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1st IAEA Research Coordination Meeting on

"COLLECTION AND EVALUATION OF REFERENCE THERMO-MECHANICAL PROPERTIES OF FUSION REACTOR PLASMA FACING MATERIALS"

November 29-30, December 1, 1994, Vienna, Austria

SUMMARY REPORT

Prepared by R.A. Langley

March 1995

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

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ABSTRACT

The proceeding and results of the 1st IAEA Research Coordination Meeting on "Collection and Evaluation of Reference Thermo-mechanical Properties of Fusion Reactor Plasma Facing Materials" held on November 29, 30, December 1, 1994 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 status and needs assessment for the physical and thermo-mechanical properties for plasma facing materials and their structural support materials, a summary of data evaluation and presentation, and recommendations regarding future work

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1 INTRODUCTION

The 1st Research Co-ordination Meeting (RCM) on "Collection and Evaluation of Reference Data for Thermo-mechanical Properties of Fusion Reactor Plasma Facing Materials" (November 29- December 1, 1994, IAEA Headquarters, 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 materials properties data 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 collected including that which they have measured,
c) to discuss the necessary requirements for inclusion of data in the database,
d) to establish evaluation criteria for data,
e) to plan for collection and evaluation of data,
f) to suggest additional sources for needed data and;
g) 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 the seven chief scientific investigators of the CRP or their representative, one observer, 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 by the Nuclear Data Section Head, Dr Charlie Dunford, the Meeting proceeded with the following sessions (see Appendix 2: Meeting Agenda):

1) Databases: ITER and JAERI
2) Databases: ORNL, Russian, EC, and JET
3) Discussion of Thermomechanical Properties Data Needs for Present and Planned Fusion Devices
4) Discussion of Collection and Evaluation of Data
5) Meeting Conclusions and Recommendations

A brief account of the presentations presented at the meeting is given in Section 2 The findings of the discussions on the data status and needs are summarized in Section 3 Discussion of the evaluation of data is presented in Section 4 and the meeting conclusions and recommendations are given in Section 5

2 BRIEF MEETING PROCEEDINGS

In the first Meeting session on databases the status of the ITER Materials Properties Handbook (MPH) was described by Mr P Smith He outlined the objectives, organization, contents and gave an overview of the status The handbook contains engineering properties and is to be used for design and input to analysis codes and provides expert evaluation of existing property data for the materials of present interest to ITER, this includes plasma facing materials, vacuum vessel internal and external structural materials This effort is a four party collaboration consisting of EU, JA, RF, and US. The materials which are being included at present are stainless steel 316, Inconel 625, beryllium (sintered and plasma sprayed), Cu-Cr-Zr (composition TBD) and Incoloy 908 A list of prioritized material properties was given. The MPH was discussed and examples given for annealed 316 stainless steel. In conclusion he described the philosophy for inclusion of materials in the MPH stating that the list of materials would be restricted to those materials which were already chosen for use in ITER and others would only be included later if they were chosen at a later date Dr. J. Davis described the MPH in detail Of particular interest to this RCM were the plasma facing materials (PFM) and their support structural materials These are presented on data sheets with the format chosen to satisfy the different requirements of conceptual designers, detail designers, structural analysts, safety engineers and others The data sets are generally incomplete with regard to many of the needed parameters therefore trend curves are presented which are only indications of what the data reviewer thought was reasonable Dr S Suzuki, representing Dr M. Araki (the chief scientific investigator), presented information on a database being collected at JAERI on the Thermo-mechanical Property Data of Plasma Facing Materials The data were divided into two parts a) structural support materials for plasma facing materials and b) plasma facing materials (PFM). Both the structural material list and the PFM list included not only materials of interest to ITER but also materials of interest to present machines, e g JT-60 SU, and DEMO Of particular interest to this CRP are the carbon fiber composites (CFC) materials which are both doped and overlaid with coatings, e g B_4C, and tungsten In addition interest was shown in functional graded materials (FGM) Only a few of the physical properties have been measured for the coating materials and almost no measurements have been made for the thermo-mechanical properties Of particular interest is the effect of neutron irradiation on the property data and erosion data both by sputtering and by plasma disruption. These last two effects are the subjects of other CRP's within the A&M Data Unit

The second session began with a discussion of the ORNL database on carbon materials by Dr. T. Burchell The property data measured for graphites and CFC's was presented for both neutron irradiated and unirradiated materials Irradiation effects were studied for the dose range 2-10 DPA (displacements per atom). An algorithm was presented which was used to predict the change of properties as a function of neutron fluence and temperature This algorithm applied for some of the properties but not for others. Experimental data was used to verify the algorithm where possible Dr V. Barabash, an observer from the ITER center at IPP Garching, presented a talk on the status of materials selection for ITER plasma facing components He pointed out the major tasks for the R&D Expert Group related to PFM and diverter target materials These include determination of the design of high heat flux components and choice of PFM, determination of the design and manufacture methods for high heat flux components, build an integrated testbed and determination of the design and manufacture method for cassette and baffle modules He reviewed studies of disruption lifetime, allowable impurity influx, and sputter lifetime which were done for ITER. He also reviewed studies of tritium inventory in neutron irradiated PFM, and codeposition Three materials are being considered for ITER for PFM at present, these are Be, C, and W. The reference design at present has Be on the first wall in the main plasma chamber, W on the wings, dome and part of the baffle and Be on the dump/vertical targets with an option of C in relatively small area of high power flux on the dump/vertical targets. Dr. P Fenici of ISPRA discussed the Joint Research Centre Data Bank for mechanical and physical properties of materials used in fusion technology. He described the overall problem and the long term objectives and stated that a more comprehensive range of materials should be considered with particular emphasis on the modelling of the effects of neutron damage on the materials properties. He stated that the group at ISPRA is the European Task Leader for the ITER-EDA Materials Handbook and they propose to contribute to the IAEA database with data on stainless steel 316L and 316LN and on SiC/SiC composites A review of the current status and prospects of PFM database collection and evaluation in Russia was given by Dr. I Mazul of the D V Efremov Institute, St Petersburg, Russia He outlined the past results on the initial preparation of a beryllium database and presented a synopsis of their planned activity for 1995 and 1996 He especially emphased the joining of beryllium to copper and the problems inherent in those joints and the effects of neutron irradiation on material properties He also summarized their programs on carbon materials and tungsten and included the effects of joining both carbon materials and tungsten to copper One of the joining approaches was a silver based solder It was pointed out by some of the meeting participants that silver was considered to be extremely bad for inclusion inside the ITER vacuum vessel because of the neutron induced transmutation reaction of silver to cadmium, which has a relatively low sublimation temperature Dr I. Mazul presented some physical property data for recrystallized graphites with titanium included both with and without the addition of boron. The final presentation on databases was made by Dr M Pick of the JET project He presented a review of the operational experience obtained on the use of beryllium and carbon fiber composites (CFC) in the JET device In many instances a beryllium coating was used to cover the CFC tiles in order to both simulate a Be coverage and to condition the vessel For situations where active cooling was required a beryllium covered copper tile (hypervaporton) was developed Experience was gained with brazed joints under high heat flux A program was initiated with Brush Wellman to develop a beryllium based material which could withstand temperature excursions above those at which Be would melt and lose its shape The material consisted of beryllium carbide fiber reenforced beryllium Dr. Pick presented some property data for the various materials made from this reenforced beryllium. In addition he stated that they intend to use no fine grained graphite in the future because of its propensity to crack under thermal shock Finally he presented information on the completely successful decontamination of the JET vacuum vessel prior to the installation of the new diverter, i e. the removal of the deposited beryllium layers and the co-deposited layers of carbon and hydrogen (tritium).

Dr. Javier Botero of the A&M Data Unit gave a presentation explaining AMDIS and ALADDIN Many questions were asked by the participants and a demonstration of the system was made for some of the participants. Suggestions were made for different ways to present the materials properties data as opposed to the standard atomic and molecular data Dr. Botero explained that the ALADDIN system was flexible enough to accommodate all the suggestions put forth and could be incorporated into the system

3 DATA STATUS AND NEEDS

After the presentations of the reports on the material properties databases, the physical and thermomechanical properties data needs for the present and planned fusion devices were discussed The previous lists on physical and thermomechanical material properties which were drawn up at a Consultants' Meeting in December 1990 and reviewed and updated at a subsequent Consultnts' Meeting in September 1993 were discussed and modified slightly. This updated list is shown in Table 1 This list now includes not only bulk materials but also coating and cladding materials. It was noted that some of the materials properties data was not applicable to the coatings and claddings materials and are noted as such in the table Although it was noted that a considerable amount of physical properties data was available for many materials, much of the data for the thermomechanical properties was severely lacking and in many cases the accepted mode of measurement of the thermomechanical property was not really applicable to the new materials being developed, e.g. CFC and FGM. It was also observed that in many cases the thermomechanical data was very dependent on the history of the material, e g heat treatment, whereas the physical properties were much less dependent on the history This presents difficulties in choosing the materials for use as PFM and leads to a dilemma, one needs all the material properties data in order to make an intelligent choice but on the other hand one needs to know the specific material for PFM in order to obtain its thermomechanical properties and since there is only limited data and, at present, insufficient financial resources for extended measurement of material properties, decisions regarding material selection for PFM must be made, based on, at best, insufficient data and, at worst, no data.

The list of materials to be considered and their priority are given in Table 2. This list is derived from the lists previously drawn from the two consultants meetings noted previously Changes were made to the list to reflect information obtained and decisions since those meetings. Many of the materials have been chosen for use in particular machines, e.g ITER, and for particular functions within the machines. In general, material properties for these materials are collected by the particular projects but many of the materials given in Table 2 are not the chosen materials at the present time but are of much interest as backup materials and the various projects are not collecting data on these. The meeting participants felt that the A&M Data Unit should collect and evaluate data on these materials while also collecting and inputing data received from the projects

A discussion was held by the meeting participants to determine possible sources of data This list is given in Table 4. In forming this list the CRP participants agreeded that they would commit to supplying the designated data as part of their work for the CRP

4. EVALUATION OF DATA

The meeting participants discussed the question of inclusion of data and its evaluation in depth Some general suggestions were made, these were

a) at a minimum the data should come from a published article or an institutional report;
b) data from weapons programs should not be presented unless the material can be described in sufficient detail to reproduce the material,
c) manufacturer's data should be used only for support,
d) graded quality should be used for evaluation of data depending on material and property

Whereas much of the data included in other Nuclear Data Section databases can have many data sources for comparison and also theoretical comparisons, the materials data usually has only one data set and usually is not backed up with a theoretical comparison It was suggested that the approach taken by the publication "Manual on the Building of Materials Databases", ASTM Manual Series MNL 19 be reviewed and followed as close as possible. These quality standards as given in the manual are

a) limited use data,
b) qualified data;
c) highly qualified data

The descriptors for each of these is given in Table 3.

5. CONCLUSIONS AND RECOMMENDATIONS

The analysis of the data status on thermomechanical properties of fusion reactor plasma facing materials with regard to the needs of the next step devices, e g. ITER, can be summarized by the following set of conclusions.

1) The physical property database for most commercially available materials of interest to the fusion community is relatively complete and accurate The thermomechanical properties database for these materials varies by material from complete and accurate to incomplete and inaccurate. In some cases the data is even non existent
2) The physical properties are usually independent of the material history but the thermomechanical properties are not and therefore to present quality data requires a detailed knowledge of not only what the material is made from but also the processes which were involved in its production up to the time of the property measurement
3) It was noted that many of the thermomechanical properties can change value significantly with many of the threats imposed by operation within a fusion reactor environment, e g neutron irradiation, and that the property should measured as a function of that variable and presented as such in the database
4) It was strongly suggested that only data be included in the database which had been published in a journal or an institutional report and that manufacturer's data only be used for support
5) That not only plasma facing materials be included but also structural materials for support of plasma facing materials be included in the database
6) That the properties list and the materials list developed at previous meetings and modified at this meeting be used for the formation of the database

SPECIFIC RECOMMENDATIONS TO THE IAEA

1) That the ALADDIN system be used for the materials properties database
2) That materials for structural support of the PFM also be included in the database
3) That Tables 1 and 2 be used for the formulation of the database but that these lists be reviewed at appropriate times so that they can reflect the current needs of the fusion community.
4) That the A&M Data Unit collect and evaluate data for those materials of interest to the fusion community on which the various specific experimental programs are not collecting data.
5) The ITEP Materials Properties Handbook be incooperated into the IAEA ALADDIN system

Appendix 1

IAEA Research Coordination Meeting on
"Collection and Evaluation of Reference Thermo-mechanical
Properties of Fusion Reactor Plasma Facing Materials"

29 November - 1 December 1994, IAEA Headquarters, Vienna, Austria

LIST OF PARTICIPANTS

Dr. P Fenici	European Commission, Institute for Advanced Materials, Materials Performance & Reliabil, 21020 Ispra (Varese), ITALY
Dr. S Suzuki	NBI Heating Laboratory/JAERI, 801-1 Naka-machi, Naka-gun, Ibaraki-ken 311-01, JAPAN
Dr V R Barabash	ITER Garching Joint Work Site, Max-Planck-Institut für Plasma-physik, Boltzmannstrasse 2, D-85748 Garching bei München, GERMANY
Dr I. Mazul	D V Efremov Scientific Research, INST Electrophysical Apparatus, Fusion Materials Laboratory, P O Box 42, St Petersburg 189631, Metallostroi, RUSSIA
Dr. M Pick	JET Joint Undertaking, Abingdon, Oxfordshire OX14 3EA, UNITED KINGDOM
Dr. T.D Burchell	Oak Ridge National Laboratory, Oak Ride, Tennessee 37931-6088, U S A
Dr J. Davis	McDonnell Douglas Corporation, High Energy System, P O Box 516, St Louis, Missouri 63166-0516, U S A
Mr P Smith	ITER JCT, San Diego Joint Work Site, 11025 N Torrey Pines Road, La Jolla, CA 92037, U S A

IAEA

Dr. R.K. Janev	IAEA Atomic and Molecular Data Unit, Wagramerstrasse 5, P O Box 100, A-1400 Vienna, AUSTRIA
Dr C. Dunford	IAEA Nuclear Data Section, Wagramerstrasse 5, P O. Box 100, A-1400 Vienna, AUSTRIA
Dr R. Langley	IAEA Atomic and Molecular Data Unit, Wagramerstrasse 5, P.O Box 100, A-1400 Vienna, AUSTRIA
Dr. J. Botero	IAEA Atomic and Molecular Data Unit, Wagramerstrasse 5, P O Box 100, A-1400 Vienna, AUSTRIA

Appendix 2

IAEA Research Coordination Meeting on
"Collection and Evaluation of Reference Thermo-mechanical
Properties of Fusion Reactor Plasma Facing Materials"

29 November - 1 December 1994, IAEA Headquarters, Vienna, Austria

MEETING AGENDA

Tuesday, November 29

10:00 - 10:30	Opening Address Adoption of Agenda	**Meeting Room: A11-71**
Session 1:	Databases. ITER and JAERI	
	Chairman: V. Barabash	
10:30 - 11:00:	Smith:	Status of ITER Material Properties Handbook and Development of PFC Datapages
11:00 - 11:30.	Coffee Break	
11:30 - 12:00.	Davis	Structure of ITER Material Properties Handbook and Development of PFC Datapages
12:00 - 12:30:	Suzuki.	Thermomechanical Properties Data of Plasma Facing Materials at JAERI
12:30 - 14:00.	Lunch	
Session 2.	Databases, ORNL, Russian, EC	
	Chairman: Smith	
14:00 - 14:30.	Burchell	Radiation Damage in Carbon Materials - An Overview of ORNL Data
14:30 - 15:00.	Barabash:	Status of Materials Selection for ITER Plasma Facing Components
15:00 - 15:30;	Fenici:	JRC Data Bank for European Fusion Programme
15:30 - 16:00:	Coffee Break	
16:00 - 16:30.	Mazul:	Current Status and Prospects of PFM Data Base Collection and Evaluation in Russia
16:30 - 17:00	Discussion	

Wednesday, November 30 **Meeting Room: A11-71**

Session 3:	Collection of Thermomechanical Properties of Fusion Reactor Plasma Facing Materials	
	Chairman J Davis	
09:30 - 10.00	**Discussion:** Physical and Thermomechanical Properties Data Needs for Present and Planned Fusion Devices	
10.00 - 10.30.	Coffee Break	
10:30 - 12:30	**Discussion:** Continuation	
12 30 - 14.00	Lunch	
Session 4	Collection and Evaluation of Data	
14 00 - 14 30	Botero	A+M Data Unit ALADDIN Database
14 30 - 15 00	**Discussion:** Collection of Data and Evaluation Procedures	
15 00 - 15 45:	Pick	Properties of Plasma Facing Materials used at JET
15 45 - 16 15	Coffee Break	
16 15 - 17 30.	**Discussion:**	Continuation
19:00 -	**DINNER at Heuriger / Grinzing**	

Thursday, December 1 **Meeting Room: A11-71**

	Chairman R Langley	
09 30 - 10 00	**Discussion:** Evaluation of Data	
10:00 - 10 30:	Coffee break	
10.30 - 12.30	**Discussion:** continued	
12.30 - 14 00	Lunch	
14:00 - 15 00	**Discussion:** continued	
15.00 - 17:00	Preparation of Final Report	
17 00 -	**Adjourn of the Meeting**	

Table 1: Material Properties

Common Information	Coating & Cladding	Structural
Description	x	x
Production history	x	x
Baseline Physical Properties		
Melting Temperature	x	x
Vapor Pressure (T)	x	
Heat of Fusion	x	
Heat of Vaporization	x	
Thermal Conductivity (T)	x	x
Density (T)	x	x
Coeft. of Thermal Expansion (T)	x	x
Electrical Resistivity (T)	x	x
Viscosity (T)	x	
Surface Tension	x	
Baseline Mechanical Properties		
Elastic Modulus (T)		x
Poison Ratio (T)		x
Ultimate Strength (T)		x
Uniform Elongation (T)		x
Total Elongation (T)		x
Reduction of Area (T)		x
Creep (T,G)		x
Fatigue (T,G)		x
Fracture Toughness (T)		x
Stress/Strain (@3T)		x
Fatigue Crack Growth (T)		x

(T) = as a function of Temperature

Table 1: (Contd.)

Radiation Effects (dpa, dpa/t,T)	**Structural**
Physical Properties	
Thermal Conductivity	x
Specific Heat	x
Coefficient of Thermal Expansion	x
Electrical Resistivity	x
Swelling / Density	x
Mechanical Properties	
Ultimate Strength	x
Yield Strength	x
Uniform Elongation	x
Total Elongation	x
Reduction of Area	x
Creep	x
Fatigue	x
Fracture Toughness	x
Residual Activity	x
Impact Toughness (DBTT) (W,Mo,V, Ferritic Steels)	x
Stress/Strain Curve	x
Corrosion / Chemical Effects	
Compatibility @ H_2O & other Coolants	x
Joints (dissimilar metals, e g Be/Cu,W/Cu, C/Cu)	x

dpa = displacements per atom
dpalt = displacements per atom per second
DBTT = ductile to brittle transition temperature

Table 2: Priorities of Materials Data Generation and Evaluation

Materials	
I. Plasma Facing Materials and In Vessel Structural Materials	
A. Low-Z Materials	
Be, CFC (+ Doped B, Si), Graphite	1
PG, C + Ti	2
C + B, SiC (Fibers), BeB	3
B High-Z Materials	
W	1
Mo, Nb	3
C Medium-Z Materials	
SS (316 LN Annealed), V-4Cr - 4Ti, Cu, Cr, Zr, Dispersion Strengthened Cu	1
Ferritic Steel, Inconel 625, Cu Be Ni	3
D. Advanced Materials	
Liquid Materials	2
II. Interface	
Brazes (Thixotropic)	
FGM (W ↔ Cu, CFC ↔ Cu)	2

CFC = carbon fiber composits
PG = pyrolytic graphite
FGM = Fuctionally Graded Material

Table 3: Suggested Data Quality Standards

Limited Use Data

1. Data are traceable to an individual, organization, or reference (both the data "Source" and "Digitizer" are identified)
2. After independent review, an identifiable authority approved the digitized version for inclusion in the database
3. Basis of the data is identified
   - a experimental measurements
   - b. derived data - specify theoretical basis and data
   - c estimated data
4. Type of data is indicated
   - a original point values
   - b. analyzed data
     - b1 standard fit - specify fit and data
     - b2 fit unknown

Qualified Data

1. Number of measurements and data sets stated
2. Nominal confidence limits estimated (i e , 0.90, 0 95, *n*)
3. Traceable materials specification assures reproducibility
4. Testing methods are specified and conform to a standard
5. Data are traceable to a testing/data generating organization or individual

Highly Qualified Data

1. High confidence limits determined (i e , 0 99, 0 95, *n*)
2. Perform minimum number of individual measurements
   - a. from minimum number of sample lots
   - b from multiple suppliers (if appropriate)
3. Data determined for each variable (i e , form, processing condition, size, and so forth) that significantly affects property
4. Independent testing performed (other than the producer and preferably by several testing labs)
5. A second, independent evaluation (evaluator identified)
6. All features explainable
7. Producer(s) identified

Taken from ASTM Manual Series MNL 19 (1993) 21.

Table 4: Potential Sources of Material Properties Data

Materials	Data Source Institution (Contact Person)
Be	ORNL (Burchell) Efremov Research Center, RF (Mazul)
CFC	Efremov Research Center, RF (Mazul) JAERI (Akıba, Saito) ORNL (Burchell)
Graphite	ORNL (Burchell) JAERI (Etoh) Efremov Research Center, RF (Mazul)
Pyrolytic Graphite	ORNL (Burchell) KFK Julıch (Theıle)
C + Ti, B	Efremov Research Center, RF (Mazul)
SiC	Inst Adv Mater (Fenıci) ORNL (Sneed)
W, Mo, Nb	Efremov Research Center, RF (Mazul)
SS, V-4Cr-4Ti, CuCrZr	Inst. Adv Mater (Fenici) ORNL (Sneed)
Ferritic Steel	KFK Jülıch (Ehrlich) JAERI (Hishinuma)
Galium	Efremov Research Center, RF (Mazul)
Brazes	Sandia Natıonal Labs (Ulrıckson) JET (Matera)
Cu/Be	Efremov Research Center, RF (Mazul)
W/Cu, CFC/Cu (FGM)	JET (Matera) JAERI (Akıba)
SS316, Inconel 625, Be, Cu-Cr-Zr, Incoloy 908	ITER (Davis, Material Properties Handbook)