International Atom'c Energy Agency

INDC(NDS)-226/MA

INDC **INTERNATIONAL NUCLEAR DATA COMMITTEE**

IAEA ADVISORY GROUP MEETING ON "PARTICLE-SURFACE INTERACTION DATA FOR FUSION"

Vienna, 19-21 April 1989

SUMMARY REPORT

Prepared by

R.K. Janev and A. Miyahara

August 1989

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

INDC(NDS)-226/MA

IAEA ADVISORY GROUP MEETING ON

"PARTICLE-SURFACE INTERACTION DATA FOR FUSION"

Vienna, 19-21 April 1989

SUMMARY REPORT

Prepared by

R.K. Janev and A. Miyahara

August 1989

Abstract

The present Report contains the Summary of the IAEA Advisory Group Meeting on "Particle-Surface Interaction Data for Fusion" which was organized by the IAEA Atomic and Molecular Data Unit and held on April 19-21, 1989, in Vienna, Austria. The Meeting Proceeding is briefly described. The Working Group Reports and the Meeting Conclusions and Recommendations are also included in this Summary Report.

Reproduced by the IAEA in Austria
October 1989

89-04756

Table of Contents

1. INTRODUCTION

Following a recommendation by the Subcommittee on Atomic and Molecular Data for Fusion of the International Fusion Research Council (IFRC Subcommittee), given at its 5th Meeting (October 7-8, 1988), the IAEA Atomic and Molecular (A+M) Data Unit convened an Advisory Group Meeting on "Particle-Surface Interaction Data for Fusion" on April 19-21 April 1989, at the IAEA Headquarters in Vienna.

The Meeting objectives were:

1) to review the data status and needs in the area of plasma-surface interaction (PSI) processes in view of the ongoing fusion research on the largest operating tokamaks (JET, TFTR, JT-60, DIII-D, T-15, Tore Supra, ASDEX), as well as with regard to the ITER conceptual design needs for PSI data;
2) to define the scope and prepare recommendations regarding the IAEA A+M Data Unit immediate and long-term activities in the fields of compilation, evaluation and generation of PSI data for the present and next-generation fusion devices, and
3) to identify sets of existing data for certain classes of PSI processes which have a sufficient level of completness and accuracy for storage in the IAEA PSI database, and their dissemination to fusion laboratories.

The motivations for organization of this Advisory Group Meeting were to provide a forum for discussion of the status and the most urgent PSI data needs for the current fusion experiments and for the conceptual design of ITER, to investigate the possibilities for co-ordination and enhancement of the efforts for PSI data compilation, evaluation and generation through an efficient assistance of the IAEA A+M Data Unit, and to obtain specific recommendations regarding the content and format of the PSI recommended database for fusion.

The importance of undertaking the above actions on an international level has become clear during the recent experiments on the large operating tokamaks and has been strongly emphasized by the ITER design effort. The plasma-wall interaction phenomena seems to impose the most stringent requirements on the design options of reactor-grade fusion devices, and set the practical limits on the achievable power level. These phenomena have also a strong impact on the operation scenario and are critical to the overall plasma and reactor performance. The lifetime of the first wall and plasma facing components, the plasma purity, the design of an efficient power and particle exhaust system, are all influenced by a wide spectrum of plasma-material interaction processes. Establishing a credible database for these processes for the prospective fusion relevant materials is, therefore, essential both for understanding the performances and operational limits of present tokamak experiments, and for a successful design of the next-step devices.

One of the principal tasks of the IAEA Atomic and Molecular Data Unit within the Agency's Fusion Programme is to create an international base of recommended PSI data for fusion, in close collaboration with the national Atomic Data Centres for Fusion, experimental laboratories producing such data and with the fusion research laboratories, using such data. The IAEA A+M Data Unit has already published a "Data Compendium for Plasma-Surface Interactions" (R. Langley et al, "Nuclear Fusion", Special Issue, 1984), which proved to be a very useful data source for the PSI processes.

The developments in the field since 1984, both in terms of accumulated knowledge and data on PSI processes and in terms of the expanded PSI data needs in the fusion research, have led the IAEA IFRC Subcommittee on A+M Data for Fusion to suggest the organization of this Advisory Group Meeting, with the objectives mentioned at the beginning of the Section. A Co-ordination Group, consisting of Drs. R. Behrisch, W.B. Gauster, M.F.A. Harrison, R.K. Janev and A. Miyhara, has been nominated by the IFRC Subcommittee (with A. Miyahara acting as a liaison officer) to co-ordinate the PSI data activities of the IAEA A+M Data Unit and the relations between plasma and PSI physics communities in the data area. This Group, together with Dr. J. Bohdansky, provided assistance to the Agency in the preparations of the Advisory Group Meeting.

The Meeting was attended by 30 participants (27 from nine IAEA Member States and 3 from the Commission of European Communities), the list of participants being given in Appendix 1. The Meeting Programme covered all important particle-surface interaction processes, including some topics from the area of the global material response to the plasma-material interaction. The details of the scientific programme are given in Appendix 2. For each of the eight scientific topics included in the programme, a subject co-ordinator has been designated (by the IFRC Subcommittee Co-ordination Group) prior to the Meeting with the task to prepare, in consultation with the other prospective Meeting participants contributing to that topic, a coherent coverage and presentation of the pertinent material, as well as a general review of the subject. The preparative work of the subject co-ordinators has been instrumental for the efficient work of the Meeting.

2. MEETING PROCEEDINGS

The Advisory Group Meeting was opened by Prof. M. Zifferero, Deputy Director General of the IAEA Department of Research and Isotopes. The work of the Meeting then proceeded in eight scientific sections and three working group meetings. The Meeting Agenda is given in Appendix 3.

The sections of the Meeting were as follows (the names of corresponding co-ordinators are also indicated):

1) General overview of the data status and requirements for PSI processes (R. Behrisch);
2) Ion backscattering (W. Eckstein);
3) Particle impact induced electron emission (E.W. Thomas);
4) Trapping, detrapping and release of implanted and co-deposited ions (K. Wilson, R.J. Bastasz);
5) Physical sputtering (J. Bohdansky);
6) Chemical sputtering, radiation enhanced sublimation, surface segregation (J. Roth);
7) Arcing, pulse heating, effects of disruptions and run-away electrons (J. Whitley);
8) Particle induced desorption (E. Taglauer);

9a) Working group meeting on particle-impact induced effects (Organizers: R. Behrisch, J. Bohdansky and M.F.A. Harrison);

9b) Working group meeting on thermal effects and material response (Organizers: W. Gauster, J. Whitley, H. Wolff and H. Bolt);

9c) Working group meeting on PSI data compilation, evaluation and recommendation procedures, and data storage and exchange (Organizers: E.W. Thomas, R.K. Janev, A. Miyahara and W. Eckstein);

10) Adoption of meeting conclusions and recommendations.

The first section of the Meeting was intended to provide a general overview of the PSI data status and to address more specifically the PSI data requirements in the current research on the medium and large size fusion machines, and for the design of next-step devices, in particular

ITER. Dr. R. Behrisch presented an extensive overview on the particle induced surface phenomena and the associated PSI physics research, including examples from the most recent experimental work on the operating large tokamaks. A clear, general picture on the data status, and data needs and on the current understanding of PSI processes has emerged from this talk. Within the current design concept of ITER, Dr. M.F.A. Harrison presented an in-depth analysis of the role of PSI processes in defining the machine power level, the operational limits of the power and particle exhaust system for ITER, the impact of PSI processes on the options for the impurity control, as well as for the heating and current drive systems, etc. The role of specific PSI processes, as well as the associated data requirements, were individually analyzed from the viewpoint of erosion of prospective ITER candidate first wall materials and plasma facing components, impurity generation and ITER edge plasma cooling, ITER divertor operation, impurity and hydrogen recycling, and some other aspects influencing the ITER performance, design options, and physics and technology R&D programmes. Within this section, Dr. P. Stangeby presented an extended talk on the PSI data needs for interpretation of recent experimental data from the large tokamaks (mainly JET and TFTR), and for modelling the boundary plasmas behaviour and the dynamics of the plasmas-wall coupling. The importance of establishing the effect of surface roughness on the yield enhancement of physical sputtering at high angles of ion incidence, and of establishing the energy distribution of physically sputtered neutrals, particularly the high energy tail, was stressed in this talk. Prof. A. Miyahara provided a talk on the work being done and/or being pursued by several Atomic Data Centres for Fusion and fusion laboratories on the compilation and evaluation of PSI data for fusion. He provided specific details on the procedures and mechanics of this work within the Nagoya Research Information Centre, as well as on the PSI database available in the centre.

Within the section on Ion Backscattering, Dr. W. Eckstein presented a review on the progress being done in this area of research since 1984. Both the experimental and theoretical work was covered. Particular attention was paid to the ion backscattering data produced by the recent, highly sophisticated version of the TRIM code. Dr. D. Ruzic presented a very interesting contribution to the area of numerical backscattering simulations by applying the theory of fractals in conjunction with the TRIM code to describe the effects of surface roughness on ion backscattering (as well as on sputtering).

In the section on particle-induced electron emission, Dr. E.W. Thomas presented a general overview on the recent progress in the field, with emphasis on the electron induced electron ejection. The kinetic secondary electron emission from solids was covered in the presentation by Dr. J. Schou, while the data and recent research on electron emission processes, induced by heavy-particle (including multiply charged ions) collisions with surfaces, were presented by Dr. H. Winter.

The section on trapping, detrapping and release of implanted and co-deposited ions was focused on carbon and graphite first wall materials. Two review talks were presented within this section (Drs. R.J. Bastasz and T. Tanabe), which covered all aspects of these complex processes for implanted/co-deposited hydrogen in carbon, graphite and berillium. These reviews, together with the contributions by Drs. K. Morita and Y. Hirooka, devoted to the hydrogen depth profiles in graphite and to hydrogen plasma pumping properties of graphite, respectively, provided extremely valuable information relevant not only for the hydrogen recucling in the plasma edge, but also for the enhanced confinement regimes in tokamaks (such as the "supershot" regime in TFTR) and for tritium inventory in the first wall material. Dr. V. Philipps presented an exhaustive information on the dynamics and characteristics of oxygen and helium retention in carbon, which is of direct relevance to reactors. There is an oxygen cycle at the plasma-carbon wall boundary, with CO playing the role of a coupling intermediate.

The section on physical sputtering highlighted some recent developments in the field, and most of the presentations were again concentrated on carbon, graphite and carbon-containing materials. Dr. J. Bohdansky presented a broad overview of the recent research in this area and on the data availability for fusion relevant materials. This talk also stressed the importance of information on differential yields for coupling the PSI data with the plasma boundary modelling codes. The important question of the conditions under which a unity sputtering yield is produced on graphite by carbon ion bombardment was discussed in detail by Dr. J. Roth. Dr. E. Vietzke presented a very extensive experimental information on the energy distribution of sputtered particles from graphite and carbides under argon ion bombardment. The results are consitent with the Thompson distribution. Dr. M.I. Guseva provided arguments and experimental evidence that an appropriate pre-treatment of the fusion reactor structural materials may lead to a significant reduction of the sputtering yield. (Such favourable structure changes for some materials may take place during the reactor operation). Dr. Yu.V. Martynenko, presented a theoretical investigation of the "inelastic sputtering" of semi-conducting and insulating materials under multicharged ion bombardment. The inelastic sputtering is quadratically dependent on the ionic charge, and may enhance the sputtering yield by 4-5 orders of magnitude. Drs. A.A. Haasz and C.H. Wu presented important information on the dependence of sputtering yield on the angle of incidence of projectile ions. Data for hydrogen, helium, carbon and oxygen ions on carbon and graphite surfaces were provided, including the parametric dependences (incident ion energy, target temperature) of the incidence angle dependent sputtering yield. Reduction of the incidence angle (below 20-30^{o}) greatly reduces the sputtering yield. Dr. W. Eckstein reported on the recent improvements in the structure of TRIM code, which significantly enhance its capabilities for description of a wide spectrum of processes taking place during the particle penetration in solids.

The section on chemical sputtering, radiation enhanced sublimation and surface segregation brought a wealth of new information on the erosion effects for fusion relevant materials induced by plasma-surface interactions. The subject of chemical erosion of low-Z materials was extensively reviewed by Dr. E. Vietzke. The erosion from carbon, graphite and boron-doped graphite by both high and low-energy light ion impact was analyzed in detail (dependence on the ion impact energy, target temperature, target structure, etc). The release of hydrocarbons (mechanisms, relative and absolute yields, parametric dependences), as well as the oxygen reactions on graphite were also discussed in depth. Dr. J. Roth presented a review talk on the radiation enhanced sublimation of graphite, covering the recent experimental results, the results of model calculations, and providing a semi-empirical analytic expression for estimation of the radiation enhanced sublimation yield. At target temperatures above some threshold value ($\approx$ 1200 K for graphite), this process appears to be the dominant erosion mechanism (up to the threshold for thermal sublimation). Dr. V. Philipps presented further information about this process for carbon materials, including also a model for the process, based on the formation and thermal diffusion of vacancy-interstitial (Frenkel) pairs in the target material. Dr. A. Haasz provided an extensive review on the synergistic effects in chemical sputtering of graphite. He highlighted the results obtained under controlled conditions in laboratory experiments with simultaneous surface bombardment by: thermal H^o and energetic H^+, thermal H^o and energetic Ar^+, thermal O_2 and energetic Ar^+, and both $H^{(+)}$ and e^- energetic. The formation of light and heavy hydrocarbons and carbon oxides under such conditions was discussed, including a model for methane formation due to combined H^o(thermal) and H^+ (energetic) bombardment. A very extensive and systematic information on the release of hydrocarbons by chemical sputtering of carbon materials was provided by Dr. R. Yamada. The recent experimental data on hydrocarbon production rates were analyzed in detail from the point of view of their dependence on the projectile and target parameters and their chemical character, as well as from the point of view of the present theoretical understanding of the underlying physical and chemical processes. Some problems in the understanding of the C_2-hydrocarbon sputtering yields were outlined. The complicated chemistry taking place on carbon and graphite solid surfaces during the ion bombardment was analyzed in detail by Dr. T. Tanabe from the point of view of plasma and surface thermodynamics and the kinetics of chemical reactions. A comprehensive review on the plasma-surface interaction research being done and in progress at the PISCES-A&B facilities at UCLA was presented by Dr. Y. Hirooka. This experimental work is unique in that plasma-surface interaction processes are studied under conditions which are close to those existing in large tokamak (ITER-like) experiments (high fluxes and long pulses). The results for the following research subjects were presented: chemical erosion of selected graphite materials and carbon compounds (including boron-doped graphite, SiC-impregnated graphite and "tokamakium"-tokamak redeposited carbon from TFTR), effects of redeposition on the net erosion yield, radiation enhanced sublimation of graphite, hydrocarbon formation during recycliing, and the surface topograhy effects on particle recycling. Within this section, Dr. B. Terreault provided several enlightening comments regarding the coupling of chemical erosion with the edge plasma physics.

The section on particle induced desorption began with a review by Dr. E. Taglauer on the recent data in this PSI area. Dr. K. Morita provided a set of new data on the partial desorption cross sections for monolayer (Cr, Au, Ag) impurities on various solid surfaces (including graphite, silicon, nickel) induced by H_2^+ and Ar^+ impact. Dr. E. Vietzke presented data on carbon monoxide desorption from a carbon surface induced by proton and atomic hydrogen impact, while Dr. J. Schou discussed the electronic sputtering from insulations, including both the theoretical aspect and experimental data.

One section of the Meeting was devoted to the fusion material response, properties and phenomena induced by high heat fluxes, discharge disruptions, energetic run-away electrons and unipolar arcs. A general introduction to this area of plasma-material interaction problems was given by Dr. W. Gauster, who also provided detailed information on the thermal loads in the present-day and next-generation (reactor level) fusion devices. The material response and the phenomena induced by high heat fluxes from the plasma were reviewed by Dr. J.B. Whitley. Experimental results and computer code simulations were presented for the vaporization and melting of tokamak materials under intense energy deposition (occuring during plasma disruptions), as well as results on the effects of run-away electrons (generated during a disruption) on material properties (erosion, cracking, etc). The results on the thermomechanical response phenomena of prospective fusion reactor materials to thermal stresses were also reviewed. The material response phenomena to off-normal heat fluxes (disruptions and run-away electrons) were also discussed in detail by Dr. H. Bolt in the context of the NET/ITER design studies. A material ranking, with respect to their response to off-normal events, was undertaken for various plasma facing components (limiters, divertor plates). Dr. J. Linke presented extensive experimental results from the high heat flux testing of several types of first-wall candidate materials (metallic, ceramic and graphitic materials), by using several testing facilities available at KFA, Jülich. Qualitative and quantitative information on the effects of disruptions on metallic surfaces was also provided by Dr. P. Schiller, using simulated plasma disruptions.

The knowledge of thermophysical and thermomechanical response of materials for plasma facing components to highly intense thermal and particle fluxes from the plasma is not sufficient to characterize their behaviour under realistic reactor conditions. The high heat flux induced phenomena in fusion reactor materials are coupled with the effects of the intense neutron irradiation (swelling, embrittlement, hardening, physical properties degradation etc). Dr. J. Whitley presented some comments and results on the effects of this coupling, and outlined several ongoing and planned programs for neutron irradiation material studies.

The database and data needs for material erosion due to arcing was reviewed by Dr. H. Wolff. In present-day tokamaks, with extensive wall cleaning and use of carbon (or carbonized materials), arcing is a rare event and does not contribute considerably to the total wall erosion. Under the high thermal load conditions, expected in the next-generation devices, this situation may be changed due to elevated temperatures of the plasma facing components.

On the third day, the Meeting participants split into three Working Groups to summarize the results of the meeting presentations and discussions, and to formulate the Meeting conclusions regarding the data status and needs for PSI processes for fusion, and recommendations regarding the near- and long-term IAEA activity in the PSI data area. The reports of these Working Groups are given in the next section.

3. WORKING GROUP REPORTS

3.1. Working Group Report on Particle-Impact Induced Effects

The effects of the particle-surface interaction processes in a fusion plasma confinement device define the lifetime of plasma facing materials and components, the content and amount of impurity influx into the plasma, the radiation properties of the plasma edge, the efficiency of power and particle exhaust system, and have a strong impact on the plasma energy balance. The plasma-wall coupling, established through these processes, presents a boundary condition for the main plasma dynamics, provides strong source/sink terms for plasma particle, momentum and energy fluid equations, and defines most of the properties of the plasma edge. Indirectly, through the plasma edge conditions, this coupling affects the global plasma energy confinement time, influences the recently observed enhanced confinement regimes in tokamaks, and may serve as a tool for control of plasma parameters at the edge.

The effects of particle-surface interaction processes were discussed in six sections:

- Ion backscattering,
- Particle induced electron emission,
- Particle induced desorption,
- Trapping, detrapping and release of implanted/co-deposited ions,
- Physical sputtering,
- Chemical sputtering and radiation enhanced sublimation.

In all of these sections, comprehensive reviews were presented on the corresponding subject, covering the available database, the main directions in the ongoing research (illustrated by representative results), and identifying important gaps in our knowledge or/and in the database. A large amount of new data were reported by the participants in each of the sections, reflecting the recent progress in all of the research areas discussed, but also the existing research problems in the experimental and theoretical work, and in our understanding of the basic physical mechanisms of considered processes. The review presentations and individuals reports have shown that the database for particle induced effects has significantly expanded during recent several years (particularly in certain areas, such as chemical sputtering, particle induced release, radiation enhanced sublimation, synergistic effects in sputtering), both in terms of fusion relevant materials and in terms of broadening the projectile-target parameters space. Advancements in the data generation for realistic tokamak conditions and materials has also been apparent in the presentations (inclusion of the surface roughness in backscattering and physical sputtering, chemical sputtering yield dependence on angle of incidence, studies of synergistic effects, experiments with plasma conditions simulators-PISCES, concentration on graphite and carbon-containing materials, etc). It was stressed during the meeting discussions that, while the work on the quantitative characterization of particle-impact induced effects under well defined laboratory experimental conditions should continue for a broad class of materials of fusion interest, (for reasons of advancing our basic understanding of PSI processes), generation of data under conditions similar to those in fusion devices and/or on material samples already exposed to a fusion plasma environment, should be pursued with priority. The surface state (degree of roughness, amount of deposited material) and structure of the material may undergo significant changes during the discharge pulse (several hundreds of seconds for ITER, for instance), which may cause drastic changes in the characteristics of the particle-surface processes. The surface and material-structure changes during the long-pulse tokamak discharge may well have some positive effects on the results of PSI processes, e.g. reduction of sputtering yields (M. Guseva).

For the purpose of inclusion of the particle-surface interaction effects in plasma modelling codes, differential characteristics of released (or back-scattered) particles are required. The information on these characteristics is still inadequate, even for well controlled surface conditions. For edge plasma modelling, low-energy data for physical sputtering and temperature dependent data for chemical sputtering, and particle release by other mechanisms, is required for many plasma facing candidate materials. Radiation enhanced sublimation is apparently the most powerful mechanism at elevated target temeratures and its characterization is still incomplete.
Semi-empirical formulae, although in many cases without a well understood physical basis, may be very useful in providing information for many of the gaps in the database for particle-impact induced processes. The systematics of hydrocarbon release from various types of graphite and carbonized matterials, as well as the understanding of underlying mechanisms, need further investigation.

The exchange of information and the discussions at the Meeting where useful for assessment of the status of the existing data and, especially, for identifying the gaps in the database with respect to the design of next-step fusion devices (ITER, in particular). Co-ordination of the PSI research activities and further exchange of information would be very useful from the point of view of meeting the data needs of fusion research and design work, within the required time-scale. Closer co-operation between the PSI and fusion research communities would also be beneficial for better definitions of the required material properties, material options, for reduction of particle and thermal loads on the materials (by e.g. choice of proper geometry, field configuration, SOL-surface distances, reduction of off-normal events, etc). The IAEA could provide an adequate framework for such co-ordinations and information exchange.

3.2. Working Group Report on Thermal Effects and Material Response

(Prepared by W.B. Gauster and J.B. Whitley)

The performance of plasma facing components (PFC's) in magnetic fusion devices will be dictated to a large degree by their response to the thermal loads generated by interactions with the plasma. Since these interior components are directly coupled to the plasma, their successful performance is mandatory to maintain the plasma at the required purity levels. Their location inside the vacuum boundary means that replacement or repair requires entering the torus, an activity which is difficult, time consuming and costly. The thermal performance of plasma facing components is one of the critical technologies that limits the device's ultimate power level and availability and as such is a technology that will play an important role in determining the economic viability of fusion as an energy producing source.

The thermal loads on PFC's are commonly divided into "normal" loads and "off-normal" loads. Normal loads are the power fluxes incident on the components during a typical discharge. These loads range from the order of 0.05 MW/m^2 for first wall panels up to 10-30 MW/m^2 for divertor plates. Pulse lengths will be long, maybe hundreds or even thousands of seconds, and the components will reach thermal equilibrium during the pulse. In many cases, active cooling with a flowing coolant (typically water, helium, or a molten salt) will be required to remove the incident energy. Measurements of the power flow in the plasma edge of existing tokamaks are used to validate and calibrate edge models. At this time, our ability to predict power flows seems reasonably good, with a relatively modest uncertainty involved as we scale these calculations up to an ITER size machine.

Off-normal events are characterized as those events that deliver power loads greater than twice the normal loads for any time period. Examples of off-normal events are edge localized modes (ELM's), plasma disruptions, and runaway electrons. These events are usually random, unanticipated, and are caused by either a hardware failure or by unexplained plasma processes. ELM's are often observed during H-mode operation and present themselves as either frequent, low intensity events or less frequent, more severe thermal events.

Disruptions and runaway electrons are much more serious excursions from normal discharge conditions. Disruptions deliver thermal loads of the order of 10 MJ/m^2 over times of about 0.1 ms and also generate severe oddy currents in components which produce large mechanical forces. Runaway electrons can be generated during low density plasma events, during RF heating, and during disruptions. These electrons can be accelerated up to energies greater than 100 MeV and are very intense beams. Models to predict the occurrance and thermal loads from these events are very crude and the scaling laws to predict ITER conditions are very uncertain. It is clear that the occurrance of these off-normal events must be minimized and that the phenomena must receive much more attention in the future if reliable machine operation is expected.

Once the thermal environment has been defined, the next step is to predict the component response to this environement. The desired response is to have the component absorb and transfer the incident energy to the coolant for the total number of machine cycles while not contaminating or otherwise negatively impacting the plasma. In reality, the component can fail by, for example, evaporation or sublimation, by thermal shock causing fracture, by thermal fatigue generated cracking, or by exceeding the coolant heat transfer limits. Component fabrication often locks in residual stresses that interact with the operational stresses to cause fracture. Finite element modeling is used to predict these temperature and stress states, but a great deal more data on the behavior of components under these conditions must be generated and work on the development of limetime codes needs to be emphasized.

The final environmental effect that will start playing a critical role in ITER components is that of neutron damage. ITER and other power producing devices will produce sufficient fluxes of high energy neutrons to substantially alter the material properties of all PFC's. These changes include reduction in thermal conductivity, an increase in strength, a reduction in density, and volume changes densification or swelling). These effects will alter both the components stress state and surface temperature and will most likely shorten its expected service life. Data on these effects are just staring to be generated and will require substantial investments in reactor space for irradiation and in the development of specialized test equipment to determine the response of these irradiated components to the pulsed thermal environment.

The Working Group recommends the scheduling of an IAEA Specialist' Meeting in 1990 on the topic of "Thermal Response of Plasma-Facing Materials and Components". The choice of this title is motivated by several factors. It combines the phenomenology of plasma-surface interaction (PSI) processes with the important engineering considerations for plasma-facing components. This step is possible now because of the progress made in the last several years in the understanding of plasma-materials interaction processes and is timely because of the needs posed by the engineering design requirements of high heat flux components for ITER. In fact, it can be argued that the problems relating to impurity control engineering may be the dominant design concerns for ITER and similar devices.

At the same time, the Working Group held the view that the Specialists' Meeting and other IAEA activities in the area of PSI data for fusion should be formulated somewhat more broadly and should not address only ITER requirements. Such a perspective would in the long run even be beneficial to the ITER process.

An evaluation of the data should include its scope and quality. Areas of interest include PSI phenomena, materials response, as well as the characterization of materials (thermal shock effects, fracture toughness, thermal and physical properties) with the aim of providing data in a form that is useful for design engineers. In considering material response, both normal operation conditions and off-normal events (disruptions, run-away electrons) should be included. It is recognized that off-normal events can be the "drivers" for design, and that ultimately control and mitigation of these phenomena will be necessary to arrive at acceptable solutions.

Tasks at the meeting would include:

- discussion of data needs and the establishment of priorities;
- discussion of data scope and quality;
- recommendations on data storage and retrieval in terms of scope, quality and format.

The ultimate aim of the process to be begun at the Specialists' Meeting is a <u>coordination of research activities</u>, with current emphasis on the requirements of ITER, but also with a balanced prospective on other, especially longer range, needs.

3.3. Working Group Report on PSI Data Compilation, Evaluation, Recommendation Procedures, Data Storage, and Exchange

(Prepared by E.W. Thomas)

The data necessary for understanding Plasma Surface Interactions falls into three distinct groups. First there are processes which are well defined where data consists of "coefficients" related to the probability of an event. These are akin to collision cross sections or rate coefficients, represent the traditional research areas of particle-solid interactions and historically have been studied rather independently of the various fusion research efforts. Substantial bodies of data are available from a variety of sources and significant effort has already been devoted to collection and assessment of information. Examples of this group are sputtering, particle reflection and secondary electron emission. The second group are observations of phenomena that involve a chain of distinct and different collision events that cannot be readily separated. A full description of experimental as well as theoretical information requires both a model as well as the parameters that are included in the model. An example would be re-emission of hydrogen from a surface. Interest in such processes has generally been stimulated by the fusion program, data is primarily related directly to fusion plasma situations but nevertheless the process can be studied in a well defined laboratory environment. The third group are complex phenomena observed in plasma devices themselves where the observation is related to the conditions of the plasma and the process could not be reliably simulated by a laboratory based experiment involving a defined beam incident on a surface. Often such phenomena cannot be reproduced from one plasma device to another. An example would be the net erosion of a limiter plate which is governed by the interplay between erosion and subsequent re-deposition. These observations come directly from the fusion device community, are important to the understanding of device operation, but do not represent a specific definable process. One must address the question of how to collect, evaluate and disseminate data of all three types.

We will discuss separately each of the three different types of data and the potential for collecting and disseminating such data in a form valuable to the fusion community. Finally we will review briefly the form in which the data might be stored and made available.

PSI Data Types

(1) Coefficients for well Defined Processes

We include here processes which can be defined by a single parameter, often a coefficient or sometimes a cross section, for a defined particle interaction with a solid, and represented as a function of experimental parameters such as projectile energy, quantum state, incidence angle and target temperature. Such processes are very similar to atomic collision cross section data that a already being collected by the A+M Data Unit of IAEA and can probably be handled in a very similar manner. The processes that fall in this category include:

Sputtering:	Total ejection of material;
	Charge states of ejected particles;
	Excited states of ejected particles;
	Molecular states of ejected particles.
Reflection of heavy particles:	Total coefficients;
	Charge states;
	Excited states;
	Reflection of electrons.
Electron ejection:	By heavy particle impact;
	By electron impact;
	By photons.
Desorption:	By heavy particle impact;
	By electron impact;
	By Photons.
Sticking Coefficients:	Of different incident particles.

Major data collections are available in certain of these areas and their status is briefly as follows:

Sputtering, total ejection of materials, has been covered by reports from Garching (IPP 9/26) and IPP Nagoya (IPPJ-AM-26, IPPJ-AM-32, IPPJ-AM-40).

These include collections of data from the literature, assessment of reliability, tabulations of data and provision of algebraic representations of the data suitable for use in modelling routines. It was reported that the IPP reports are currently under revision and upgrade, with the objective of producing revised versions by the end of the present year.

Reflection of heavy particles has been covered by reports from Garching (IPP 9/32) and from IPP Nagoya (IPPJ-AM-18, IPPJ-AM-41, IPPJ-AM-34). Again they include collections of data from the literature, assessment of reliability, tabulations of data and provisions of algebraic representations suitable for use in modelling routines. It was reported that Garching was developing a further report covering results of simulations for hydrogen reflection from light targets; this is to be available in a few months.

Secondary electron emission by electrons and electron reflection have both been covered by bibliographic listings in the literature of the 1960s but are not in a form that is suitable for use by the fusion community.

Desorption by particle impact has been covered in two JAERI reports (JAERI-M 85-100, JAERI-M 84-094) and an IPP Nagoya report (IPPJ-AM-22) which are comprehensive but represent only tabulations and are not directly suitable for modelling.

In general terms, the existing reports on total sputtering and heavy particle reflection provide a good fundation for creation of an IAEA database and guidance for extrapolation to new situations. For certain other areas, such as secondary electron ejection, electron reflection, and charge states of reflected and sputtered particles, data is widely available and could be collected together for inclusion in the IAEA database; this is not however part of any of the current programs of the data collection groups. It is recommended that collection and assessment be organized by the IAEA in these cases.

(2) Complex Processes

We include here processes that involve a variety of interrelated mechanisms. These are best described by listing the most significant subjects.

Chemical sputtering;
Ion induced chemical changes;
Ion induced segregation;
Radiation enhanced sublimation;
Trapping;
Detrapping;
Release.

In all cases the observed parameter cannot be expressed simply as a function of kinetic parameters of the collision process. In general, a full description of the process requires a model involving a number of discrete processes each of which has a specific coefficient, cross section, or rate. Frequently the process is strongly related to conditions of the surface including temperature and detailed structure. In many cases there is not agreement on the model that represents the phenomenon.

There would be no unanimous agreement on how such data can be collectively presented. There are some data collections on trapping and re-emission by JAERI (JAERI-M 82-118, JAERI-M 84-093, JAERI-M 85-099) which reproduce data from the literature in tabular and graphical form; these are not in a form that can be incorporated directly into modelling codes. Activity by the IAEA may best be confined to tabulation of representative and adequately assessed data. The functional and parametric dependences of observed quantities, when presented in a systematic manner, could also be useful in fusion applications, and even used in modelling codes.

(3) Machine Related Phenomena

There is considerable interest in phenomena caused by the interaction of a plasma itself with surfaces. Due to the complexities of the situation it is not feasible to fully define the conditions of bombardment or the mechanisms that occur. The process may be peculiar to a particular machine and to particular operating circumstances. Representative subjects include:

Erosion and redepostiton;
Arcing;
Sheath related effects;
Synergistic effects.

The role of the IAEA could be confined to a systematic compilation of such data, their categorization, and bibliographic coverage.

(4) Summary

The well defined processes listed under (1) above should be subjected to detailed collection, assessment and presentation of data. The complex processes in (2) above should be subjected to data collection activities and where the process is understood a form of data presentation and assessment can be designed. The machine dependent processes listed in (3) could be subject of a systematic data compilation, categorization and, when possible, comparison analysis.

Data Presentation

The IAEA A+M Data Unit has already adopted the ALADDIN system for database construction. The system is based on FORTRAN 77, which ensures maximum portability between computer systems and is widely used. A practical labeling scheme is utilized for data search routines. Under a particular label one can provide the data in the form of tables, algebraic formulae based on theoretical understanding, or in the form of polynomial fitting routines. Since ALADDIN is already accepted for the atomic and molecular data handling, it should also be implemented for particle solid interaction data.

The first step in implementation is creation of a suitable indexing scheme. The A+M system can provide a useful guide but there will need to do some modifications. For example, in particle solid collisions leading to ejection, the prior collision conditions may be specified by two species (particle and solid) while the post collision conditions may require specification of a different particle (e.g. ejected particle) and the solid, while providing no information (nor interest) on the fate of the original projectile. Particle solid interactions require a larger number of specified parameters to specify the process, such as incidence angle, target temperature, to mention two. These are relatively minor concerns but they need to be covered by procedures that does not compromise the basic simplicity of the ALADDIN system.

The general attitude of the working group was that the ALADDIN system should be applied immediately to the simple processes described in (1) above and used to present and exchange data that is available from existing compilations as well as their projected revisions. ALADDIN might later be applied to presentation of representative data from the more complex processes listed in (2) and (3) above.

4. MEETING CONCLUSIONS AND RECOMMENDATIONS

4.1. Preliminary remarks

The world fusion programme is entering the stage of demonstration the scientific and technological feasibility of fusion power. The ongoing conceptual design of engineering test reactors (ITER, NET, TIBER-II, FER, OTR) has demonstrated that the fusion reactor plasma and power performances are critically influenced by the properties of the plasma surounding solid materials, by their response to the plasma thermal and particle (including neutrons) action upon them. Establishing a validated database for the plasma-material interaction processes and the behaviour of plasma facing components under reactor operation conditions is a prerequisite for a sound fusion reactor design. In view of the limited present information on these issues and of the ongoing test reactor design activities, this task acquires a top priority.

The Advisory Group Meeting considered in detail the status of the plasma-material interaction (PMI) data (availability, quality, relevance) as required in the fusion research work on the present large fusion machines and in the engineering test reactor design work. The PMI data needs for further development of this work were also analyzed in detail, with emphasis on the ITER design requirements. Within the Working Group meetings, the potential role of the IAEA in establishing the required PMI database for fusion was also discussed, and number of actions were suggested. The meeting conclusions and recommendations regarding the above issues are given below.

4.2. Status of the database for plasma-material interactions

a) Since 1984, when the "Compendium on the plasma-surface interaction data" was published (Nuclear Fusion, Special Supplement, 1984) as an outcome of a similar IAEA meeting, the database for the PSI processes required for fusion research has considerably expanded. This was result of the increase of experimental capabilities in fusion and other research laboratories, up-grading of computer PSI simulation codes and other theoretical developments, but also as a result of the increased demand for PSI data from the fusion community and due to certain shifts in the prefered fusion material options and in the projectile-target parametric space. On the general the existing PMI database is still far to be satisfactory for the presently ongoing fusion research and design work.

b) For the simpler particle-surface interaction processes, such as backscattering, physical sputtering, particle induced desorption, etc., the database for mono-atomic materials (as target or substrate) is fairly abundant, and the corresponding, Monte Carlo based, computer simulation codes can provide data of acceptable accuracy, at least for sufficiently high projectile energies and flat surfaces. Semi-empirical analytic formulae for most of these processes under such physical conditions are also available. However, at low ion impact energies (pertinent to the edge plasma ions), for composite target materials (alloys, compounds, etc), and for realistic (rough) solid surfaces, the database even for these, physically simplest processes is still very sparce. The information about the parametric dependences of these processes, as well as the information on their differential characteristics, are still incomplete for target materials of fusion interest.

c) For the more complex plasma-material interaction processes, such as chemical sputtering, radiation-enhanced sublimation, ion-induced segregation, trapping/detrapping, erosion/redeposition, arcing etc, the existing database covers currently the most preferred plasma facing candidate materials (mostly carbon-based), and it is expanding rapidly. The lack of a more detailed understanding of the background physics and chemistry for these processes prevents developing of predictive theoretical models and one has to rely only on the empirical information. Erosion data on carbon-based material and various types of graphite are rather abundant, but still no systematic information exist on the parametric and target-structure dependences of the released particles, their differential characteristics (energy and angular distributions) and, in the case of hydrocarbons, on the dependence of their chemical composition on the projectile-target parameters (projectile incidence angle, target temperature and structure, etc).

d) The experimental database on the global thermomechanical and thermophysical response of plasma facing materials to high plasma

plasma heat fluxes is very limited, particularly for off-normal conditions (disruptions, run-away electrons and ELM activity). The information on the thermal induced effects of plasma facing materials is usually provided by complex simulation codes, although several experimental facilities are now available (and a few are being planned) for simulation and study of these effects. The numerical codes for material evaporation and melting of plasma facing materials under intense pulse heating, and for energy deposition by energetic run-away electrons into tokamak materials have the required accuracy to realistically predict these effects. Data on the material behaviour under the simultaneous action of the plasma particle and heat fluxes and neutron irradiation are still absent. Such data are, however, of critical importance for prediction of the reactor materials performance.

4.2. Further PMI data requirements for fusion

The existing database on PSI processes, although incomplete, provides a useful orientation both in fusion research and reactor design. For the further fulfillment of this role more systematic investigations of all the PSI processes under well controlled laboratory conditions are required. Such investigations are encouraged also from the point of view of better understanding the physics of PSI processes, and for devising appropriate theoretical models, with predictive power. Since the selection of optimum options for plasma facing fusion materials is a result of a multi-step iteration procedure, which includes the advancements in the PSI data information and fusion research/reactor design requirements, it would be wise to conduct the basic, physically well-defined PSI investigations within a reasonably wider scale than suggested by the immediate fusion demands. Within the same spirit of systematics, rigour and broadness, the studies of individual and composite (synergistic) PSI processes under realistic plasma environment conditions should be continued and further expanded. The information from such studies could be highly useful in the reactor design (or design of devices with long pulse operation) only if the environment factors (including their time evolution) are well specified. Obviously, it would be highly desirable if the experimental studies of this kind are accompanied by correspondingly designed computer simulation codes, for which the experiments could provide either appropriate checks, or input for determination of various fitting parameters. The parametric space of PSI processes (including the time evolution of structural changes) should be more completely investigated with the idea of finding regious in which the material and/or plasma performance degrading effects of PSI processes are minimized.

Because of the synergistic nature of PSI phenomena in long-pulse fusion devices, comparision of laboratory and machine (or plasma simulator) produced data could also be very instructive. This comparison may eliminate some of the problems which appear important from a laboratory point of view, but also may reveal some new aspects, ignored in the laboratory experiments.

Some of the specific issues which need more investigation and on which more data is required from the point of view of current fusion research and reactor design are:

- effects of surface roughness on particle-impact induced processes (reflectron, sputtering, impact induced desorption),
- differential (in energy and angle) characteristics of observed reaction products in PSI processes,
- better characterization of erosion yields in projectile-target parametric space (including target structure),
- inclusion of certain high-Z refractory materials in the database,
- study of synergistic PSI effects in well controlled laboratory experiments and in tokamak (or adequate plasma simulator) condtions.

The database for the thermophysical and thermomechanical effects of high heat pulses and neutron irradiation on plasma facing materials requires further characterization both in terms of operating conditions (normal and off-normal) and in terms of processes and candidate materials. More extensive experimental information is needed on a broad range of materials, and further validation of the numerical simulation codes of PMI phenomena and material behaviour is required. Particularly defficient is the information on the effects of off-normal events (plasma disruptions, run-away electrons) and of the synergistic thermal and neutron irraditaion effects on material properties. Studies aimed at providing this information for the ITER design process have an urgent character. Such information is of critical importance for the fusion reactor technology, and is also relevant to the reactor engineering and economics.

4.3. PSI data compilation, evaluation, storage and dissemination

The process of PSI data generation should be paralleled with a data compilation and evaluation activity to make the data available to fusion researcher, appropriately formatted and validated. The PSI data compilation activity has already been being pursued in three national Atomic Data Centres for Fusion (Oak Ridge, Nagoya University, Kurchatov Institute) and in a number of fusion laboratories (IPP Garching, Culham, JAERI). This activity requires adequate co-ordination through the IAEA. Organization of the PSI data evaluation/validation process, which is necessary for selection of recommended PSI data for fusion, should also be done through the IAEA, with involvement of competent experts from the pertinent PSI fields.

For a number of PSI processes, there already exist a significant body of data with sufficient accuracy (backscattering, physical sputtering, particle impact induced secondary emission), which, after an appropriate validation, can be recommended to fusion users. A preliminary analysis of the ALADDIN data storage and exchange system (performed by E.W. Thomas, R.K. Janev and J.J. Smith) has shown that the PSI data can be formatted in this system, provided an appropriate extension of its dictionaries and the corresponding software are prepared. (Note: This work is presently in progress, and will be discussed at the forthcoming IAEA A+M Data Centre Network Meeting in September 14-15, 1989).

4.4. Actions recommended to the IAEA

In view of the above conclusions regarding the PMI data status and the requirements for such data in the present fusion research and reactor design work, the participants of the Advisory Group Meeting recommend that the following actions be taken by the IAEA in the field of PMI data compilation, evaluation and generation:

a) To start as soon as possible with the establishment of a numerical database of recommended PSI data for fusion. Recommendable sets of data exist on:
   1) Ion backscattering (data sets from IPP Garching and IPP Nagoya);
   2) Physical sputtering (data sets from IPP Garching and IPP Nagoya);
   3) Secondary electron emission (data set from ORNL).

The ALADDIN system is recommended for data formatting and exchange.

b) In order to provide a frame for co-ordination of PSI data generation activity and a forum for the data evaluation/validation process, iniciation by the IAEA of a Co-ordinated Research Programme (CRP) on a selected number of PSI processes is recommended. In determining the specific scope of this programme, the IAEA A+M Data Unit will use the advices of the PSI Co-ordination Group of the IFRC Subcommittee on A+M Data for Fusion. It is recommended that this CRP starts during 1990.

c) It is recommended to convene an IAEA Specialists'/Consultants' Meeting during 1990 on the "Thermal Response of Plasma-Facing Materials and Components" to review and evaluate the data in this area, and to discuss the co-ordination of future data generation and evaluation activities, with particular emphasis on ITER design requirements.

d) It is recommended that the results of AGM discussions regarding the PSI data availability, the current research and the data needs for fusion be summarized in a number of review articles, prepared by the Meeting Section Organizers. It is recommended to publish these reviews in the "Nuclear Fusion Supplement for Atomic and Plasma-Surface Interaction Data for Fusion", as a material of general interest to fusion research community.

Advisory Group Meeting on "Particle-Surface Interaction Data for Fusion"

Vienna, 19-21 April 1989

LIST OF PARTICIPANTS

R. Bastasz	Physical Res. Div. 8347, Sandia National Laboratories, Livermore, CA 94551-0969, U.S.A.
R. Behrisch	Euratom Association, Max-Planck-Institut für Plasmaphysik, D-8046 Garching bei München, FRG
J. Bohdansky	Max-Planck-Institut für Plasmaphysik, D-8046 Garching bei München, FRG
H. Bolt	CEC - Commission of the European Communities, NET Team, Max-Planck-Institut für Plasmaphysik, D-8046 Garching bei München, FRG
W. Eckstein	Max-Planck-Institut für Plasmaphysik, Boltzmann Strasse 2, D-8046 Garching bei München, FRG
M. Guseva	Institut Atomnoi Energii I.V. Kurchatova, Ploshchad I.V. Kurchatova, Moscow D-182, 123182, USSR
W.B. Gauster	Sandia National Laboratories, Department 6510, Albuqherque, New Mexico 87185, U.S.A.
A.A. Haasz	University of Toronto, Institute for Aerospace Studies, 4925 Dufferin St., Downsview, Ontario, M3H 5T6, Canada
M.F.A. Harrison	Culham Laboratory, United Kingdom Atomic Energy Authority (UKAEA), Abingdon, Oxon. OX14 3DB, UK
Y. Hirooka	University of California, Los Angeles, Institute of Plasma Physics & Fusion Research, Los Angeles, CA 90024, U.S.A.
J. Linke	Kernforschungsanlage Jülich, Postfach 1913, D-5170 Jülich, FRG
Y. Martynenko	Institut Atomnoi Energii I.V. Kurchatova, Ploshchad I.V. Kurchatova, Moscow D-182, 123182, USSR
A. Miyahara	National Institute for Fusion Science, Nagoya 464-01, Japan
K. Morita	Department of Crystaline Materials Science, Faculty of Engineering, Nagoya University, Furoo-cho, Chikusa-ku, Nagoya 464-01, Japan
V. Philipps	Institut für Chemie 1, Kernforschungsanlage Jülich, Postfach 1913, D-5170 Jülich, FRG

J. Roth	Max-Planck-Institut für Plasmaphysik, Boltzmann Strasse 2, D-8046 Garching bei München, FRG
D. Ruzic	University of Illinois, Dept. of Nuclear Engineering, 103 S. Goodwin, Urbana, IL 61801, USA
P. Schiller	CEC - Commission of the European Communities, Joint Research Centre, Ispra Establishment, I-21020 Ispra (Varese), Italy
J. Schou	Physics Department, Risoe National Laboratory, P.O. Box 49, DK-4000 Roskilde, Denmark
P.C. Stangeby	University of Toronto, Institute for Aerospace Studies and Centre for Nuclear Engineering, 4925 Dufferin St., Downsview, Ontario, M3H 5T6, Canada
E. Taglauer	Max-Planck-Institut für Plasmaphysik, Boltzmann Strasse 2, D-8046 Garching bei München, FRG
T. Tanabe	Osaka University, Dept. of Nuclear Engineering, Faculty of Engineering, Osaka 565, Japan
B. Terreault	National Institute of Scientific Research, P.O. Box 1020, Varennes, Quebec J0L 2P0, Canada
E.W. Thomas	School of Physics, Georgia Institute of Technology, Atlanta Georgia 30332, USA
E. Vietzke	Institut für Chemie 1, Kernforschungsanlage Jülich, Postfach 1913, D-5170 Jülich, FRG
J.B. Whitley	Sandia National Laboratories, Fusion Technology, P.O. Box 5800, Albuquerque, NM 87185, U.S.A.
H. Winter	Institut für Allgemeine Physik, Technische Universität Wien, Wiedner Hauptstr. 8-10, A-1040 Wien, Austria
H. Wolff	Academy of Sciences of GDR, Central Institute of Electron Physics, Hausvogteiplatz 5-7, DDR-1086 Berlin, DDR
C.H. Wu	CEC - Commission of the European Communities, NET Team, Max-Planck-Institut für Plasmaphysik, D-8046 Garching bei München, FRG
R. Yamada	Plasma Engineering Laboratory, Japan Atomic Energy Research Institute (JAERI), Tokai-mura, Ibaraki 319-11, Japan

IAEA Advisory Group Meeting on
"Particle-Surface Interaction Data for Fusion"

April 19-21, 1989, Vienna, Austria

MEETING PROGRAMME

Section 1: General overview on data status and requirements for plasma-surface interaction (PSI) processes for the present and next-step fusion devices

1) R. Behrisch#: Particle bombardment data for plasma-surface interactions
2) M.F.A. Harrison: Plasma-surface interactions and data requirements for ITER
3) P. Stangeby: Some problems in edge modelling related to PSI data
4) A. Miyahara: Data collection, evaluation and presentation

Section 2: Ion Backscattering

* 1) W. Eckstein#: Backscattering: new data since 1984. Theoretical work and experimental data simulations
2) D. Ruzic: The effects of surface roughness on backscattering and sputtering. The addition of fractal geometry to TRIM

Section 3: Particle induced electron emission

* 1) E. Thomas#: Particle induced electron emission. An overview and electron induced ejection
2) J. Schou: Kinetic secondary electron emission from solids
3) H. Winter: Heavy particle-induced electron emission (HPEE) from surfaces, relevant for magnetic fusion

Section 4: Trapping, detrapping and release of implanted and co-deposited ions

* 1) R.J. Bastasz, K. Wilson#: Trapping, detrapping and release of implanted and co-deposited hydrogen isotopes from carbon and beryllium
* 2) T. Tanabe: Hydrogen behaviour in graphite
3) V. Philipps: Retention of oxygen and helium in carbon
4) K. Morita: Dynamic measurements of hydrogen depth profile in graphite during and after implantation
5) Y. Hirooka: Hydrogen plasma pumping by graphite

\# Co-ordinator for the section
* Review talk

Section 5: Physical sputtering

* 1) J. Bohdansky[#]: Physical sputtering data for PSI
2) J. Roth: Unity yield conditions for sputtering of graphite by carbon ions
3) E. Vietzke: Energy distributions of sputtered particles from graphite and carbides
4) M. Guseva: Some peculiarities in the sputtering of structural materials for fusion reactors
5) A. Haasz: Angle of incidence dependence of light ion physical sputtering of carbon
6) C. Wu: Impact of angles of incidence on physical sputtering and erosion scenario of plasma facing components - graphite
7) W. Eckstein: Progress in sputtering calculations
8) Yu. Martynenko: Sputtering by heavy impurities in a fusion reactor. Inelastic sputtering by multiply charged ions

Section 6: Chemical sputtering, radiation enhanced sublimation, surface segregation

* 1) E. Vietzke: Chemical erosion of low-Z materials
* 2) J. Roth[#]: Radiation enhanced sublimation of graphite
* 3) A. Haasz: Synergistic effects in chemical sputtering of graphite
4) R. Yamada: Recent results on chemical sputtering of carbon materials
5) V. Philipps: Radiation enhanced sublimation on a-C : H, a-C/B : H and diamond films
6) T. Tanabe: Surface chemistry under ion bombardment
7) Y. Hirooka: Erosion and redeposition under high flux plasma bombardment
8) B. Terreault: Comments on chemical sputtering

Section 7: Arcing, pulse heating, effects of disruptions and run-away electrons

* 1) H. Wolff: Review on arcing phenomena and data in tokamaks
* 2) J. Whitley[#]: Pulse heating, disruptions and the effects of runaway electrons
3) W. Gauster: Comments on thermal loads
4) J. Linke: High heat flux testing of metalic, ceramic, and graphitic first wall materials
5) H. Bolt: Materials response to off-normal heat fluxes in NET/ITER
6) P. Schiller: Qualitative and quantitative observations during simulated plasma disruptions on metalic surfaces
7) J. Whitley: Comments on neutron damage

Section 8: Particle induced desorption

* 1) E. Taglauer[#]: Review of recent data on desorption
2) K. Morita: Partial cross sections of particle induced desorption for monolayer impurities on solid surfaces
3) E. Vietzke: Particle induced desorption of CO from carbon by H^0 and H^+ (He glow discharge)
4) J. Schou: Electronic sputtering from insulators

Sections 9a-c (parallel): Discussions in working groups (WG's) and preparation of AGM conclusions and recommendations

Section 9a: WG on particle-impact induced effects

Tasks:
1) Identification of most urgently required PSI data for the present experiments and ITER;
2) Definition of an IAEA Co-ordinated Research Programme on evaluation and production of PSI data for Fusion (with particular emphasis on ITER needs);
3) Identification of existing PSI data sets which can be recommended in fusion applications or subjected to an evaluation procedure.

WG organizers: R. Behrisch, J. Bohdansky, M.F.A. Harrison, E. Vietzke

Section 9b: WG on thermal effects and material response

Tasks:
1) Data status and identification of most important PMI data required for ITER;
2) Recommendations on the IAEA activities in the PMI area;
3) Definition of the programme of an IAEA Specialists'/ Consultants' meeting on PMI data for 1990

WG organizers: W. Gauster, J. Whitley, H. Wolff, H. Bolt,

Section 9c: WG on PSI data compilation, evaluation and recommendation procedures, and data storage and exchange

1) Data evaluation and recommendation procedures
2) Recommended data storage and exchange
3) Data exchange format (ALADDIN?)

WG organizers: E.W. Thomas, R.K. Janev, A. Miyhara, W. Eckstein

Section 10: Adoption of Meeting Conclusions and Recommendations

IAEA Advisory Group Meeting on
"Particle-Surface Interaction Data for Fusion"

April 19-21, 1989
IAEA Headquarters, Vienna, Austria

Meeting Agenda

WEDNESDAY, 19 April

9:30 Opening: M. Zifferero (Room C02-I)

9:45 Section 1: Data Status and Needs
Behrisch (30')
Harrison (30')

Chairman: Gauster

10:45 BREAK

11:00 Section 1: (cont'd) (Room C02-I)
Stangeby (30')
Miyahara (30')

Chairman: Gauster

12:00 LUNCH

14:00 Section 7: Arcing, pulse heating, etc. (Room A-19)
* Wolff (40')
* Whitley (40')
Gauster (25')

Chairman: Miyahara

15:45 BREAK

16:00 Section 7: (cont'd)
Linke (30')
Bolt (30')
Schiller (30')
Whitley (30')

Chairman: Miyahara

Section 3: Electron emission (Room B0742)
* Thomas (40')
Schou (30')
Winter (30')

Chairman: Harrison

THURSDAY, 20 April

9:40 Section 4: Trapping, etc. (Room A-19)
- * Bastasz (35')
- * Tanabe (35')
- Philipps (20')
- Morita (20')
- Hirooka (20')

Chairman: Behrisch

Section 2: Backscattering (Room B0742)
- * Eckstein (40')
- Ruzic (30')

Chairman: Guseva

11:10 BREAK

11:25 Section 5: Physical Sputtering (Room A-19)
- * Bohdansky (35')
- Roth (20')
- Vietzke (20')

Chairman: Behrisch

12:40 LUNCH

14:00 Section 5: (cont'd) (Room A-19)
- Guseva (20')
- Haasz (20')
- Wu (15')
- Eckstein (15')
- Martynenko (15')

Section 6: Chemical Sputtering etc.
- * Roth (35')

Chairman: Bohdansky

16:00 BREAK

16:15 Section 6: (cont'd)
- * Vietzke (35')
- * Haasz (35')
- Yamada (20')
- Philipps (20')
- Tanabe (20')
- Hirooka (20')
- Terreault (20')

Chairman: Bohdansky

FRIDAY, 21 April

9:00 Section 8: Particle induced desorption (Room A-19)
* Taglauer (35')
Morita (20')
Vietzke (20')
Schou (20')

Formation of working groups (10')

Chairman: Philipps

10:45 BREAK

11:00

Section 9A	Section 9B	Section 9C
WG on Particle-impact (Room A-19)	WG on Thermal effects etc. (Room B0742)	WG on PWI Data evaluation (Room C0753)

12:30 LUNCH

14:00

Section 9A	Section 9B	Section 9C
(cont'd)	(cont'd)	(cont'd)

15:45 BREAK

16:00 Section 10: Discussion of WG Reports and Recommendations (Room C02-I)

Chairman: Behrisch

17:00 BREAK

17:30 Section 10: (cont'd) Adoption of WG Reports and Recommendations

Chairman: Miyahara

18:00 Closing