabe:	Tritium imaging of tokamak tiles
A. Pisarev:	Analysis of tritium transport in liquid metals (Li/Pb, Flibe (?). (Terai experiments)
V. Alimov:	Deuterium retention in W preirradiated with protium and He ions and deuterium retention in B_4C
S. Artemov:	Improve sensitivity of NERD and depth resolution
N. Bekris:	Tritium retention on carbon coated with Be (Russ will provide samples, Paul will analyse Be concentration)
P. Coad:	Tritium content and tritium removal from dust and flakes (with Nicolas) flash heating inside JET (Counsell)
C. Skinner:	Thermal conductivity of blistered tungsten (ion damaged samples)

Appendix 1

First IAEA Research Co-ordination Meeting on
"Tritium Inventory in Fusion Reactors"

4-6 November 2002, IAEA Headquarters, Vienna, Austria

Scientific Secretary: R.E.H. Clark

LIST OF PARTICIPANTS

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Appendix 2

First IAEA Research Co-ordination Meeting on
"Tritium Inventory in Fusion Reactors"

4-6 November 2002, IAEA Headquarters, Vienna, Austria

Scientific Secretary: R.E.H. Clark

MEETING AGENDA

Monday, 4 November **Meeting Room: A-22 10**

09:30-10:00	Meeting Opening: Adoption of Agenda, A. Nichols, R.E.H. Clark	

Session 1: Current research

Chairman: C. Skinner

10:00-10:40	G. Federici	Tritium inventory in the materials of the ITER plasma facing components
10:40-11:10	*Coffee Break*	
11:10-11:50	R. Doerner	Mixed-material, Be/C, surfaces
11:50-12:30	A. Pisarev	Modeling of release of ion implanted hydrogen
12:30-14:00	*Lunch*	

Session 2: Current research continued

Chairman: R. Doerner

14:00-14:40	N. Bekris	Detritiation of complete JET tiles for waste disposal
14:40-15:20	P. Coad	Studies of tritium retention in JET and of de-tritiation
15:20-15:50	*Coffee Break*	
15:50-16:30	C. Skinner	Application of a scanning laser to tritium removal and heat transfer issues in tokamaks
16:30-17:10	R. Causey	Deuterium uptake in co-deposited layers after flash heating in vacuum

Tuesday, 16 November **Meeting Room: A-22 10**

Session 3: Current research continued

Chairman: P. Coad

09:30-10:10	V.Kh. Alimov	Deuterium retention in tungsten carbide and tungsten trioxide
10:00-10:40	*Coffee Break*	
10:40-11:20	A.A. Haasz	Hydrogen retention in tungsten
11:20-12:00	J. Roth	Deuterium retention in tungsten in dependence of the surface conditions
12:00-13:30	*Lunch*	

Session 4: Current research continued

Chairman: R. Causey

13:30-14:10	S. Artemov	Possibilities of the NERD-method for the tritium inventory purpose and present-day activity on its improvement
14:10-14:50	T. Tanabe	Tritium retention on PFM determined by imaging plate technique
14:50-15:20	*Coffee Break*	

Session 5: Summary and discussion of current research

Chairman: V.Kh. Alimov

15:20-17:00	All	Summary of current status, discussion of directions for new research

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Session 6: Future data needs

Chairman: J. Roth

09:30-11:00	All	Discussion of general data needs for fusion reactors
11:00-11:30	*Coffee Break*	
11:30-12:30	All	Formation of summary of data needs
12:30-14:00	*Lunch*	

Session 7: Work plan and conclusion

Chairman: A.A. Haasz

14:00-15:00	All	Formulation of specific needs to be provided by this CRP
15:00-15:30	*Coffee Break*	
15:30-16:30	All	Matching of specific tasks with participants and formulation of meeting conclusions

Appendix 3

Background and Overall Objectives of the CRP

1. Title of CRP: Tritium Inventory in Fusion Reactors

2. Background Situation Analysis:

Current designs for nuclear fusion reactors call for the use of tritium and deuterium as the fuel for the energy producing fusion reactions. The use of tritium (T) must be carefully controlled due to its radioactivity. Its safety aspects will attract intense public scrutiny. An additional problem that did not arise in deuterium (D) fuelled experiments is the issue of fuel economy. Experiments in existing fusion machines indicate that tritium retention, while not a problem for plasma operations, would be unacceptable in a fusion reactor due to fuel economy reasons.

Tritium retention and the control of the tritium inventory depends strongly on the choice of plasma-facing materials (PFM) and their operational conditions (e.g. temperature, flux of impinging particles), plasma edge conditions, and geometry effects. The quantification of the inventory depends on an accurate knowledge of processes for both retention and release of tritium from the machine materials. To date there are still large uncertainties in quantifying the in-vessel tritium inventory of future devices such as ITER. They arise mainly from the plasma edge physics parameters, which are anticipated to strongly affect the erosion, deposition and co-deposition patterns and rates. Moreover, mixed-materials effects, arising from the simultaneous use of different plasma-facing materials introduce significant uncertainties.

The Atomic and Molecular (A+M) subcommittee of the International Fusion Research Council (IFRC) has noted that the problem of tritium inventory is one of the most important areas in atomic physics for the design of a fusion test reactor. The subcommittee recommended in the Summary Report of their meeting of 8-9 May, 2000 that a CRP on tritium retention be initiated as soon as possible.

On 2-3 July, 2001 an Advisory Group Meeting was held at IAEA Headquarters in Vienna to discuss these issues and to advise the Atomic and Molecular (A+M) Data Unit. The main conclusion of the AGM was that this topic is one of the most important facing the successful design of a fusion energy reactor. The AGM strongly advised the A+M Data Unit to initiate a CRP on this topic at the earliest possible time. The AGM suggested a number of specific topics to be addressed in the CRP and suggested a number of possible participants in the CRP.

3. Overall Objectives:

The proposed CRP will focus on gathering and generating new data relevant to the overall inventory of tritium in fusion reactors. Special emphasis will be placed on the interactions

of tritium with plasma facing components and in-vessel materials (e.g. dust). Data on tritium accumulation in and release from plasma-facing components (PFC) will be collected. Methods which could be used for detritiation and to purge the system of tritium will be considered. Data of direct application in the description of tritium transport in other reactor systems (e.g. the blanket) will also be accumulated.

4. Specific Research Objectives (purpose):

The specific purpose of this CRP is to provide a database relevant to the overall tritium inventory in a fusion reactor. This encompasses a number of specific research objectives.

Designs for next generation fusion machines such as ITER employ several plasma facing materials (PFM) selected for their suitability to regions of the vessel with different power and flux characteristics. Among the materials under consideration are carbon based materials, beryllium, tungsten as well as steels and other materials. A complication is the realization that material mixing will be important in devices that use more than one PFM It is often the case that the mixed material has different properties than the pure material (e.g. T-retention, erosion yields, thermal conductivity).

There are a number of important issues for the interaction of tritium with graphites and carbon-based materials. These materials have a number of desirable properties in the construction of tiles for the PFC of a fusion reactor. There are, however, serious concerns regarding the retention of tritium by the carbon-based materials. Major areas to be investigated include the absorption of tritium by neutron-irradiated carbon, the diffusion of tritium in carbon, and the outgassing of tritium from graphite tiles. In addition topics such as laser detritiation of carbon-based tiles should be investigated as a means of releasing tritium. Recent experiments with a scanning laser have shown that the thermal response of codeposits is different from that of manufactured graphite. The experiments also revealed microscopic hot spots due to the granular inhomogeneous morphology of codeposits. It is therefore important to study codeposits to obtain reliable predictions of the temperature rise of codeposits in tokamaks under high heat flux.

In addition to carbon, there are other materials under consideration for PFC design. Beryllium is the primary candidate of the ITER first-wall. Much study has already gone into beryllium, and results are encouraging. The recent successful use of high-Z metal PFC in working tokamaks has also been welcome news in this respect. There are still some important areas for research for Be and tungsten. Issues for Be concern D-retention and release behaviour of C/Be mixed layers, including effects of thermal oxidation on release of hydrogen. Further study must be conducted to better characterise deposition (rates and patterns) of Be films on C as a function of the substrate temperature and relative D+/Be+ fluxes. Further work on W includes investigations on blister cracking under high hydrogen fluxes, thermal response of blisters to heat flux, effect of neutron irradiation on the tritium retention, permeation of tritium as well as tritium retention of tungsten mixed with other materials such as Be and C.

Further research could also be done on steel, especially concerning the permeation issue. There is also some possibility of considering using a liquid metal such as lithium for

continual removal of tritium from the machine. Other types of mixed materials may also be of importance.

These specific issues need to be addressed in order to have some confidence of successfully modeling the total tritium inventory of a fusion reactor machine. This CRP should be able to begin a serious investigation of these problems and make available an extremely useful database on a number of these processes.