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INDC INTERNATIONAL NUCLEAR DATA COMMITTEE

IAEA Technical Committee Meeting on

"ATOMIC AND MOLECULAR DATA FOR FUSION REACTOR TECHNOLOGY"

12-16 October 1992, Cadarache, France

SUMMARY REPORT

Prepared by R.K. Janev

March 1993, Vienna

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

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ABSTRACT

A brief summary is presented on the programme, proceedings and main results of the IAEA Technical Committee Meeting on "Atomic and Molecular Data for Fusion Reactor Technology" held on October 12-16, 1992 in Cadarache, France. The meeting conclusions and recommendations, formulated in the form of three Working Group Reports, are also reproduced in the present summary.

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Table of Contents

Appendices

1. INTRODUCTION

On recommendation of the Subcommittee on Atomic and Molecular Data for Fusion of the International Fusion Research Council (IFRC A+M Subcommittee), the IAEA Atomic and Molecular (A+M) Data Unit has initiated the organization of the IAEA Technical Committee Meeting (TCM) on "Atomic and Molecular Data for Fusion". On request by the IAEA, the Government of France, through its Atomic Energy Commission, has accepted to host the Meeting and appointed the Department for Controlled Fusion Research of the Centre for Nuclear Studies at Cadarache to be responsible for the technical organization of the Meeting. The Meeting took place on October 12-16, 1992, at the Chateau de Cadarache. The local Organizing Committee, chaired by Dr. H.W. Drawin, and the Laboratory for Controlled Fusion Research, have provided excellent conditions for the successfull work of the Meeting.

The Meeting was attended by 58 participants from 12 Agency Member States and one international organization (CEC). Three Agency's representatives, two Agency's consultants and one observer took also part in the Meeting. The List of Meeting Participants is given in **Appendix 1**.

The IAEA TCM on "Atomic and Molecular Data for Fusion Reactor Technology" was the third in a series of similar meetings organized by the Agency to provide a broad international forum for a comprehensive analysis of the status and needs for atomic, molecular and plasma-material interaction (PMI) data for fusion energy research, to assess the impact of international A+M and PMI data activities, particularly those co-ordinated by the IAEA, on the fusion energy research development, and to provide directions for the Agency policies and long-term programmes in the area of A+M and PMI data for fusion. The first meeting of this kind, held in Culham 1976, has formulated for the first time the comprehensive scope of A+M and PMI needs for fusion energy research and pointed out the necessity of an organized international co-operation in A+M and PMI data compilation, evaluation and generation. As the result of the recommendations of this meeting, and through the strong support of IFRC, the international A+M Data Centre Network has soon afterwards been established and the IAEA has established an Atomic and Molecular Data Unit charged with the responsibility to conduct the Agency programmes in this area. The second IAEA TCM on A+M and PMI data for fusion was organized in 1980 in Fontenay-aux-Roses, France, to review the data status and needs in relation with the experimental programmes of the series of large tokamak devices (TFTR, JET, JT-60, T-15) then under construction or design. This meeting, through its recommendations, has also provided a strong impetus for the Agency activity on promoting, assisting and supporting the international co-operation in the areas of compilation, evaluation and generation of A+M and PMIdata for fusion.

The IAEA TCM on "Atomic and Molecular Data for Fusion Reactor Technology" in Cadarache was organized after the successful accomplishment of the Conceptual Design Activities on the International Thermonuclear Experimental Reactor (ITER CDA) and at the beginning of ITER Engineering Design Activities (ITER EDA). At the same time, the large operating tokamak machines (such as JET, TFTR, JT-60, DIII-D, Tore Supra) have produced sufficient information on the role of A+M and PMI processes in achieving good plasma performance and on their impact on certain critical reactor design issues (such as impurity control, power and particle exhaust, neutral beam heating and other reactor systems). The principal motivation for organizing the Meeting in Cadarache was to bring together representatives of all relevant segments of atomic, plasma-surface interaction, material science and fusion research communities to discuss in detail the status and the needs for A+M and PMI data in relation with the experiments on currently operating large tokamaks and the design of next-step fusion devices, and to define the scope and objectives of Agency policies and future activities in the A+M and PMI data area.

2. MEETING OBJECTIVES AND PROGRAMME

The IAEA TCM on "Atomic and Molecular Data for Fusion Reactor Technology" was organized with the following objectives:

(i) to review the present situation in the fields of A+M and PMI data for fusion in the light of the needs for such data in the current and planned experiments on the operating fusion machines;

(ii) to identify the A+M and PMI data needs for the design of next generation of reactor-level fusion devices (such as ITER, NET, FER etc);

(iii) to determine the short- and long-term priorities in the work on A+M and PMI data generation, compilation and evaluation related to the fusion research and reactor desgin; and

(iv) to provide recommendations for the IAEA regarding its future activities and programmes in the A+M and PMI data area.

The programme of the meeting was composed to ensure full accomplishment of the above objectives. The meeting participants were also carefully selected to competently represent all relevant segments of fusion, atomic physics and plasma-material interaction communities, including representatives of the ITER EDA Team, major fusion laboratories and A+M Data Centre Network. The Meeting Programme (see **Appendix 2**) included the following sessions:

(1) Overview of the fusion programme and its atomic and plasma-material interaction aspects;
(2) Atomic and molecular data needs for present large fusion experiments;
(3) Plasma-material interaction data needs for present fusion experiments;
(4) Additional atomic and plasma-material interaction data needs for next-step devices;
(5) Status of A+M and PMI data bases for fusion;
(6) Detailed analysis of A+M and PMI data status and needs, and preparation of Meeting conclusions and recommendations by the Working Groups of the Meeting.;
(7) Discussion of Working Group Reports and adoption of Meeting conclusions and recommendations.

The meeting programme also included two poster sessions for presentation of individual contributions on specific A+M and PMI data generation or evaluation activities by the participants. The list of poster contributions is given in **Appendix 3**. The scientific programme of the meeting has been determined by the IFRC Subcommittee on Atomic and Molecular Data for Fusion, in consultation with a number of prominent representatives from the A+M, PMI and fusion communities.

3. BRIEF MEETING PROCEEDINGS

On behalf of the IAEA Director General, the meeting was opened by **Dr. V.A. Konshin**, Director of the IAEA Division for Physical and Chemical Sciences. On behalf of the hosting institution, the meeting participants were addressed by **Dr. R. Gravier**, Deputy Head of the Association Euratom-CEA for Fusion, Cadarache. The work of the meeting then proceeded in plenary sessions, (1)-(5), (7) (see above), poster sessions and working group sessions, (6). The highlights of the presentations and discussions at these sessions are briefly described below.

3.1. Plenary Sessions

The first plenary session of the Meeting was devoted to the current status of thermonuclear fusion research and the role of A+M and PMI physics in this research. **Prof. H. Bruhns** presented a comprehensive overview of the recent progress in the controlled fusion development, while **Dr. H.W. Drawin** and **Prof. A. Miyahara** addressed the A+M and PMI aspects of this development.

The A+M data needs for the experiments on the present large tokamak devices were discussed by representatives of the major fusion laboratories (JET-Culham, PPPL, Jülich, Cadarache) who use such data extensively in their work. The A+M data needs for the spectroscopic and neutral beam based diagnostics of central and edge plasmas in currently operating large and medium size tokamaks were reviewed by **Prof. H.P. Summers** (JET), **Dr. M. Bitter** (PPPL), **Dr. M. von Hellermann** (JET), and **Dr. A. Pospieszczyk** (Jülich), while the A+M data requirements for the modelling of these plasmas (including the impurity and neutral particle transport) where discussed in the presentations of **Dr. R. Hulse** (PPPL), **Prof. P. Stangeby** (JET), **Dr. D. Reiter** (Jülich) and **Dr. M. Chatelier** (Cadaraceh).

The third session of the Meeting reviewed the current status and the needs for plasma-material interaction and material properties data for present large tokamak experiments. **Dr. J. Roth** (IPP Garching) presented an exhaustive review on the data status and needs for the basic impurity generation particle-surface interaction processes, while **Dr. J. Brooks** (ANL, Argonne) and **Dr. Y. Hirooka** (UCLA) presented comprehensive reviews respectively on theoretical and experimental modelling of plasma-induced erosion and redeposition processes under reactor relevant conditions. **Dr. K. Wilson** (SNLL) discussed comprehensively the present knowledge on the retention and release of hydrogen isotopes in reactor first wall candidate materials, **Dr. M. Akiba** (JAERI) presented information on the thermal response of fusion reactor plasma-facing materials, while **Dr. M. Ulrickson** (PPPL) discussed the status and the needs for thermo-mechanical properties data of carbon based and Be/B materials. The fourth plenary session of the Meeting was devoted to the identification of the A+M and PMI data needs for the next step fusion devices. **Dr. D.E. Post** (PPPL) presented a detailed survey of the research and reactor design problem areas in which accurate A+M data information is of critical importance. The review prepared by **Dr. M.F.A. Harrison** (NET) and presented at the Meeting by Dr. D.E. Post, concentrated on the A+M (and partly PMI) data needs for resolving the power and particle exhaust problems in fusion reactors. **Dr. M. von Hellermann** (JET) provided a comprehensive review on the A+M data needs for active beam based alpha particle diagnostics. The PMI data needs for the impurity control in next generation fusion devices were reviewed by **Dr. M. Shimada** (JAERI). An extensive review of the requirements on thermo-mechanical properties of plasma-facing reactor materials was prepared by **Dr. W. Gauster** (SNLA) and presented by Dr. K. Wilson (SNLL).

In the same session, **Prof. C. Deutsch** (Orsay) presented a comprehensive review of the atomic physics aspects of inertial confinement fusion (in both laser and ion beam approaches) and emphasized the atomic data information required in the development of this approach to controlled fusion.

The fifth plenary session of the Meeting provided an overview of the existing evaluated A+M and PMI databases for fusion, some of which have been "recommended" by international experts bodies for use in fusion applications. The status of spectroscopic A+M data bases was reviewed by **Dr. W.L. Wiese** (NIST, Gathersburg), while the status of A+M collision databases was presented by **Dr. R.A. Phaneuf** (ORNL and Univ. of Nevada-Reno). The IAEA and PMI data programmes and recommended data bases were presented by **R.K. Janev** (IAEA A+M Data Unit).

3.2. Poster Sessions

Two poster sessions were organized during the meeting, at which individual contributions on A+M and PMI data generation, evaluation and use in fusion applications were presented. The programme of these sessions included:

Poster Session I

1) Atomic collision and radiative processes,
2) Compilation and evaluation of A+M collisional and spectroscopic data,
3) Fusion applications of A+M data (modelling and diagnostics).

Sixteen contributions were presented in this session (**see Appendix 3**).

Poster Session II

1) Particle-surface collision processes,
2) Plasma-material interaction processes,
3) Thermal response of plasma facing materials,
4) PMI data compilation and evaluation.

Eight contributions were presented in this session (**see Appendix 3**).

3.3. Working Group Sessions

The sixth Meeting session was held as three parallel Working Group sessions and lasted 1½ day. The purpose of splitting into three Working Groups was to allow an in-depth discussion and analysis of the A+M and PMI data status and needs for both the current and next step fusion experiments and to prepare appropriate meeting conclusions and recommendations for each of the specific data areas. The division in working group was as follows:

A) Working Group on A+M data: status and requirements (Co-chairmen: D.E. Post and R.A. Phaneuf)

B) Working Group on plasma-surface interaction data: status and requirements (Co-chairmen: J. Roth and K. Wilson)

C) Working Group on material properties data: status and requirements (Co-chairmen: A. Miyahara and V.R. Barabash)

Based on the presentations at the plenary sessions, as well as on the personal expertise of Working Group participants, the tasks of the Working Groups were defined as follows:

(1) Assessment of the status of existing data bases in general, as well as for specific fusion research and reactor design areas;

(2) Identification and prioritization of the basic data needs for specific fusion application areas;

(3) Assessment of necessary data generation, compilation and evaluation efforts for providing the required data information, and of possibilities for effort co-ordination;

(4) Data formatting and interfacing with fusion application codes;

(5) Formulation of specific recommendations regarding:
   a) Priorities in the data generation, compilation and evaluation work;
   b) International co-operation in data generation and evaluation;
   c) The role and size of involvment of the IAEA in the co-ordination of worldwide efforts on establishing the required database for fusion research and reactor design;
   d) Definition of priorities for the future Agency's A+M and PMI data programmes and activities related to fusion, and the means of their implementation.

The Working Groups have fully accomplished the above tasks. The Working Group Chairmen were charged with the responsibility to prepare the final versions of the Working Group Reports, which are reproduced in the next section. These versions of the Working Group Reports also incorporate the comments and the suggestions given at the last plenary Meeting session.

4. WORKING GROUP REPORTS

4.1. Atomic and Molecular Data: Status and Requirements

Working Group Report*

Prepared by D.E. Post and R.A. Phaneuf

The two key areas where atomic and molecular data are needed are power and particle control and plasma diagnostics. Power and particle control includes successful operation of divertors and the maintenance of adequate impurity control. These are the most critical issues in the design of next-step tokamaks, such as ITER. Further development of adequate plasma diagnostic techniques for the present and future generation of experiments is also a key issue for the fusion research program.

Power and Particle Control

Power and particle control is presently the most difficult design problem for the next generation of tokamaks. The peak heat loads of the present power exhaust systems are too high (tens of megawatts/m^2) to allow a reliable engineering design. The plasma temperature is too high to avoid significant erosion and plasma contamination. The plasma density and neutral pressure is marginal for pumping and removing the He ash. In addition, achievement of even marginal conditions for power and particle control requires a plasma density which is too high to allow reliable steady-state operation with non-inductive current drive.

The present approach to solving this problem involves the optimization of present divertor concepts and the development of new design concepts.

*** This report was prepared by the Working Group Co-chairmen on the basis of the analyses and discussions at the A+M Working Group Session. The members of this Working Group where all the meeting participants excluding those mentioned explicitly at the beginning of the other two Working Group Reports (see Sections 4.2 and 4.3).**

Divertor Optimization

Present divertor concepts rely upon high levels of neutral recycling to lower the plasma temperature and increase the plasma (and neutral) density at the divertor plate. This reduces the plasma erosion and impurity production rate, aids in retaining the impurities in the divertor chamber, and increases the neutral pressure, thereby easing the pumping requirements. Predictions for the divertor operating parameters indicate that the divertor performance will be marginal. However, these predictions are based on incomplete models which do not include effects which are expected to be important and would improve the divertor performance. In addition, there are relatively few data at present from divertors to calibrate the models. Much of the existing data indicates that the predictions of the models may overstate the difficulty of achieving acceptable divertor experience. Thus documentation of present divertor experiments and inclusion of known processes is important. Atomic and molecular data are needed, both for the analysis of divertor operation and for including all of the processes known to be important in divertor operation.

Concept Improvement

A number of divertor concepts are being considered which offer the promise of improved divertor performance. These involve increasing the level of recycling by improved baffling to reduce the escape of neutrals from the divertor chamber and increasing the level of impurity radiation in the divertor chamber to radiate the energy to the divertor chamber walls.

In the limit of very high recycling, most of the energy could be transferred to the neutral gas and then to the walls of the divertor chamber. Increased levels of impurity radiation to the divertor chambers walls would also reduce the peak heat loads.

Data Needs

The data needs for modelling and diagnosing edge plasmas are outlined in Figure 1 and Table 1.

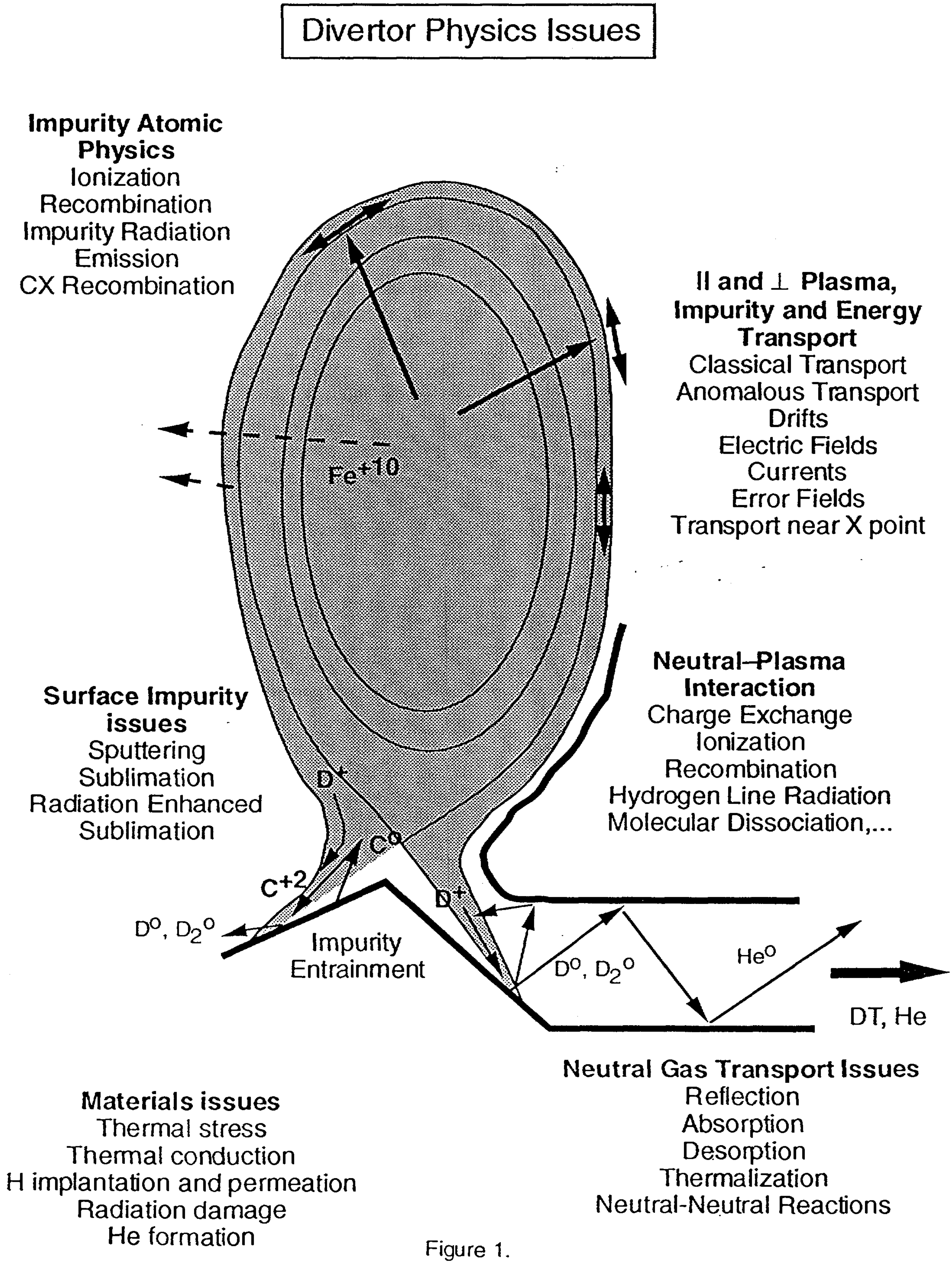
Divertor Physics Issues
Impurity Atomic Physics
Ionization
Recombination
Impurity Radiation
Emission
CX Recombination
II and ⊥ Plasma, Impurity and Energy Transport
Classical Transport
Anomalous Transport
Drifts
Electric Fields
Currents
Error Fields
Transport near X point
Fe+10
Surface Impurity issues
Sputtering
Sublimation
Radiation Enhanced Sublimation
Neutral–Plasma Interaction
Charge Exchange
Ionization
Recombination
Hydrogen Line Radiation
Molecular Dissociation,...
D+
C0
C+2
D+
D0, D2 0
Impurity Entrainment
D0, D2 0
He0
DT, He
Neutral Gas Transport Issues
Reflection
Absorption
Desorption
Thermalization
Neutral-Neutral Reactions
Materials issues
Thermal stress
Thermal conduction
H implantation and permeation
Radiation damage
He formation

Figure 1.

Table 1: Data needs for Edge Plasmas

Hydrogen	H + p,e^-, heavy particle elastic scattering,...
Hydrogen Molecules	H_2+p,e^-, A^{q+},...
He	He + p,e^-; He+He+, elastic scattering,...
Impurities	H,He + A^{q+} ; A^0+e^-->A^+ ; A^{q+}+e^-,...
Impurity molecules	C_nH_m + e^- ; A^{q+} –> $C_?H_?^{+?}$
Neutrals	elastic heavy particle collisions

Hydrogen Collisions

The major collisions are H+p,e^-. These collisions determine the level of hydrogen recycling and energy losses due to hydrogen radiation and charge exchange. The processes are treated in the codes with collisional radiative models. There are at least six such models used by the modelling groups. The data is generally thought to be adequate, but a comparison of the models would be useful since the data are a very important part of the models. It is thus recommended that the groups with such models (JET, Jülich, Kurchatov, Nagoya (Fujimoto), Orsay, and PPPL) compare their results for ionization, recombination, and the cooling rates.

A second issue is the optical opacity of a high density, low temperature plasma with a high density of neutrals with respect to line radiation. If the divertor plasma is optically thick to hydrogen line radiation, then the behavior of high recycling divertors will be modified, and hydrogen radiation losses would likely be reduced.

In addition, measurement of the particle flux, usually by H_a radiation, in the divertor and edge region is very important in understanding particle transport in those regions. From H_a emission data, the neutral particle source is calculated using a collisional-radiative model. However, cross sections for excitation to and from high-n states for H, H_2 and H_2^+ are not known to sufficient accuracy. More reliable data for these cross sections are needed to improve the accuracy of particle flux measurements.

Hydrogen Molecules Collisions

A portion of the plasma in a divertor recycles as molecules. Data for molecular collisions has been tabulated and is used in the models. The major uncertainties are in the fraction of molecules versus atoms desorbed from the wall and divertor plate, and in the role of vibrationally excited hydrogen. Measurements of vibrational states of hydrogen molecules in divertors would be useful. In addition, as mentioned in the section on hydrogen collisions, more reliable data for high-n states for interpreting H_α radiation to determine the particle flux would be very useful.

He Collisions

The major collisions are $He^{0,+1}$+p,e^-. Collisional radiative models are in use by five groups, and the rates appear to be in fairly good shape. However, discrepancies may exist for high n states. Elastic scattering of He^0 on H+ is a potentially important process and better data is needed. Work on He data should be part of a general CRP on H and He recycling.

Impurities

The major collisions are H,He + A^{q+} ; $A^0+e^- \rightarrow A^+$; $A^{q+}+e^-$,..., including ionization, recombination, excitation, and charge transfer (with neutral atoms). The major elements of interest are listed in order of priority in Table 2. One major area where there is still a need for data is the charge transfer cross section for low energy collisions with H and H_2. This is very important for determining the charge state balance for the plasma in the divertor chamber. Quite a bit of data is available for C and O, but data for higher Z ions and metals is not available.

Improved radiation emission rates are also needed, especially for low electron temperatures. These are needed to accurately calculate the cooling of divertor plasmas by impurity radiation. Calculations using codes that incorporate meta-stables and improve upon the average ion treatments are needed. Such codes exist and have been applied to C and O. They need to be applied to the elements listed in Table 2.

Table 2
Plasma Edge and Divertor Modelling/Diagnostics
Data Priorities and Status for Impurities

Priority	**Species**	**Current Status of Database**			
		Database Assessment	**Data Availability**	**Database Status**	**Alladin formatted?**
Highest (Immediate Need)	He	recent	nearly complete	recommended data	yes
	C	recent	nearly complete + cooling rates	recommended data (except D.R.)	yes
	Fe	recent	nearly complete	recommended data (No D.R.) (need cooling rates + low q CEX)	yes
	Kr	none	far from complete (some CX and ionization)	compilations available	No
High (Short-term Need)	Be B	In progress	nearly complete for electron collisions, gaps for CX	Some recommended data - CRP in progress to fill gaps	No
	O	recent	nearly complete + cooling rates	recommended data (except D.R.)	Yes
	Ar Cl	none	far from complete (some CX and ionization)	compilations available	No
	Mo W	none	Almost non-extent (even spectroscopy unknown)	Non-existent	No
Lower (Longer-Term Need)	Cl Ga	none	Almost non-existent	Non-existent	No
	Si Xe	none	Far from Complete (some CX and ionization)	Some data compiled (CX + ionization)	No

It is also important that the data be collected in a general format that is convenient for use by modelers, i.e. tabular fits for ionization, recombination, excitation, and radiative cooling rates as a function of n_e, T_e, n_H, ionic charge, and $t_{residence}$.

For effective control of impurities, their generation, shielding and transport must all be considered. To address these issues, spatial profiles of impurity neutral particles in low-to-medium ionization stages ($q<10$) must be measured and compared with predictions of impurity transport codes. For these measurements and model calculations, accurate rate coefficients and cross sections for ionization, recombination, excitation and charge exchange are required. Based on data needs for current fusion experiments, as well as for the design of next-step ignited plasma devices (such as ITER), the priorities for impurity species indicated in Table 1 were established. Included in Table 1 is an assessment of the status of the available atomic database for each impurity constituent. The databases for many metallic impurity species is either inadequate or unreliable. For example, some existing experimental measurements for ionization or charge exchange are distorted by the presence of unknown populations of metastable states in the reactant beams.

Impurity molecules

These arise due to the chemical reaction of the plasma constituents and impurities with each other and the plasma facing components such as C and Be. They include C_nH_m, H_20, CO, CO_2, etc. A complete set of rates is needing including reaction rates for ionization, dissociation, and recombination, together with the reaction products and the kinetic distribution of those products for electron and heavy particle collisions. These data are important for modelling the evolution of impurities in the divertor and for diagnosing the behavior of impurities in the divertor.

Although some data collections exist, reliable data for these molecules are still limited. In particular, the cross sections for the production of neutral and charged species due to dissociation are very unreliable. The photon emission rates are also not reliable. One complication is that some of the cross sections involving molecules vary by an order of magnitude depending on their internal energy. The internal states of molecules in plasmas (in particular in the divertor region) should be different from those in laboratory collision experiments so that care is needed for using such cross sections in divertor models and divertor diagnostics. The urgent issues involve collisions of state-selected molecular species, measurement of neutral as well as charged products, including the energy and angular distribution, and accurate measurements of the photon emission cross sections. Systematic measurement for collision cross sections are urgently needed.

Neutral collisions

These include elastic collisions of H and H_2 with the plasma and elastic and inelastic collisions with other neutral atoms. Some data is available in the form of simple scattering potentials. However, better data is needed, particularly at low energies. Elastic scattering of neutral atoms and molecules with the plasma has been included in a number of divertor models, but more accurate data, and data which has been more conveniently tabulated is needed. In particular, a convenient tabulation of the differential cross section is needed similar to the tabulation of reflection coefficients for neutral particle reflection.

Elastic and inelastic collisions between neutral atoms and molecules are also important for high density divertor operation, particularly the regime where it is hoped to operate divertors for such large, high power machines such as ITER. This issue was identified at a recent meeting of the A&M Data Center Network following which the ORNL Controlled Fusion Atomic Data Center has assessed the availability of relevant data for this process, and determined the database to be almost non-existent. As a result, a research program has been initiated at ORNL to develop theoretical methods to determine the relevant elastic scattering cross sections. However, the major limitation in determining the effect of neutral-neutral collisions is the need to develop an efficient computational technique for computing particle and energy transport when these effects are important.

Vapor Shielding Models

Plasma disruptions can deposit a lot of energy (~ 10 MJ/m^2) on plasma facing components in a short period (~ 100 ms). This can lead to melting and ablation of the surface of the plasma facing component, resulting in a relatively short life of the plasma facing component. The density of the ablated plasma is high (10^{22}—10^{23} m^{-3}) and the temperature is low (~ 1—5 eV). This ablated plasma can form a barrier to the further deposition of energy on the plasma facing component by radiating much of the deposited energy away and by absorbing the heat before it reaches the surface. The models being constructed for these processes will need atomic data in regimes normally encountered only in inertial fusion. It is recommended that the status and needs for such data be assessed along with the data needs for inertial fusion.

Atomic and Molecular Data Requirements for Spectroscopic Diagnostics

Next step experiments such as ITER will pose new challenges for plasma diagnostics. These plasmas will be large, very hot, dense, and radioactive. Access will be difficult and limited, and remote maintenance will be required. In addition to the usual requirements for measuring the bulk plasma parameters such as the electron temperature profile, there will be a need to measure the plasma parameters in the divertor and at the plasma edge.

Plasma Edge Parameters

It will be necessary to characterize the plasma parameters in the plasma edge and divertor, including the plasma temperature profile, the plasma density profile including impurities, and the fluxes of neutral and charged particles. The atomic and molecular physics data required for such measurements are, for the most part, similar to those required for modelling divertor plasmas.

In particular, accurate cross sections and rates are needed for ionization, recombination, excitation, and charge transfer (low energy) for **W**, He, **Be**, B, C, N, O, **Ne**, **Ar**, Ti, Cr, Fe, Co, Ni, Cu, **Kr**, Mo, and Xe. There is very little data for low-ionized metals and heavy metals at low T_e ($1<T_e<100$ eV). As mentioned in the modelling section, radiative cooling rates for these elements, esp. low ionized metals, heavy metals and noble gases at low T_e ($1<T_e<100$ eV) are also needed. Collisional radiative models for H_2, H_2^+, H, and He are needed with emphasis on line excitation rates and line positions for interpreting spectroscopy data to determine the particle recycling. In addition, rates are needed for impurity molecules with the additional emphasis on line excitation rates and line positions, particularly on transitions in the visible range which allow the use of fiber optics, interference filters, polarizing filters, and simple detectors. The priority needs for edge diagnostics in terms of elements are given in Table 3.

Table 3. High priority elements for diagnostics

Relevance	**Element**
plasma constituents	**H, H_2, He, O**
PFC	**Be, B, C, W,** Si
structural materials	**Fe,** Ni,
diagnostic T_i	**Kr,** Ar

Central Plasma Parameters

For next-step fusion devices such as ITER, the central electron temperature T_i (0) will be in the 20-40 keV range. Spectroscopic diagnostic measurements of central plasma parameters will require the introduction of higher-Z elements such as Kr (Z=36), for which the He-like charge state will predominate. However, the injection of an impurity species such as Krypton must satisfy two conditions:

1) Z_{eff} of 1.7 or less must be maintained, and
2) The energy release from the plasma by Kr radiation should contribute to the radiative cooling (100 kW), but it should not cause disruptions or a decrease of central electron temperature.

These conditions determine the maximum amount of Kr that can be ejected into the plasma.

For such diagnostic measurements, highly accurate atomic data for the line-strengths of the unresolved $n \geq 3$ satellites are required. Data are also needed for the wavelengths, which are strongly influenced by relativistic and QED effects. Experiments on devices such as EBIT are capable of verifying theoretical predictions for both the wavelengths and line strengths, as well as measuring the excitation, ionization and recombination rate coefficients.

In order to control the power radiated from the various ionization stages of Kr and to utilize it for radiative cooling of the plasma edge or divertor, both theoretical and experimental atomic data on electron-impact ionization, recombination and excitation is required for all charge states. Radiative cooling rates are also required for all charge states. Tokamak experiments should be performed on TFTR, JET, JT-60, Tore Supra, etc. to study the impact of injected Kr on plasma performance. Since the permissible amount of injected Kr will be limited, new, more efficient spectrometers with doubly-focusing (toroidally and spherically bent) crystals should be developed to increase the observed X-ray intensity for the T_i diagnostics.

Another important consideration is the determination of the central $T_i(0)$ from chord-integrated measurements. Evaluation of $T_i(0)$ depends on the shapes of the radial ion temperature and emissivity profiles $T_i(r)$ and e(r). The "chord-integrated T_i value" is equal to $T_i(0)$ if the width of the emissivity profile e(r) is small compared with the width of the ion temperature profile $T_i(r)$. In general, $T_i(0)$ must be determined from modelling calculations, which require knowledge of e(r). e(r) is determined by the radial profiles of the electron temperature $T_e(r)$ and the electron density $n_e(r)$, the radial profile of the helium-like charge state $n_{He}(r)$, and the excitation rate coefficient <sv>, which is a function of the electron temperature. Since modelling calculations of e(r) must be based on theoretical predictions for the ion charge-state distributions as well as the rate coefficients, accurate data for these quantities are needed. To date, it has been found that the measured impurity ion charge-state distribution in tokamak plasmas is not in agreement with coronal equilibrium calculations.

Discrepancies also exist between the observed and predicted intensity ratios of the He-like lines w, x, y and z in tokamak plasmas. The ratios z/(x+y) and (x+y+z)/w are also used as electron-density and electron-temperature diagnostics in laser-produced plasmas. Better theoretical data are therefore needed for these line ratios. Theoretical data are also needed for polarization measurements to determine anisotropic electron velocity distributions. For practical reasons, a general emphasis should be given to cross sections and rate coefficients for any processes involving plasma constituents or impurities that lead to photon emission in the visible region of the electromagnetic spectrum. The emission of H_a radiation represents a particularly important subset of such reactions. Processes involving excited, or metastable reactants should also be emphasized (especially for He).

Data Requirements for Active Neutral-Beam Diagnostics

Active neutral-beam diagnostics for either present or planned Tokamak experiments may be divided into three main categories:

a) Charge-Exchange Recombination Spectroscopy
b) Beam-Emission spectroscopy
c) Active-Beam Alpha-Particle Diagnostics.

The first two techniques are being successfully used in all major Tokamak experiments, and preliminary tests of the third diagnostic method have been made recently in JET. Accurate atomic and molecular data are required for each technique, with the emphasis somewhat different in each case. Beam diagnostics on future ignited plasma devices such as ITER will likely require the use of He rather than H beams because of beam penetration issues.

a) Charge-Exchange Recombination Spectroscopy (CXRS or CHERS)

This technique has involved the injection of an energetic neutral H beam into the plasma to probe the central ion temperature. Charge exchange collisions between the injected neutrals and fully stripped impurities in the core plasma populate excited levels of the H-like impurity ion which is detected by measuring the emitted photons as the excited state decays. This method is in principle capable of providing measurements of the central ion temperature $T_i(0)$, Z_{eff}, local impurity densities and fluxes, local deuteron density, thermal neutron emissivity and non-thermal velocity distributions. The potential of the technique has been demonstrated in recent experiments on JET, TFTR, JT-60 and other devices for all but the last item.

The desirability of using fibre-optics to couple the light flux to the detectors makes the visible region of the spectrum the most attractive from a practical standpoint. This means that the transitions of interest involve electron capture to high-n levels of the H-like ion (e.g. $O^{7+}(n=10)$. These are the non-dominant channels for the electron capture process, for which cross sections are difficult to calculate theoretically or to measure experimentally with high accuracy at the present time. Further work is required for electron capture by bare ions from both H and He into specific n,l levels to improve this situation. Capture from metastable components in the neutral beams must also be considered for these high-n levels, since the cross sections are considerably larger than from the ground-state atom. A "consistency loop" connecting the photon intensity measurements with the basic atomic collision data and other diagnostic measurements is critical to the effectiveness of this technique. Beam attenuation, including allowance for multi-step processes, is another critical issue for this diagnostic method. Accurate data for ionization and charge exchange collisions of H and He with $H^+(D^+)$ and multiply charged impurity ions at energies in the 100-200 keV range are needed for beam-stopping calculations. The required database is relatively complete for ground-state neutrals, but more accurate data are needed for metastable and excited neutrals (particularly for He). The most important impurity species are identified and prioritized in Table 1. The beam-stopping data requirements are common to all neutral-beam-based diagnostics.

b) Beam-Emission Spectroscopy

This method involves measurement of excitation of the injected neutrals due to collisions with plasma electrons and ions as the neutral beam penetrates the plasma. The technique has the potential to provide measurements of both the toroidal and poloidal magnetic fields via the Zeeman and motional Stark effects. It may also be capable of ion density fluctuation measurements. Data for collisional excitation of neutral H and He in collisions with electrons, protons (deuterons), and impurity ions are needed to interpret the diagnostic measurements. The existing database for excitation of H and He in collisions with electrons and H^+ (D^+) is relatively complete, but for collisions with multiply charged impurity ions , data are extremely sparse. More experimental and theoretical effort in this area is required. The first experimental results with this new technique for both H and He beams are extremely promising, but intense experimental and theoretical effort will be required to realize its full diagnostic potential. Signal-to-noise and beam-attenuation considerations favor He beams for the next-generation of fusion devices such as ITER, where plasma densities will be much higher. Again, beam-stopping cross sections (for ionization and charge exchange) are of critical importance.

c) Active-Beam Alpha-Particle Diagnostics

This technique, which has been proposed for measuring the absolute density and the slowing-down velocity distribution of fusion-product alpha particles in an ignited plasma, involves the injection of a fast neutral He beam into the plasma and detecting the 304Å He Lyman-a line produced by double electron capture by alpha particles in the plasma. There is some question whether this is the optimal choice of emission line for the diagnostic. Accurate data for the double-electron-capture cross section into n=2 is required over a range of energies from 150 keV down to a few keV. The available data for this collision system should be critically evaluated. Some preliminary tests of the technique have been performed on JET, which indicate that for ITER-like machines, a probe beam power of the order of 10 MW may be required, which is 5% of the total heating power. Even in this case, the expected alpha-particle density produced by a He probe beam is negligible compared to expected fusion-product alpha particles.

Status of Spectroscopic Database

The coverage of atomic structure data is quite complete for light elements (H, He, Li, Be, B, C, O, Ne) and elements of the iron group (Cr, Fe, Ni). However, data involving higher n- and l-states (n>8, l>5) are often missing, and transition probabilities are typically only accurate to within 10-20% for C and O spectra, and 25-50% for most Cr, Fe and Ni spectra.

For heavier elements (Kr, Mo, W, Ta), our knowledge of ionic spectra is very incomplete. For Kr, adequate atomic structure data are only available for Kr, Kr^+, Kr^{2+} and Kr^{7+}. For all other spectra of Kr, data are either fragmentary, or not available at all. For Mo, data are very inadequate for Mo^{16+} and practically all higher stages, up to Mo^{39+}. Finally, for W and Ta, little or nothing is known for most spectra, except that they are extremely complex, featuring thousands of weak lines spread over all spectral ranges. Limited spectral analyses have been performed only for W, W^+, W^{4+}, W^{5+}, W^{6+}, W^{7+}, and Ta, Ta^+, Ta^{3+}, Ta^{4+},

Ta^{5+}. No reliable transition probability data are available, except for some lines of neutral W and Ta.

Programs and Activities of the Atomic and Molecular Data Unit

The effective coordinating role of the IAEA Atomic and Molecular Data Unit during the past five years is recognized and most strongly commended. The synergistic coordination of extremely limited global resources has been accomplished through a strengthening and expansion of the Atomic and Molecular Data Centre Network, as well as the effective use of other IAEA instruments. These include topical Consultants' Meetings, Advisory Group Meetings, Experts' Meetings, Research Coordination Meetings and Coordinated Research programs. Each of these initiatives has been directly focused on high-priority issues that have been identified independently by the present Technical Committee Meeting. Coordination of global data compilation and assessment activities through the A&M Data Center Network has reduced the duplication of efforts, and effectively focused these efforts on the most important technical issues in fusion, as identified in the topical meetings attended by the experts in fusion research.

In addition, the recent IAEA Coordinated Research Programs (CRP) have been successful in focusing worldwide capabilities and resources in atomic and molecular physics on fusion-related issues. Recent contributions to the fusion databases have been made by most of the major atomic and molecular research laboratories and groups throughout the world. The CRP on Atomic and Molecular Physics for Fusion Edge Plasmas has been particularly effective in directing resources to fusion-relevant data needs from major laboratories performing research with molecules, molecular ions and neutral atoms. None of these laboratories was previously aware of or directed toward fusion-related problems prior to these meetings. The review and assessment of data requirements for modelling and diagnostics of the plasma edge at this meeting indicates that additional data are required in this area, particularly for issues related to divertors and radiative or charge-exchange cooling. It is therefore strongly recommended that this CRP be extended for two-to-three more years, with special emphasis directed to the priorities listed in Table 2. For both core diagnostics and radiative cooling of next-generation devices (such as ITER), the spectroscopic and collisional databases for Kr should be assessed and data needs should be evaluated. Other noble gases such as Ne, Ar and Xe, and also Ga are also of potential interest in this regard, but constitute a lower priority at present.

The recent initiative by the A&M Data Unit to calculate radiative cooling rates for all charge states of C and O impurity ions represents an important effort to bridge the gap between the atomic and plasma physics communities by producing data in reduced forms that are more directly usable by the fusion community. If possible, this initiative should be extended to include Fe impurities. The efforts by the Data Unit to format data in ALADDIN using parametrized forms that may be accurately extrapolated beyond the energy range of the available data is also to be encouraged. Along these lines, the Data Unit should continue to shift its emphasis toward "deliverables" by including plasma physicists in projects as collaborators (as was done in the case of the C and O radiative cooling rates). The Springer publication on H-He plasmas has been extremely successful in implementation, and an update of this database is encouraged.

The ALADDIN system has been successful as an exchange format between Data Centers, as a database management tool, and as a means of disseminating recommended data to the fusion community. Its further development and promotion should be continued.

Specific Recommendations to IAEA and A&M Data Unit

1. The significant contribution of the A&M Data Unit to the international effort in fusion energy research should be appropriately recognized within the IAEA, and adequate resources should be made available to the Data Unit for these critical data assessment and research coordination activities. The present and planned activities are focused on the most critical issues for both present fusion experiments and for next-step devices such as ITER.

2. The existing coordinated research programs of the Data Unit in intermediate and high-Z impurities and in H-recycling and He-ash removal should be continued.
3. The coordinated research program for the edge plasma should be extended for 2-3 more years, and broadened to include a focus on divertor issues. In addition to the needs identified earlier in this report, this CRP should include an assessment of the data needs and status for neutral-neutral collisions in divertor plasmas, modelling vapor shielding effects in disruptions, impurity molecules in divertor plasmas, and the role of radiation transport in divertor plasmas, specifically the opacity of divertor plasmas to H line radiation.
4. The database for collisions of Kr impurities with electrons, H, H_2 and He should be critically assessed.
5. To maximize the Data Unit's impact on fusion research, the emphasis of data compilation activities should continue to be shifted toward "deliverable" formats for the end users in fusion research. The active involvement of plasma physicists from the fusion community is to be encouraged whenever possible.
6. Emphasis should be given to collision processes that give rise to visible photon emissions, with special emphasis on those that lead to H_a emission.
7. Emphasis should continue to be given to ALADDIN formatting of existing recommended databases, and to upgrades of the ALADDIN program and environment.
8. The Data Unit and Data Center Network should continue to direct some of their attention to the data needs of next-step ignited plasma experiments such as ITER, and should attempt to establish formal contact with the ITER team both to obtain direction and to ensure that their efforts have an impact.

4.2. Plasma-Surface Interaction Data: Status and Requirements

Working Group Report

J. ROTH, MPI *
K. WILSON, SNL *
E. VIETSKE, KFA
Y. HIROOKA, UCLA
A. HAASZ, Univ. of Toronto
E. THOMAS, GIT
M. SAIDOH, JAERI
K. MORITA, Nagoya Univ.
A. PERUJO, Ispra
W. ECKSTEIN, MPI
J. BROOKS, ANL
D. REITER, KFA
G. BETZ, Wien
D. GUILHEM, Cadarache

* Co-Chair

I. Introduction

Eight Plasma-Surface Interaction data bases were evaluated by the Working Group. Five are concerned with various erosion mechanisms. The remaining data bases involve hydrogen properties, outgassing properties, and the characteristics of redeposited materials. The data base assessments (Section II) are as follows:

- Physical Sputtering
- Radiation Enhanced Sublimation (RES)
- Chemical Erosion
- Evaporation
- Disruptions
- Hydrogen Properties
- Outgassing
- Redeposited Materials

All of these data bases are required in order to characterize the response of a plasma facing material to plasma exposure and to predict the effects on the plasma by plasma-material interactions.

II. Data Status and Requirements for Erosion Processes and Hydrogen Properties

1. Physical Sputtering

Data Base Assessment

For surface erosion due to physical sputtering an extensive data base exists, especially for light ions such as H, D, and He for fusion relevant materials. Selfsputtering data and sputtering data for typical impurity ions are less comprehensive. Several computer codes, such as TRIM, Fractal Trim, and Molecular Dynamic (MD) Codes successfully reproduce experimental data and can be used for extension of the data base, e.g., to T sputtering and selfsputtering or to obtain differential sputtering yields, such as angular and energy distribution of sputtered atoms.

Prioritization

Cases of disagreement of computer simulation with experimental data mostly occur at non-normal incidence and are often related to the influence of surface roughness not adequately included in the code calculation. For the erosion of plasma facing surfaces with grazing incidence of magnetic field, typical angles of incidence are 50 +/- 10° for light ions including C and O and 20° for heavy ions such as Mo and W. It was agreed that for validation of different codes including surface roughness, the case of 50 eV D and 600 eV Be sputtering of Be for an angle of incidence of 50° should be calculated and compared to experimental data.

Areas with scarce data base include the low energies relevant to divertor plasmas around 10 to 100 eV, the energy and angular distribution of sputtered atoms especially for non-normal incidence as well as precise selfsputtering data close to the yield values of unity. Combined experimental and computational efforts are necessary.

A quick screening test of new materials, often fiber enforced graphites and computes exhibiting large surface roughness, should be done for 1 keV D and C bombardment.

Data Formatting

Physical sputtering data are collected in IAEA Data Compendia and for many materials a new IPP Report will appear soon. The energy dependence of the data is given in a 2-parameter fit after Bohdansky. The angular dependence is given in a 2-parameter fit after Yamamura. For the energy distribution, the Thompson equation appears adequate and the angular distribution can be assumed to be cosine.

2. RES

Data Base Assessment

RES occurs only for carbon and carbon-based materials. The underlying processes are basically understood and laboratory results can be reproduced in model calculations in cases of small defect concentrations within the ion range. Extrapolation to limiter of divertor erosion suffers from the limited understanding at high ion fluxes and high damage concentrations. The direct observation of RES in Tokamaks is also contradictory and may be due to carbon surface contamination with various amounts of metallic impurities. The emission of thermal carbon atoms often does not seriously effect the plasma and carbon blooming combined with performance degradation occurs only at temperatures where carbon sublimates strongly.

	RES	Carbon Bloom	Influence on Plasma
TEXTOR	no	2200°C	yes
Tore-Supra	?	yes	no
JET	yes/no	2300°C	yes, strong
TFTR	yes	>2300°C no bloom with improved tiles	yes
JT60-U	no		
DIII-D	no		

Prioritization

An important parameter for the prediction of RES for plasma-facing components is the dependence, both for D and C ions. Efforts involving ion beams, plasma simulators, and measurements in the edge plasma of Tokamaks are necessary.

Surface contamination has been shown to influence the RES yields, but no systematic investigation for different metals, surface concentrations, and chemical states have been performed. Dopants in the bulk material, such as B, Si, and Ti also affect RES but their stability at high temperatures needs investigation.

Routine testing of new carbon-based materials should involve at least 1 keV D sputtering at room temperature and 1200°C.

Data Formatting

The energy dependence of RES can be adequately described using Bohdansky's equation for physical sputtering with a temperature dependent yield factor with an activation energy of 0.8 to 1 eV. No angular dependence is observed. The energy distribution of emitted atoms is thermal; the angular distribution cosine.

3. Chemical Sputtering

Data Base Assessment

Chemical sputtering due to hydrocarbon formation is extensively investigated and a broad data base exists for temperature dependence, energy dependence, emitted molecular species, synergistic effects of simultaneously incident ions and thermal atoms and flux dependencies. The erosion yield is strongly dependent on dopants in the bulk graphite, such as B and Si. However, no good model description is available for pure carbon materials and compounds or doped graphites.

Additionally, the observation of chemical sputtering in Tokamaks remains contradictory and its influence on the main plasma is weak due to the thermal energies of the emitted molecules.

Oxygen ion irradiation results in CO and CO_2 formation with yield values close to unity independent on ion energy.

Prioritization

The most critical need for the estimation of importance of hydrocarbon formation is the formulation of a comprehensive model. The experimental information available should allow to develop an analytic model for chemical sputtering, at least as far as methane formation is concerned.

The contradictory evidence of chemical sputtering in Tokamaks is currently attributed to a possible flux dependence or surface contaminations. An essential parameter for further investigations is therefore the flux dependence involving plasma simulators and direct measurements in the edge plasma.

In order to evaluate the redeposition of carbon after dissociation of hydrocarbons, the sticking probability of radicals on a graphite surface needs to be investigated. Information could be obtained from investigations of plasma induced film deposition.

The screening test for new, carbon based materials should include 1 keV sputtering with D ions. Oxygen irradiation should be included in the screening tests, especially for low reactivity doped graphites.

Data Formatting

For chemical sputtering with hydrogen isotopes, the temperature dependence is not separable from the energy dependence. Additionally, the composition of emitted molecules is dependent on ion energy. At the moment, only a crude analytical description for the total yield is available. The energy distribution of emitted molecules can be assumed to be thermal; the angular distribution cosine.

4. Evaporation

Data Base Assessment

Evaporation as an erosion process will be included in the report from the Materials Properties Working Group.

Prioritization

Evaporation is often quantified by the vapor pressure for elements and compounds. It was pointed out that vapor pressures alone do not give erosion rates if the composition of evaporated atoms and molecules is not taken into account. Therefore, differential evaporation rates for different components should be given rather than total vapor pressures.

For multi-component materials, diffusional effects and surface segregation, possibly enhanced by ion bombardment, can change evaporation rates. Screening tests of new materials should therefore include tests for the preferential loss of dopants.

Data Formatting

Data formatting will be discussed by the Materials Properties Working Groups.

5. Disruption Erosion

Data Base Assessment

Predictions for disruption erosion rates under fusion reactor conditions has been reported to be drastically reduced by the shielding effect of the vapor cloud in front of the solid surface. This reducing effect depends, however, strongly on the heating scenario, i.e., on the contribution of high energy ions or electrons to the heat flux to the solid surface. Large discrepancies in the judgment of importance of disruption erosion still persist. As the NET report still regards disruption erosion as the largest erosion process, it is not regarded as lifetime limiting for plasma facing materials by the US report.

Prioritization

An assessment of the heat deposition in plasma gun experiments compared to Tokamak disruptions should be performed. Ultimately, direct erosion measurements in Tokamak disruptions experiments have to be performed.

6. Hydrogen

Database Assessment

Hydrogen retention and release data are needed for:

- Recycling Models
- Tritium Inventory Estimates
- Tritium Permeation Calculations
- Hydrogen Embrittlement Characterization

The models used for the characterization of hydrogen retention and release fall into three general classes:

Recycle Models
- Ion- Solid Interaction Codes like TRIM
- Reflection (Energetic Atoms)
- Ion Induced Sputtering (Energetic Atoms)
- Molecular and Atomic Re-emission (Thermal)

Tritium Retention and Permeation
- Codes such as PERI, DIFFUSE, TMAP
- Bulk Hydrogen Transport and Trapping
- Sensitive to Surface Reaction Rates

Co-deposition
- Codes such as REDEP
- Depends on Molecule- Plasma Database
- Assumptions on Redeposited Properties

These codes in turn rely on accurate data . The following is a database assessment for the various hydrogen mechanisms that are modeled by the various computer codes.

Reflection

The database and TRIM model are adequate for 100 eV ions at normal incidence for all materials. Experimental data are needed to benchmark the codes for glancing angle incidence on rough surfaces. Adequacy of fractal approach to surface roughness modeling must be determined. Below 10 eV, binary collision approximation breaks down, and thermal binding effects to the surface can become important. Molecular dynamics calculations might be warranted to determine trends.

Ion-induced Effects

Ion-induced desorption calculations for the energetic release of trapped hydrogen by incident ions is calculated with TRIM. The critical data needs are the binding energies of the hydrogen in the various materials. The data are often represented by a desorption cross section.

Ion-induced detrapping followed by thermal diffusion is much harder to model. There are a number of models in the literature and a large empirical database (see the recent Nuclear. Fusion Supplement). However there is no generally agreed upon model to calculate the ion assisted reemission of molecules from carbon surfaces at temperatures below 1000K.

Thermal Release Processes

Thermal diffusion and release of hydrogen is modeled with numerical solutions to the Fickian diffusion equation. This approach is valid at elevated temperatures (>1000K for graphite, >700K for beryllium) where mobile hydrogen concentrations are small (< 1%).

Data required for this modeling includes hydrogen diffusivity and solubility, which are fundamental materials properties of each material; molecular recombination rate constants, which depends on both the bulk hydrogen properties and the surface composition and catalytic reactivity; and trapping at defect sites from neutron or ion damage. All of this data can be expressed in terms of activation energies and appropriate exponentials. The following table summarizes the current status of the data for these key parameters:

	Graphite	Beryllium	Tungsten	304SS
Solubility	3	2	4	5
Diffusivity	3	3	4	5
Recombination	2	2	1	5
Trapping	3	2	1	5

SCALE: 5 = EXCELLENT; 4 = GOOD; 3 = FAIR; 2 = POOR; 1 = NONE

The database for graphite's diffusivity has always shown a large scatter attributed to the variation in graphite microstructures. However, some recent data has shown a significant deviation from the previously accepted activation energy for migration. Several measurements have been conducted on neutron damaged graphites, and their results indicate that trapping concentrations can reach 0.1 atomic percent. The database for beryllium solubility shows poor agreement, and few data exist for diffusivity. Trapping measurements are beginning to be done on neutron irradiated beryllium, and indicate that trap concentrations can reach similar levels to that of graphite. There exist several measurements of hydrogen transport properties of metals such as tungsten and molybdenum. However, little or no data exist for neutron damage trapping in high z metals like tungsten. For comparison purposes, the database for 304 stainless steel is excellent in all respects. The molecular recombination rate constant is poorly known for graphite, beryllium, and tungsten, and it is known to be a strong function of the surface composition.

Prioritization

The most critical data needs for the area of hydrogen effects in materials are the development of a hydrogen transport and trapping database for the leading plasma-facing materials. In particular data are needed for the diffusivity and solubility in the ITER selected graphite (CFC) and beryllium. The trapping of tritium in neutron damage must be characterized for all candidate materials. Finally, the sensitivity of the molecular recombination constant to surface impurities must be assessed. The present database and modeling for hydrogen recycling is believed to be adequate for divertor modeling.

Data Formatting

In virtually all cases, the data can be converted into simple values for model inputs into standard expressions for thermally activated processes. For example, the diffusivity can be characterized by a pre-exponential and an activation energy. Trapping is described by a trap concentration (which can be a function of neutron fluence and energy spectrum) and a detrapping energy. In the case of ion-induced desorption, a fundamental input is the hydrogen binding energy. The desorption data can be converted into a desorption cross section for use in recycle codes. Only in the case of molecular dynamics calculations for recycling at low energies would the data have to be stored in some tabular form.

7. Outgassing

Database Assessment

The outgassing characteristics of PFMs define the bakeout temperature requirements for ITER. Reduction in bakeout temperature through improved materials selection, pre-treatment, and in-vessel conditioning could result in a significant cost savings and simplification of the ITER vacuum vessel design.

There is a reasonably good database for the outgassing characteristics of graphites and CFCs, although the data has not been collected or analyzed in detail. Few data exist for other candidate plasma-facing materials such as beryllium or tungsten.

Prioritization

Data are needed in the systematic study of the effects of microstructural changes, such as porosity, on the observed outgassing rates. Data is needed for plasma spray beryllium and tungsten.

Data Formatting

The data are typically in the form of weight gain or absorbed gas volume as a function of time. Thermal desorption spectra show the evolution of a gas species as a function of temperature. In certain cases fundamental parameters of binding energies can be extracted, although this is not often done.

8. Redeposited Materials

Database Assessment

Redeposited materials are the true plasma facing material that interacts with the plasma. Often called tokamakium, this material is formed by the deposition of eroded wall materials and plasma hydrogen. The co-deposition of eroded carbon and tritium onto plasma facing surfaces is expected to be a major source of in-vessel tritium inventory for ITER. Removal techniques, such as helium-oxygen GDC, must be developed.

The database is made up of detailed composition, morphology, and property measurements on materials removed from tokamaks or created in plasma simulators. Data are available for all major machines, although there is no consistency in reporting of the data.

Prioritization

Data are needed for beryllium redeposited materials. The effects of various contaminants such as carbon or oxygen must be assessed. The tritium content of beryllium deposits must be determined. Adhesion is a critical concern. The thermal and thermo-mechanical properties must be measured. The effects of neutron irradiation on these properties must also be determined.

Data Formatting

A consistent format for data reporting must be defined. The data are often composition depth profiles, micrographs, etc.

III. Data Generation, Compilation, and Evaluation

Erosion measurements involving physical sputtering, RES, or chemical erosion require a dedicated ion beam or plasma implantation facility. Disruption simulation requires the use of plasma gun facilities with a time constant of 0.1 ms. The fundamental hydrogen transport data (diffusivity and solubility) can be measured by a number of techniques. Measurements of molecular recombination are more difficult, and should only be conducted by those groups that are experienced in low energy ion implantation studies. Tritium trapping in neutron damaged materials require extensive safety facilities, and can only be carried out in a few laboratories in the world. There are a number of dedicated outgassing facilities that can provide the necessary data for fusion. All operating tokamaks are currently analyzed for their redeposited materials. Plasma simulators such as PISCES are used to produce simulated films.

New materials must first meet a set of minimum property values such as thermal conductivity before they are considered for testing. Materials are then subjected to a series of screening tests:

- Erosion
- Outgassing
- Hydrogen Retention
- Disruption Simulation

Those materials that look the most promising are then subjected to an in-depth analysis including neutron irradiation and tokamak testing. Tokamak testing begins with small scale sample exposures followed by full tile exposures, and finally to component tests.

Measurements are conducted by the various national programs to meet their ITER or national fusion energy research program goals. The collection, analysis, formatting, and dissemination of the PMI data base is best carried out by an international organization such as IAEA. In this way all of the data is compared on a common basis, and the data bases are compiled in a single location in a common format. Expert panels can be convened by the IAEA to provide critical evaluations of the data.

IV. Recommendations

1. We suggest that PSI databases be collected and evaluated in Erosion, Hydrogen, Vacuum Properties, and Redeposited Materials.

2. The IAEA is appropriate to collect this data and put it into a usable format and to widely and rapidly disseminate this data base.
3. We would like to establish an internationally coordinated screening test for new candidate plasma facing materials. The IAEA could assist in implementing this recommendation.
4. We recommend that the RCM, Plasma-Interaction Erosion of Fusion Reactor Materials be held at Vienna, Austria, on June 14-16, 1993.
5. We recommend that the Specialists Meeting on Tritium-Materials Interaction be held on June 17-18, 1993 at Vienna, Austria.

4.3. Materials Properties Data: Status and Requirements Working Group Report

Members of Working Group:
M. Ulrickson, V.R. Barabash, M. Akiba,
R. Behrisch, A. Miyahara

Introduction

The success of the development of Fusion Reactors and the ITER reactor, first of all, strongly depends on the resolution of several materials problems. The current status of the ITER design is that we do not have precise choice of materials for plasma facing components.

The resolution of materials problems requires from the world community the following main directions of the activity:

- careful evaluation of existing materials;
- investigation of the missing but needed materials properties;
- development and investigation of new promising materials.

The IAEA meeting "Atomic and Molecular data for fusion reactor technology" discussed the current situation with materials data and the main requirements for PFC and PF materials and reached the following conclusions.

1. Assessment of the status of the existing database

The analysis of the current situation with existing databases on thermomechanical properties of fusion reactor materials has revealed that now exist a few databases:

- Fusion Materials Handbook developed in USA,
- Materials Data Base in Japan,
- NET material data, EC,
- Materials Data Base of Plasma Facing Components, RF.

The materials properties of ITER-CDA related materials were analyzed at ITER Group Meetings and partly published in the ITER materials data base (ITER Documentation Series, No. 29, 1991). The analysis of the existing databases has shown that all these databases have a wide range of materials and several properties for each of the materials.

For further development of fusion reactors, primarily for ITER project, it is important to provide a comparison of existing databases and establish a common collection of all these databases. We recommend that the collection should be established through the IAEA.

2. Identification and prioritization of materials databases

The development of fusion technolgoy determined that several different materials should be included for consideration in the database. The current status and prioritization of materials for plasma facing components is presented in Table 1. As plasma facing materials for ITER design the initial choices are Be and carbon fiber composites (CFC). Other new materials shuch as Ti- and B-doped graphites should be analised and their properties should be investigated. The choice of the high heat flux materials strongly depends on the operating conditions of the PFC.

Table 2 shows the main materials properties which should be included in the database. The different properties have different priorities, but for full validation of materials we need all these properties.

3. Required data package for material database

An IAEA specialist meeting was held in Decebmer 1990 to discuss the structure of a possible fusion plasma facing materials properties database. It was agreed at that meeting that the database should be in ALADDIN format. The types of data to be included were discussed and agreement was reached. Data for pyrolitic graphite and a few other graphites were assembled at the meeting. Data on Be have been added in this data base since the Meeting. The results of the meeting are summarized in an IAEA publication INDC(NDS)-246/MO.

4. Assessment of data generation, copmilation, and evaluation

Data Generation

Generation of the necessary data can only be performed by the national laboratories and associated laboratories. It should be performed with the advice and consent of ITER and include the needs of other devices in the host countries. It should be supported by the host organisations.

Data Compilation

It is strongly recommended that the data generated at the different laboratories should be stored on disks and made available to IAEA in ALADDIN format.

The IAEA should coordinate the gathering, evaluation and finally distribution of the database.

Data Evaluation

IAEA can provide distribution of the data to experts in the field and coordinate gathering of the experts for evaluation of the data. IAEA should provide facilities for the experts involved in the data evaluation.

IAEA will finally provide distribution of the data to ITER, to national laboratories and all fusion laboratories interested in these data compilations.

5. Recommendations

a) Priorities in data generation:

Several new carbon fiber composite (CFC) materials have been developed recently. These materials have high thermal conductivity and are potentially useful for PFC applications. Generation of complete data sets for these materials should be given high priority in order to allow them to be considered for ITER.

Several important properties of Be, e.g., fatigue, fracture toughness, and post irradiation properties are not well known. Acquisition of data in such areas should be high priority since Be is one of the candidate PFC materials in ITER.

New classes of materials are being developed. One example is the Ti-doped graphite from the Russian Federation. Data generation for such materials must be given a priority if initial screening tests show the materials to be promising for ITER.

The effect of neutron irradiation on materials is profound.

These effects are only partially quantified for most candidate materials. While data from fission reactors are very useful, it is important to get data from 14 MeV neutron irradiation because processes such as gas (helium) generation and displacement cascades are strongly affected by neutron energy. Irradiation affects the thermal conductivity and mechanical properties.

The design of ITER PFCs are very sensitive to the existing uncertainties in the materials data. In particular the space required for the divertor, the lifetime of the divertor and the reliability of the divertor are very sensitive to the uncertainties in the thermo-mechanical properties (especially after irradiation). The material selection is very sensitive to hydrogen retention and irradiation effects. The design of the remote handling devices is very sensitive to the uncertainties in induced activation.

b) Priorities in data evaluation and compilation:
The priorities for data compilation are shown in Table 1.

Data evaluation is most important for new materials, such as new CFC materials and Ti doped graphites. Several existing CFC materials (including the new CFC's) and Be have databases which are incomplete and sketchy. Evaluation of these data is required for using them for component design. A critical evaluation of the database on PFC/heat sin, joining (bonding) materials would help identify areas where additional data generation is needed.

c) International cooperation in data generation and evaluation

Most rapid progress forward in establishing a materials properties database necessary for ITER can be made if the partners coordinate their database generation activities. The combined pool of experts among the partners represents the best source for critical evaluation of the data. The IAEA should assist the evaluation by coordinating efforts of the expert panels.

d) Role of the IAEA and priorities of its future activities

The IAEA has taken a leadership role in establishing the A+M database. This has been very successful. The new activity on establishing a recommended materials properties database would benefit from the leadership of the IAEA in coordinating the database construction. IAEA participation in the materials database compilation would benefit the program of the partners in projects outside of ITER by making the data from all contributors available to all members. This provides a mechanism for development and testing of new materials and technologies. Both ITER and other fusion research programs would benefit from such improvement since the IAEA can provide rapid distribution of new data in a standard format.

In its PMI data programmes, the IAEA should include the criticality of divertor design and the sensitivity of the design to materials uncertainties in setting priorities for distribution of efforts between the different groups of parties.

The IAEA should organize a meeting to establish a CRP for compilation of the of the materials database in 1993. This meeting could be held in conjunction with the ICFRM-6 meeting in Italy.

Table 1. Priorities of Materials Data Generation and Evaluation

MATERIALS	PRIORITY
I. Plasma Facing Materials	
A. Low-Z materials	
Be, CFC	1
PG, C+Ti	2
C+B, SiC, BeB	3
B. High-Z materials	
W	2
Mo, Nb, Ta	3
C. Medium-Z materials	
V, SS, Ni-based	2
D. Advanced materials	
liquid metals	2
II. Heat Sink Materials	
Cu, Nb	1
Mo, SS	2

Table 2. Materials Properties Needed for Database

COMMON INFORMATION

Description of materials
Production history

BASELINE PHYSICAL PROPERTIES

Melting temperature
Boiling temperature
Vapor pressure
Heat of fusion
Heat of vaporization
Thermal conductivity (T)
Specific heat (T)
Density (T)
Coefficient of thermal expantion (T)
Electrical resistivity (T)
Viscosity

BASELINE MECHANICAL PROPERTIES

Elastic modulus (T)
Poison ratio (T)
Ultimate strength (T)
Yield strength (T)
Uniform elongation (T)
Total elongation (T)
Reduction of area (T)
Creep (T,G)
Fatigue (T,G)
Fracture toughness (T)

RADIATION EFFECTS (ϕ, ϕt, T)

- Physical propertries:
  - Thermal conductivity
  - Specific heat
  - Coefficient of thermal expansion
  - Electrical resistivity
- Swelling
- Mechanical properties:
  - Ultimate strength
  - Yield strength
  - Uniform elongation
  - Total elongation
  - Reduction of area
  - Creep
  - Fatigue
  - Fracture toughness
- Residual activity

CORROSION/CHEMICAL EFFECTS

- Hydrogen/Tritium
  - Solibitlity
  - Diffusivity
- Helium transport/trapping

CORROSION/ENVIRONMENTS

COMPONENTS PROPERTIES:

- Joining, including influence of radiation

5. MEETING CONCLUSIONS AND RECOMMENDATIONS

The Working Group Reports, as official documents of the Meeting, contain a detailed account of the A+M and PMI data status and needs for fusion, and the major conclusions and recommendations regarding the future activities in this area, including the role of the IAEA in these activities. Below we provide a summary of the Meeting conclusions and recommendation in a more condensed form.

5.1. Summary of Meeting Conclusions

(i) Role of A+M and PMI data in fusion research and reactor design

The current fusion research has reached the reactor relevant level and is entering into an engineering design phase of the first experimental fusion reactor. Several critical research and design areas, related to the reactor plasma performance and to the selection of reactor operational scenario, depend on the availability of reliable atomic, plasma-material interaction and materials properties data bases. These areas include: control of the plasma impurity content (defined by the plasma-wall interactions and shielding properties of the scrape-off layer), thermal power exhaust (defined by the atomic-collision induced radiative and non-radiative power losses in the plasma edge and by the thermo-conduction properties of plasma facing components), helium ash exhaust (determined by the neutral gas transport and recycling in the divertor region, helium recycling and wall a divertor pumping capabilities), characterization of plasma facing materials (defining the conditions for thermal power exhaust, coupling with coolants, allowed thermal peak loads, divertor plate lifetimes and tritium related safety issues), optimization of heating and diagnostic neutral beam heating line (including the ion source, neutralizer and beam-plasma interaction regions) and other fusion plasma diagnostic areas (such as charge-exchange diagnostics, X-ray VUV and optical spectroscopy, etc). The power and particle (helium) exhaust and the response of plasma facing materials to the high heat plasma and particle fluxes are currently among the most critical reactor design issues, requiring urgent establishment of the necessary A+M and particle-surface interaction and material properties data bases.

(ii) Status of the data bases and further data needs

There already exists a significant body of information regarding the characteristics of atomic and plasma-material interaction processes in fusion plasmas, as well as the thermo-mechanical properties of selected materials considered as suitable candidates for the reactor plasma facing components (as specified, for instance, during the ITER CDA). The most complete A+M and PMI data bases are those related to the core plasma impurity radiation (of the common plasma impurities), impurity and neutral particle transport in the plasma edge (including impurity and hydrogen recycling), neutral beam (hydrogen and helium)-plasma interaction, erosion and thermo-mechanical properties of low- and medium-Z candidate plasma facing materials (Be, C-C and CFC, Fe). Although adequate for rough estimates, these data bases are still insufficient (either too fragmentary or of inadequate accuracy) to provide a sound basis for precise modelling of the performance of specific reactor subsystems. Further data needs have been identified for the power exhaust system (divertor radiative cooling by high-Z impurities and/or dense, cold gas flow), helium exhaust (full collisional-radiative model for He and He^+, momentum transfer processes of H^+, He^+ and He^{2+} ions on divertor gas neutrals), net erosion of plasma facing materials (such as Be, CFCs, W) under realistic fusion plasma conditions (i.e. including re-deposition, elevated surface temperatures, material micro-structural changes), characterisation of disruption erosion, thermo-mechanical properties of plasma facing materials under high neutron fluences, hydrogen isotope retention (and release) in the plasma facing materials, etc.

(iii) Role of the IAEA

The past and present IAEA role in co-ordinating the national efforts on A+M and PMI data compilation, evaluation and generation, as well as in the preparation of sets of recommended data in formats appropriate for fusion application codes, has been assessed as very useful and effective. The IAEA A+M and PMI data activity provides the highly desirable interaction medium for the fusion and atomic/surface physics material science communities on an international level, and through its integrative and focussing role, significantly contributes to the enhancement of data generation efficiency for fusion. The leadership role of the IAEA in several data areas (such as establishment of recommended data bases for H- and He-neutral beam injection into plasma, erosion rates of fusion reactor materials and thermo-mechanical properties of plasma facing materials) has been recognized and highly commended.

5.2. Summary of Meeting Recommendations

(i) The world effort on A+M and PMI data compilation, evaluation and generation should continue to be concentrated on provding recommended data for resolving the critical issues in fusion reactor design work, in particular on the power and particle (helium) exhaust problems, characterization of plasma-wall erosion processes and the thermal response of plasma facing components to high heat and particle fluxes, and issues related to hydrogen isotope and helium retention in plasma facing materials. These issues are likely to persist and evolve, and are thus, of long-term nature. The impurity control and plasma edge cooling are of immediate concern in the major currently operating fusion devices (and also highly relevant for reactor design) and should be adequately reflected in and supported by the ongoing A+M and PMI data activities.

(ii) The international co-operation on collecting, evaluation and generation of A+M and PMI data for fusion should be further strengthned, particularly having in mind the large amount of required data and the programmatic schedule of current fusion programmes and of ITER EDA.

(iii) The IAEA role in promoting, co-ordinating and integrating the A+M and PMI data activity has been so far highly effective and resulted in significant benefits to the fusion programme. This Agency's role should further be strengthned and more vigorously expanded in the area of plasma-material interaction data for fusion.

(iv) The IAEA A+M Data Unit has the capabilities to serve as an international centre for storage, formatting and dissemination of A+M and PMI data for fusion, and to coordinate most of the data generation and evaluation activities. The Agency ALADDIN system has proved to be very appropriate for formatting and processing of all types of A+M and PMI data, and its broad use and further development is highly encouraged.

5.3. Specific Recommendations to the IAEA

(i) Initiate during 1993 the following Co-ordinated Programmes (CRPs):

1) CRP on A+M and PMI data bases for H and He recycling and exhaust in fusion reactor divertors.
2) CRP on Radiative cooling rates of fusion plasma impurities.
3) CRP on Hydrogen and Helium retention and release in fusion reactor plasma facing components.
4) CRP on Reference data for thermo-mechanical properties of fusion reactor plasma facing materials.

(ii) Organize in 1993 the following consultants and/or specialists meetings, in conjunction with already approved meetings:

1) A two days meeting to formulate the scope and select participants for the CRP on H and He recycling.
2) A two days meeting on Tritium retention in fusion reactor plasma facing components.
3) A one day meeting on the Kr data base for X-ray core plasma diagnostics and radiative cooling of reactor divertors.
4) A one day meeting (in conjunction with the ICFRM-6 meeting in Italy) to formulate the scope and select participants for the CRP on material thermo-mechanical properties.

(iii) The Agency should continue and further enhance its efforts in providing the fusion community with data packages which can be directly connected with fusion application codes. This would require further strengthening of the technical and manpower basis for this activity in the Agency.

(iv) The IAEA A+M Data Unit and the Agency co-ordinated international A+M Data Centre Network should continue to direct some of their attention to the data needs of next-step ignited plasma experiments, such as ITER, and should attempt to establish a formal connection with the ITER Team both to obtain direction and to ensure that their efforts have the appropriate impact.

(v) The Agency should take the necessary steps to ensure a broad distribution of the results of the present Meeting (the Working Group Reports and Meeting conclusions and recommendations), including the publication of invited talks and poster contributions.

Appendix 1

List of Participants to the TCM on "Atomic and Molecular Data for Fusion Reactor Technology"

October 12-16, 1992, Cadarache, France

IAEA

Dr. V.A. Konshin	International Atomic Energy Agency, Division of Physical and Chemical Sciences, Wagramerstrasse 5, P.O. Box 100, A-1400 Vienna
Dr. R.K. Janev	Atomic and Molecular Data Unit, Nuclear Data Section, Division of Physical and Chemical Sciences, IAEA, Wagramerstrasse 5, P.O. Box 100, A-1400 Vienna
Dr. D. Banner	Physics Section, Division of Physical and Chemical Sciences, IAEA, Wagramerstrasse 5, P.O. Box 100, A-1400 Vienna

AUSTRIA

Dr. G. Betz	Institut für Allgemeine Physik, Technische Universität Wien, Wiedner Hauptstrasse 8-10, A-1040 Wien

BELGIUM

Prof. F. Brouillard	Universite Catholique de Louvain, Dept. de Physique, FYAM, Chemin du Cyclotron 2, B-1348 Louvain-la-Neuve

CANADA

Prof. A.A. Haasz	Institute for Aerospace Studies, University of Toronto, 4925 Dufferin St., Downsview, Ontario M3H 5T6
Dr. R. Marchand	INRS - ENERGIE, Universite de Québec, Institut National de la Recherche Scientifique, 1650 Montée Sainte-Julie, Case Postale 1020, Varennes Québec J0L 2P0
Dr. P.C. Stangeby	University of Toronto, Institute for Aerospace Studies and Centre for Nuclear Engineering, 4925 Dufferin St., Downsview, Ontario, M3H 5T6

COMMISSION OF THE EUROPEAN COMMUNITIES

Dr. H. Bruhns	CEC - Directorate-General for Science Research and Development, Fusion Programme Directorate, 200, Rue de la Loi, B-1049 Brussels, BELGIUM
Dr. A. Perujo	CEC - Joint Research Centre, Ispra Establishment, I-21020 Ispra, ITALY
Dr. H.P. Summers	CEC - UKAEA - JET Joint Undertaking (Joint European Torus), Culham Laboratory, Abingdon, Oxfordshire OX14 3EA, UNITED KINGDOM
Dr. M. von Hellermann	CEC - UKAEA - JET Joint Undertaking (Joint European Torus), Culham Laboratory, Abingdon, Oxfordshire OX14 3EA, UNITED KINGDOM

FRANCE

Dr. M. Chatelier	Dept. de Recherches sur la Fusion Contrôlée, Association EURATOM-CEA, Centre d'Etudes Nucléaires de Cadarache, B.P. No. 1, F-13108 Saint-Paul-Léz-Durance
Prof. J.L Delcroix	GAPHYOR, Laboratoire de Physique des Plasmas, Université de Paris XI (Paris-Sud), 15, Rue G. Clémenceau, F-91405 Orsay Cedex
Dr. C. Deutsch	Laboratoire de Physique des Gaz et Plasmas, Bât. 212, Université de Paris XI, F-91405 Orsay
Dr. H.-W. Drawin	Dept. de Recherches sur la Fusion Contrôlée, Association EURATOM-CEA, Centre d'Etudes Nucléaires de Cadarache, B.P. No. 1, F-13108 Saint-Paul-Léz-Durance
Dr. A. Grosman	Dept. de Physique des Plasmas et de la Fusion Contrôlée, Association Euratom-CEA, Centre d'Etudes Nucléaires de Cadarache, B.P. No. 1, F-13108 Saint-Paul-Léz-Durance
Dr. K. Katsonis	GAPHYOR, Laboratoire de Physique des Plasmas, Université de Paris XI (Paris-sud), 15, Rue G. Clémenceau, F-91405 Orsay Cedex
Dr. M. Mattioli	Dept. de Recherches sur la Fusion Contrôlée, Association Euratom-CEA, Centre d'Etudes Nucléaires de Cadarache, B.P. No. 1, F-13108 Saint-Paul-Léz-Durance
Dr. P. Monier-Garbet	Dept. de Physique des Plasmas et de la Fusion Contrôlée, Association Euratom-CEA, Centre d'Etudes Nucléaires de Cadarache, B.P. No. 1, F-13108 Saint-Paul-Léz-Durance

FRANCE (Contd.)

Dr. H. Bachau	Laboratoire des Collisions Atomiques, Université de Bordeaux I, 351, Cours de la Libération, F-33405 Talence Cedex
Dr. M. Druetta	Laboratoire TSI, Université de Saint-Etienne, 23, Rue du Professeur Michelon, F-42023 Saint-Etienne Cedex
Dr. W. Hess	Dept. de Physique des Plasmas et de la Fusion Contrôlée, Association Euratom-CEA, Centre d'Etudes Nucléaires de Cadarache, B.P. No. 1, F-13108 Saint-Paul-Léz-Durance

GERMANY

Dr. R. Behrisch	Max-Planck-Institut für Plasmaphysik, Boltzmannstrasse 2, D-W-8046 Garching bei München
Dr. W. Eckstein	Max-Planck-Institut für Plasmaphysik, Boltzmannstrasse 2, D-W-8046 Garching bei München
Dr. A. Pospieszczyk	Forschungszentrum Jülich, Postfach 1913, D-W-5170 Jülich 1
Dr. D. Reiter	Forschungszentrum Jülich, Postfach 1913, D-W-5170 Jülich 1
Dr. J. Roth	Max-Planck-Institut für Plasmaphysik, Boltzmann Strasse 2, D-W-8046 Garching bei München
Dr. E. Vietzke	Forschungszentrum Jülich, Postfach 1913, D-W-5170 Jülich 1

ITALY

Dr. E. Menapace (Observer)	ENEA A+M Data Center, C.R.E. "E. Clementel", Viale Ercolan 8, I-40138 Bologna

JAPAN

Dr. M. Akiba	NBI Heating Laboratory, Japan Atomic Energy Research Institute (JAERI), 801-1 Naka-machi, Naka-gun, Ibaraki-ken, 311-01
Dr. T. Fujimoto	Associate Professor, Dept. of Engineering Sciences, Kyoto University, Sakyo-Ku, Kyoto 606
Dr. T. Kato	Data and Planning Centre, National Institute for Fusion Science (NIFS), Nagoya 464
Dr. A. Miyahara	Teikyo University, Otsuka, Hachioji, Tokyo

JAPAN (Contd.)

Dr. K. Morita	Department of Crystaline Material Science, Faculty of Engineering, Nagoya University, Furo-cho, Chigusa-ku, Nagoya 464-01
Dr. M. Saidoh	Japan Atomic Energy Research Institute (JAERI), Tokai-mura, Naka-gun, Ibaraki-ken 319-11
Dr. M. Shimada	Japan Atomic Energy Research Institute (JAERI), Tokai-mura, Naka-gun, Ibaraki-ken 319-11
Dr. T. Tanabe	Osaka University, Dept. of Nuclear Engineering, Faculty of Engineering, 2-1 Yamada-Oka, Suita, Osaka 565
Dr. H. Tawara	Data and Planning Centre, National Institute for Fusion Science (NIFS), Nagoya 464

NETHERLANDS

Dr. R. Hoekstra	Kernfysisch Versneller Instituut, Zernikelaan 25, NL-9747 AA Groningen
Dr. H.O. Folkerst	Kernfysisch Versneller Instituut, Zernikelaan 25, NL-9747 AA Groningen

THE RUSSIAN FEDERATION

Dr. V.A. Abramov*	Institut Atomnoi Energii I.V. Kurchatova, Ploshchad I.V. Kurchatova, Moscow D-182, 123182
Dr. V.R. Barabash*	D.V. Efremov Scientific Research Institute of Electrophysics Apparatus, P.O. Box 42, St. Petersburg 189631, Metallostroi

SWEDEN

Dr. E. Källne	Division of Plasma Physics and Fusion Research, Royal Institute of Technology, S-10044 Stockholm
Prof. I. Martinson	University of Lund, Department of Physics, Sölvegatan 14B, S-223 64 Lund

UNITED KINGDOM AND NORTHERN IRELAND

Prof. H.B. Gilbody	The Queen's University of Belfast, Department of Applied Mathematics and Theoretical Physics, Belfast BT7 1NN

*** Consultant to the IAEA**

UNITED STATES OF AMERICA

Dr. M. Bitter	Plasma Physics Laboratory, Princeton University, James Forrestal Campus, P.O. Box 451, Princeton, NJ 08544
Dr. J. Brooks	Argonne National Laboratory, 9700 South Cass Avenue, Argonne, Illinois 60439
Dr. Y. Hirooka	Institute of Plasma Physics and Fusion Research, University of California, Los Angeles, CA 90024
Dr. R.A. Hulse	Plasma Physics Laboratory, Princeton University, P.O. Box 451, Princeton, NJ 08540
Dr. R.H. McKnight	Division of Applied Plasma Physics, ER-542, GTN, US Dept. of Energy, Washington, D.C. 20545
Dr. R.A. Phaneuf	Department of Physics, University of Nevada-Reno, M.S. 220, Reno, Nevada 89557-0058
Dr. D.E. Post	Princeton University, Plasma Physics Laboratory, P.O. Box 451, Princeton, NJ 08540
Prof. E.W. Thomas	School of Physics, Georgia Institute of Technology, Atlanta Georgia 30332
Dr. M. Ulrickson	Plasma Physics Laboratory, Princeton University, P.O. Box 451, Princeton, NJ 08540
Dr. W.L. Wiese	Bldg. 221, Room: A267, National Institute for Standards and Technology (NIST), Atomic & Plasma Radiation Division, United States Department of Commerce, Gaithersburg, MD 20899
Dr. K.L. Wilson	Physical Res. Div. 8347, Sandia National Laboratories, Livermore, CA 94551-0969

Appendix 2

IAEA Technical Committee Meeting on
ATOMIC AND MOLECULAR DATA FOR FUSION REACTOR TECHNOLOGY

Cadarache, France
October 12-16, 1992

MEETING PROGRAMME

Monday, October 12: Morning

09:30 - 10:00 Opening addresses

V.A. Konshin: IAEA representative
R. Gravier: Host institution representative

SESSION 1. **Overview on the fusion programme and its atomic and plasma-material interaction aspects**

Chairman: R. McKnight

10:00 - 10:45 Status of controlled thermonuclear fusion research

H. Bruhns

10:45 - 11:15 **Coffee break**

11:15 - 11:45 Atomic physics aspects of controlled thermonuclear fusion

H.W. Drawin

11:45 - 12:15 Plasma-material interaction aspects of controlled fusion

A. Miyahara

12:15 - 14:00 **Lunch**

Monday, October 12: Afternoon

SESSION 2. **Atomic and molecular data needs for present large fusion experiments**

Chairman: V.A. Abramov

14:00 - 14:30	Spectroscopic diagnostics of tokamak plasmas H.P. Summers
14:30 - 15:00	X-ray plasma diagnostics M. Bitter
15:00 - 15:30	Neutral particle diagnostics of tokamak plasmas M. von Hellermann
15:30 - 16:00	Modelling of impurity transport in the core plasma R. Hulse
16:00 - 16:30	**Coffee break**
16:30 - 17:00	Particle recycling in Tokamak long pulse discharges M. Chatelier
17:00 - 17:30	Diagnostics of edge plasmas by optical methods A. Pospieszczyk
17:30 - 18:00	Impurity transport in the plasma edge region P. Stangeby
18:00 - 18:30	Neutral particle transport in the plasma edge D. Reiter

Tuesday, October 13: Morning

SESSION 3.	**Plasma-material interaction data needs for present fusion experiments**
Chairman:	R. Behrisch
09:00 - 09:30	Data status and needs for basic impurity generation particle-surface interaction processes J. Roth
09:30 - 10:00	Plasma-induced erosion and redeposition of fusion reactor candidate materials Y. Hirooka
10:00 - 10:30	Theoretical modelling of erosion and redeposition processes J. Brooks
10:30 - 11:00	**Coffee break**
11:00 - 11:30	Retention and release of implanted hydrogen isotopes K.L. Wilson
11:30 - 12:00	Thermal response of plasma-facing materials and impurity generation M. Akiba
12:00 - 12:30	Thermal response of carbon based and Be/B materials M. Ulrickson
12:30 - 14:00	**Lunch**

Tuesday, October 13: Afternoon

SESSION 4.	**Additional atomic and plasma-material interaction data needs for next step devices**
Chairman:	J. Brooks
14:00 - 14:30	Atomic physics needs for the next generation Tokamak experiments D.E. Post
14:30 - 15:00	Atomic data needs for edge plasma cooling and particle exhaust M.F.A. Harrison
15:00 - 15:30	Status and future prospects of active beam based alpha particle diagnostics M. von Hellermann
15:30 - 16:00	**Coffee break**
16:00 - 16:30	Plasma-material interaction data needs for impurity control in next step devices M. Shimada
16:30 - 17:00	Requirements on thermo-mechanical properties of plasma-facing reactor materials W. Gauster (K. Wilson)
17:00 - 17:30	Atomic data needs for inertial confinement fusion C. Deutsch
17:45 - 19:30	**POSTER SESSION - I**

Scope:
1) Atomic collision and radiative processes;
2) Compilation and evaluation of atomic and molecular collisional and spectroscopic data;
3) Fusion applications of atomic and molecular data (modelling and diagnostics).

Wednesday, October 14

SESSION 5.	**Status of atomic and molecular (A+M) and plasma-material interaction (PMI) data bases for fusion**
Chairman:	J.L. Delcroix
09:00 - 09:30	The IAEA A+M and PMI data programmes and recommended data bases R.K. Janev
09:30 - 10:00	Status of spectroscopic A+M data bases W.L. Wiese
10:00 - 10:30	**Coffee break**
10:30 - 11:00	Status of A+M collisional data bases R.A. Phaneuf
11:30 - 12:00	**FORMATION OF MEETING WORKING GROUPS AND DEFINITION OF THEIR TASKS** R.K. Janev, Chairman
12:00 - 14:00	**Lunch**
14:00 - 16:30	Visit to Tore Supra and Cadarache fusion laboratories
17:00 - 19:00	**POSTER SESSION - II** **Scope:** 1) Particle-surface collision processes; 2) Plasma-material interaction processes; 3) Thermal response of plasma facing materials; 4) Plasma-material interaction data compilation and evaluation.

Thursday, October 15

SESSION 6.	**Detailed analysis of A+M and PMI data status and needs for current and next step fusion experiments. Preparation of Meeting conclusions and recommendations**
09:00 - 10:30	Parallel sessions of the Working Groups on: A) A+M data status and requirements Co-chairmen: D. Post and R. Phaneuf B) Plasma-surface interaction data: status and requirements Co-chairmen: J. Roth and K. Wilson C) Material properties data: status and requirements Co-chairmen: A. Miyahara and V.R. Barabash
10:30 - 11:00	**Coffee break**
11:00 - 12:30	Working Group Sessions (cont'd)
12:30 - 14:00	**Lunch**
14:00 - 15:30	Working Group Sessions (cont'd)
15:30 - 16:00	**Coffee break**
16:00 - 18:00	Working Group Sessions (cont'd)

Friday, October 16

SESSION 6.	**(cont'd)**
09:00 - 10:30	Working Group Sessions: Preparation of Working Group reports, with conclusions and recommendations
10:30 - 11:00	**Coffee break**
SESSION 7.	**Discussion of Working Group Reports and adoption of Meeting conclusions and recommendations** Chairman: R.K. Janev
11:00 - 12:30	- Presentation and discussion of Working Group reports - Adoption of Meeting conclusions and recommendations

APPENDIX 3

LIST OF POSTER CONTRIBUTIONS

Poster Session - I

AUTHORS	TITLES
Tk. McLaughlin, H. Tawara, R.W. McCallough, H.B. Gilbody	State selective electron capture in collisions of slow multiply charged Fe ions with H and He
W. Hess, M. Mattioli	Highly excited charge-exchange carbon ions as a neutral density probe at the plasma edge
K. Katsonis, G. Maynard	Atomic collision cross sections calculation with the CTCM method
H. Tawara et al.	Atomic and molecular data for electron collisions with impurity species relevant to edge plasma research
W. Wiese, J.R. Fuhr, W.C. Martin, A. Musgrove, J. Reader, J. Sugar, G.R. Dalton, T. Shirai	Critically evaluated spectroscopy data for atoms and ions
K. Kato, K. Masai	Time dependant X-ray spectra from laboratory plasma and solar flare
T. Kato, K. Takasugi, Y. Kanada, T. Ogasawara, K. Masai	Atomic data base in National Institute for Fusion Studies (NIFS)
M. Ulrickson	Atomic data needs for radiative divertors
D.R. Schultz, M.I. Kirkpatrick, R.A. Phaneuf	Compilation of atomic data for fusion by the ORNL controlled fusion atomic data center
M. Druetta, D. Hitz	Charge exchange spectroscopy measurements of Fe^{q+} (q=7,8,9) + He, H_2 collisions
H.O. Folkerts, R. Hoekstra, F.J. de Heer, R. Morgenstern	State selective electron capture and excitation cross sections in ion - He collisions relevant for diagnostic at JET
R. Hoekstra, F.J. de Heer, R. Morgenstern	The JET He data base: some relevant collision cross sections
T. Fujimoto	Plasma polarization spectroscopy
T. Fujimoto, K. Sawada	Hydrogen atom spectroscopy of molecules in tokamak

Poster Session - I

AUTHORS	TITLES
A.A. Haasz	Hydrogen in graphites
A. Perujo, F. Reiter, J. Composiluan, S. Fominetti	Ethel 001: a versatile facility for plasma-surface interaction research
K. Morita, Y. Muto	Modeling of retention and re-emission of hydrogen isotopes from graphite during D-T dual-irradiation
K. Morita, K. Mori, S. Ikeda, S. Takamura	Temperature and flux dependences of metal sputtering yield from metal-carbon composite materials at high temperature
E. Vietzke, P. Franzen, A.A. Haasz, D. Reiter	Atomic re-emission of hydrogen from pure and boronised graphites at temperatures above 1000 K
J. Das, H.O. Folkerts, R. Hoekstra, R. Morgenstern	Neutralization of multiply charged ions at surfaces
M. Saidoh, R. Jimbon, N. Ogiwara, T. Ando, M. Shimizu	Characteristics of B/C materials as plasma facing materials
V.R. Barabash, A.V. Naberenkov, Yu.G. prokofiev	Review of beryllium thermomechanical properties for plasma facing components of fusion reactors