IAEA
International Atomic Energy Agency

INDC(NDS)- 0607
Distr. LP,NE,SK

INDC International Nuclear Data Committee

Characterization of Size, Composition and Origins of Dust in Fusion Devices

Summary Report of the Third Research Coordination Meeting

IAEA Headquarters, Vienna, Austria

30 November – 02 December 2011

Prepared by

B. J. Braams

February 2013

IAEA Nuclear Data Section, Vienna International Centre, A-1400 Vienna, Austria

Selected INDC documents may be downloaded in electronic form from
http://www-nds.iaea.org/reports-new/indc-reports or sent as an e-mail attachment.
Requests for hardcopy or e-mail transmittal should be directed to *services@iaeand.iaea.org*
or to:
Nuclear Data Section
International Atomic Energy Agency
PO Box 100
Vienna International Centre
A-1400 Vienna
Austria

Printed by the IAEA in Austria

February 2013

INDC(NDS)- 0607
Distr. LP,NE,SK

Characterization of Size, Composition and Origins of Dust in Fusion Devices

Summary Report of the Third Research Coordination Meeting

IAEA Headquarters, Vienna, Austria

30 November – 02 December 2011

Prepared by

B. J. Braams

Abstract

Twelve experts on processes of dust in fusion experiments met at IAEA Headquarters 30 November – 02 December 2011 for the 3rd Research Coordination Meeting (RCM) of the Coordinated Research Project (CRP) on "Characterization of size, composition and origins of dust in fusion devices." Participants reviewed their work done in the course of the CRP and the current state of knowledge, and they made plans for a dust database and a final CRP report. Presentations, discussions and recommendations of the RCM are summarized here.

February 2013

TABLE OF CONTENTS

1. Introduction

Plasma-material interaction in fusion devices may cause formation of redeposited layers, melt structures, blisters and flakes, which can be released and accumulate as dust on the floor of the vacuum vessel. In present plasma physics experiments this does not pose a problem, but ITER will have a very much longer pulse length and the amount of dust that could be accumulated as well as the amount of tritium potentially trapped in that dust is a genuine concern and is a major issue for the licensing of ITER as a nuclear device. The IAEA Coordinated Research Project (CRP) on "Characterization of size, composition and origin of dust in fusion devices" was formed to improve our knowledge of properties, production mechanisms and dynamics of dust in fusion devices. The CRP held Research Coordination Meetings (RCM) on 10–12 December 2008, 21–23 June 2010 and 30 November – 2 December 2011 at IAEA Headquarters in Vienna. Presentations, discussions and recommendations of the third and final RCM are summarized in this report. Reports of the earlier two meetings, participants' presentation materials and additional information about the work of this CRP may be found through the Atomic and Molecular Data Unit web pages under **http://www-amdis.iaea.org/**.

Section 2 contains summaries of the presentations at the meeting. Section 3 describes the discussions and conclusions of the meeting. The list of participants is provided in Appendix 1 and the agenda of the meeting in Appendix 2. Appendix 3 provides a list of recent publications by participants in the CRP that are related to the subject matter of the CRP.

2. Presentations

Robin A. Forrest and Bas Braams: Opening.

Dr Forrest, head of the Nuclear Data Section, welcomed participants to the IAEA. The present CRP was formed in order to gather information on properties of dust, such as particle size distribution, composition and origins in fusion machines. Dr Forrest recalled that formation of dust and the associated tritium uptake is seen as the primary safety concern for licensing of ITER. Moreover, for ITER the dust inventory can't just be inspected between campaigns; it must be monitored continuously. Therefore this CRP is very relevant to the development of fusion energy, and Dr Forrest wished for a productive meeting. Dr Braams (scientific secretary) extended his welcome and noted the principal tasks for this meeting: to inventorise what has been learned over the past few years, review continuing concerns over dust as a safety hazard, discuss the establishment of a database of dust particle properties in fusion and make plans for the final report of the CRP.

C. Grisolia: The French contribution to dust in fusion and current perspectives

Dr Grisolia reviewed a wide range of activities being carried out in French research institutes and universities on dust in fusion plasma.

L. Couëdel and C. Arnas at the laboratory for Ionic and Molecular Interaction Physics (PIIM) at University of Marseille study dusty plasma in a DC glow discharge. Typical plasma parameters for an argon plasma with a cathode voltage of -600 V are n_e = $2\times10^{16}/m^3$ and T_e = 2 eV. On a tungsten surface the sputter yield is about 4% and in a discharge of several minutes tungsten nanocrystallites are formed. These are aggregates, not melt particles.

A group led by H. Roche and working with C. H. Skinner built and installed an electrostatic dust detector for Tore Supra that was active during the late plasma campaign of 2010. They were able to analyse 481 plasma shots for a total of 2h55m cumulated plasma discharges and assemble some statistics. Of the 481 shots 101 ended in a disruption and disruptions were associated with 92% of the dust detected. The dust appears in the detector during a period of up to 5s following the disruption and also during current ramp up in the discharge immediately following a disruption. The measurements can be correlated with visible CCD images of dust in the plasma and pumping duct. The Tore Supra group also studies the effectiveness of dust removal by air under normal atmospheric pressure. These studies are ongoing and it isn't yet clear what fraction of the dust can be brought into suspension and removed in air.

At the Industrial Thermal System Institute (IUSTI) in Marseille dust suspension measurements are made using light extinction spectroscopy (LES). The standard dust are spherical tungsten nanoparticles in a wide range of sizes, diameter from 1 to 200 nm. The LES provides an accurate measurement of the dust size.

Other work on dust that is supported by the CEA for fusion is concerned with the production of ITER relevant model dusts and with toxicology studies. Studies are just starting of dust mobilization and suspension in the "Banc de mise en suspension par Ecoulement" (BISE) at IRSN, Gensdarmes. On Tore Supra there is an active experimental and modelling programme on runaway electrons and their role in production of dust.

S.-H. Hong: Statistics on dusts in KSTAR and dust transport and removal experiments in TReD

Dr Hong reported on studies of dust in KSTAR and on dust transport and removal experiments in the TReD device.

The work on KSTAR is geared towards establishment of a dust particle properties database obtained by automated analysis of photographic images of dusts. The analysis is to be done using the ImageJ program and procedures for this are being defined. It is found that the shape description from ImageJ depends strongly on parameters such as magnification, brightness, contrast and resolution and these settings must be precisely specified in order to obtain reproducible results. ImageJ analysis then returns size, number density and shape descriptors. The chemical composition of the dust is analysed by EDX.

To be sure that dusts are created by plasma-surface interaction and not during the maintenance, silicon wafer samples should be installed after the maintenance, just before the machine closing. At KSTAR these wafers are installed every day in the morning so that the evolution of dusts can be followed with day-to-day resolution. Dust is identified after disruptions by Thomson scattering and dust impact on the first wall is analysed by looking at impact craters on coupon holders. Production of dust is strongly correlated with disruptions.

Dust creation zones are identified by CCD image analysis and their distribution is analysed over a campaign. During limiter operation the dust creation events are distributed more or less randomly over the surface as was also observed on Tore Supra. During divertor operation the dust creation events are localized at the divertor (as on AUG) and also at the upper passive stabilizer, which has been deformed due to frequent vertical displacement events.

Dust trajectories are analysed using the KSTARTV2011 program by Y. N. Nam; 1237 trajectories were analysed over the 2010 campaign and 1821 trajectories over the 2011 campaign. The dust velocity distribution is obtained and it has a peak at (30-50) m/s and extends up to about 400 m/s.

The Transport and Removal of Dust (TReD) experiment is used for laboratory study of methods of dust detection and removal. A capacitive diaphragm gauge (CDG) was manufactured to weigh the deposited dust; the sensitivity is a few mg. The dust removal efficiency in TReD is about 5-10 mg/hr under unoptimized conditions.

V. Rohde: Dust investigations at IPP: Statistically relevant dust collection in AUG and LHD, F4E dust monitor and fast camera evaluation

Dr Rohde provided a review of several dust researches on AUG and on other experiments carried out in collaboration with IPP, in particular involving Idaho National Laboratory (INL), USA, Warsaw University of Technology (WUT), Poland, Henri Poincaré University in Nancy, France, and National Institute for Fusion Science (NIFS) in Japan.

In collaboration with WUT dust is analysed that is obtained by filtered vacuum technique. Scanning and Transmission Electron Microscopy (SEM/TEM) and energy-dispersed X-ray (EDX) analysis are used. Many different interesting structures are found. However, the vacuum technique of dust collection is not ideal for analysis because one doesn't know the sampling probability and particles can agglomerate or be damaged. It is of interest to use more refined methods of dust collection.

A standard dust collector was developed and was installed on AUG and also on DIII-D, LHD and JET and the analyses were done jointly to ensure compatibility of the procedures. The design involves a Si wafer. The wafer is scanned and all particles are identified and an EDX spectrum is obtained. The analysis software runs on an FEI-Helios device and analyses 10000 particles over a weekend. The large number of particles analysed allows to define particle classes. For AUG 90% of the particles found could be described using 6 different classes: W spheres, W flakes, Carbon, Boron, Iron and Copper-containing particles. The analysis of the distribution function of these classes provides information on the particle production mechanism (INL). The scope of this method is demonstrated by the LHD investigations: C spheres, injected for transport investigations, could be separated from the normal dust observed. Other classes for LHD besides C spheres were C flakes, Al splash, various mixed conglomerates and steel agglomerates. Statistical analysis of the classifications was done, both on LHD and on AUG.

Detailed analysis of the W containing dust particles in AUG point to the importance of arcing for dust production. Whereas physical and chemical sputtering is strongly reduced in high-Z devices, arcing can locally dominate the erosion of the plasma facing components.

In addition to the Si wafer also a capacitative dust monitor (CDM) was tested for AUG following a design by G. Counsell. The main problem with this technique is the long cable length (40m) that is required in the noisy tokamak environment. Laboratory tests have been successful and it is planned that 2 CDMs will be installed below the divertor in AUG. A conceptual design is being carried out for ITER.

For real time dust measurements AUG uses a fast video camera with analysis tools developed at Nancy. Some 1500 shots have been evaluated. As on other devices dust production is strongly correlated with disruptions.

N. Ashikawa: Recent investigations of dust particles in LHD and JT-60U

Dr Ashikawa presented work on dust in the Japanese programme: (1) comparison of carbon dust in LHD and JT-60U, (2) analytical method for small amounts of W-C dust in JT-60U, (3) hydrogen retention in dust and (4) Aerogel experiment in LHD.

Dust collection is done by vacuum pump after the vessel is opened to air. Carbon dust are spheres or conglomerates. On LHD the carbon dust is found to have diameter below 1 μm whereas on JT-60U the diameter of dust ranges from 1-10 μm. It is explained by different production mechanisms; disruptions on JT-60U but not on the helical device LHD. New dust collection was done in JT-60U after its shutdown in 2010. There is a small amount of W dust, which can be detected using XPS with indium film.

Deuterium retention in dust was studied on JT-60U. It is estimated that the total surface area of dust (based on ~1 μm diameter) is 3000 m^2. The collected area in the vessel was only a small fraction, 1.4×10^{-2} m^2. The analysis indicates a D inventory of 2.1×10^{20} atoms/m^2 on the dust.

SiO_2 aerogel was used to trap dust in various locations near the first wall.

As the coordinator for dust research in ITPA Dr Ashikawa presented the tentative plans for the next phase of ITPA activities. The involved experiments are LHD, JT-60U, DIII-D, AUG, TEXTOR, HT-7, HL-2A, FTU, KSTAR, Tore Supra, JET and T-10. Studies of morphology and composition are planned on almost all devices, aerogel experiments are foreseen for LHD, TEXTOR, HT-7 and FTU with planning also on DIII-D.

S. Ciattaglia: Strategy and plan for in-vessel dust (and tritium retention) control in ITER. Status November 2011

The main safety issue for licensing of ITER is control of radioactive inventory, and ITER must convince the licensing authorities that it can verify this inventory at all times. Dr Ciattaglia presented an update of the technological issues and procedures. In early 2011 the French nuclear authority (ASN) gave the desired "acceptability" evaluation to the Preliminary Safety Analysis Report (PSAR). A Public Enquiry took place in June-July 2011 and it is hoped to obtain the license for construction in early 2012 [in fact, this was obtained on 20 June 2012] following which a detailed safety contract will be created to bind the ITER Organization and the French State for the lifetime of the project.

Two main sources of dust are foreseen. During normal steady operation redeposited layers are formed and such a layer can delaminate. During transient events large scale melting of the Be first wall and the W divertor is possible, and transient events may also cause release of deposited layers.

The baseline systems for in-vessel dust measurements are a Capacitive Diaphragm Monitor (CDM) being developed at IPP Garching and the In-Vessel Viewing System (IVVS). Tritium inventory will be measured as the difference between T injected and T recovered and also by testing samples removed from the vacuum vessel using LIBS. There is a preliminary design from FZJ for Removable Samples to be installed in the vacuum vessel. There is a need still for a method for non-invasive global hot dust measurement.

It is expected that about 10%-15% of deposited dust can be removed at each vacuum vessel opening and essentially all dust is removed when the divertor is replaced, as is planned to be done after appr. 6000 pulses. In order to remove tritium between VV replacement and before VV venting the divertor will be baked at 350 °C.

A. Widdowson: Update on dust activities at JET

Dr Widdowson provided an update on dust analysis on JET and a first estimate of carbon balance and dust generation. Note that all this is from before the introduction of the ITER-Like Wall. Dust is primarily found in the divertor with composition varying by location. The dust is collected by vacuuming and about 270 g was collected in total. The various regions were previously vacuumed at various times going back to 1998, so these measurements are integrated over multiple campaigns. Dust is primarily deposited in the inner scrape-off layer and divertor whereas erosion dominates on the outboard side.

The analysis of dust size distribution and composition is underway with support from an ITER contract. Also tritium content is studied.

For carbon balance the key question in relation to dust formation is the fraction of eroded material that is converted to dust. Erosion is measured primarily by tile profiling. The analysis is spatially resolved. Finally the present figures suggest a conversion factor of about 15%, but the work is continuing.

It is intended to install passive dust collectors in JET in collaboration with V. Rohde of IPP Garching in order to collect and analyse dust from the beryllium first wall in the JET ITER-Like Wall (ILW) campaign. The analysis will be carried out in Garching. As no manned access is planned for 2012 the collector locations shall be accessible by remote handling. There are 5 locations: two on the inboard side, two outboard and one on the upper edge of the outer divertor.

C. Skinner: Advances in electrostatic dust detection and removal

The ITER strategy is to diagnose dust inventory from divertor erosion measurements (laser rangefinder) and to install local dust monitors. Dr Skinner presented the development of local dust monitors based on electrostatic detection and removal. The technique relies on a 50V bias that is applied to a grid of interlocking copper traces on a circuit board. Impinging dust creates a short circuit, which is detected and counted. The current also vaporizes or ejects the dust and thereby recreates the open circuit. The device can work in air or in vacuum. The waveform of the short circuit provides information about the dust size. An electrostatic dust detector was demonstrated on NSTX in 2009 and on Tore Supra in 2010. (See the presentation of C. Grisolia.)

It is found that dust production on NSTX is correlated with disruptions, but the correlation is not universal. Dust is also produced independent of disruptions. There is also a strong correlation with Li particle dropper.

Not all of the detected dust is vaporized, and the residual dust may produce signals at a later time. A He puffer has been developed and optimized to remove residual dust and thereby the residual counts are reduced from ~10% to less than 0.5%.

The sensitivity of the electrostatic detector depends on the type of the dust particle; it is extremely sensitive to Li and C particles. W particles are a challenge because the copper traces are easily damaged. A new more robust design that uses tungsten wires instead of copper has been tested.

Concerning dust removal an electrostatic dust conveyor has been developed for tokamak dust removal and tested with relevant W and C particles and also glass spheres and sand. Dr Skinner outlined a concept for a mosaic of such dust conveyors on ITER in hidden areas on the lower vacuum vessel.

J. Winter: Fundamental aspects of dusty plasmas

Dr Winter uses RF or DC glow discharge laboratory plasma in argon to study C and W dust formation. Such glow discharge plasmas can be of interest for ITER as a strategy to remove dust during times when the magnetic field is switched off. The plasma has a large population of Ar^*(3P2) as is measured by laser-induced fluorescence (LIF).

There are several questions related to the viability of glow discharge cleaning for dust removal in ITER. The GDC plasma must actually reach and mobilize the dust and then the dust must be suspended and moved, either be electric fields or by thermophoretic migration. (Cold surface.) The migration may be opposed by drag on the neutral gas of the GDC plasma. A good database is available for C particles but not yet for W particles. Due to their weight the W dusts are more difficult to suspend and confine than the C dusts.

C. Castaldo: Researches on the dust component in FTU plasmas: diagnostics and modelling

Dr Castaldo's presentation emphasized the study of hypervelocity dust in the Frascati Tokamak Upgrade (FTU). Their presence is inferred from impact craters on probe tips, which have characteristics quite distinct from damage created by unipolar arcs. (There are no rough rims from ejected molten metal and there are not the mm scratches typical for an arc.) The measurements are correlated with current spikes in the probe and by optical emission. Hypervelocity impact (velocities > 2-3 km/s) is inferred based on the electro-optical tungsten probe measurements; these measurements register in coincidence W line emission at 409 nm and a spike in the ion saturation current.

In collaboration with S. Ratynskaia of KTH, Stockholm, SiO_2 aerogel collectors are used to trap dust. The technique can provide information on dust velocity and size distribution, dust flux estimates as well as a composition and texture of the captured dust. Impact tracks are typically 60 μm – 500 μm long with the particle residing at the bottom. The particle can be up to about 100 μm in size.

Numerical modelling suggests that dust particles are confined in a SOL region with poloidal angles +/- 7° with respect to the equatorial plane. Hypervelocity regimes could be reached in low density discharge (350 kA, 0.5×10^{20} m^{-3}, 7 T).

P. Humrickhouse: ASDEX dust particle size distributions, and the beryllium dust explosion experiment

In the first part of his presentation Dr Humrickhouse described his experience with analysis of size parameters of dust collected on Asdex Upgrade. The dust was collected on four silicon wafers. Size and shape information was obtained via secondary electron microscopy (SEM) and the composition determined by Energy-dispersive X-ray (EDX) spectroscopy. Eight classes of dust were determined and their sizes fitted for each Si wafer: tungsten spheres (sph) and flakes (fks), C, Cu, Fe, and B flakes, B crystallites, and remaining “unclassified” particles. Some grouping was applied and finally 46 fits were made. There is no theoretical justification for any particular size distribution, so several distributions were tried and the goodness-of-fit was determined: the lognormal distribution, Weibull distribution and the Pareto distribution (power-law distribution with cut-off). Due to the manner in which the measurements are made the distribution has a minimum: $0.28\ \mu \leq d$. In most cases the lognormal distribution was found to provide the best fit. (Because of the minimum diameter one is really fitting the tail of a lognormal distribution.) The Pareto (power-law) distribution is generally not satisfactory; also various natural weighted integrals (e.g. mass-weighted, $\sim d^3$) of the Pareto distribution diverge. A general recommendation based on this experience is to use the lognormal distribution for a simple (two-parameter) fit to dust particle sizes. Tungsten spheres on AUG were found to have a typical lognormal distribution with a visible peak at about 1 μm while for flakes the peak in the observed distribution tends to be at the minimum observable size, so their distribution is represented by the tail of a lognormal distribution.

The second part of the presentation described the beryllium dust explosion experiment at INL, which is carried out in the Fusion Safety Program under an ITER Task Agreement. The explosion is confined in a Kühner 20l sphere housed in a leak tight glove box and all is subject to stringent safety requirements. The system is being commissioned at the time of the present meeting. It is expected that initial Be scoping tests will be done by July 2012 and the ITER test series will be done by October 2012. The system will continue to be available and it might be used in the future for studies of tritiated dust.

M. Rubel: Overview of recent progress in studies of dust in tokamaks

Dr Rubel gave an overview of studies on dust carried out in the EFDA Task Force on Dust in Fusion Devices.

Video images of dust tracks are produced on several experiments. On Asdex Upgrade about 1500 fast camera movies were made over the last 5 campaigns and these were investigated to correlate dust production rates with discharge conditions. Most of the dust is observed in discharges that suffer a disruption or another unstable plasma phase. More dust is found in discharges in which NBI or NBI+ECRH is used for heating, less in ICRH-heated discharges.

Video images are also produced on TEXTOR and Tore Supra. In Tore Supra electrostatic detectors developed by PPPL were installed and data from 481 shots have been analysed. It is found that 82% of the dust particles detected are due to disruptions and the production of dust is correlated with the severity of the disruption. In TEXTOR dust was collected from various locations and classified. The size of particles ranges from sub-μm to several 100 μm, but these largest objects are really debris originating from in-vessel installation work. The dust collection on TEXTOR yielded about 200 mg of fine dust whereas some 40 g of eroded material is found as codeposit on the ALT-II limiter. Therefore about 0.5% of eroded material is turned into dust on TEXTOR. The hydrogen content (ratio H/C or D/C) is highest for redeposited material and is very small for dust on the floor of the device.

Dust is generally considered because of its explosion hazard on ITER and because it may trap tritium, but on JET it is more a concern that dust and redeposited layers contaminate the diagnostic mirrors. There are a minimum of 80 diagnostic mirrors and a broad program is carried out to investigate depositions on the mirrors.

The production of dust by brittle destruction is being studied on the EXTRAP-T2 reversed field pinch in Stockholm.

V. Rohde: Status of the IAEA dust particles database: demonstration of software and definition of first dust classes

Analysis procedures for an international dust database are being developed at IPP Garching. The objective is to have a standard system that can be used at different laboratories to yield results for which a meaningful comparison can be done. Therefore the parameters of the analysis must be precisely specified. The primary data are microscopy images supplemented by element spectra. Automated image analysis by the ImageJ program provides geometric parameters such as area, perimeter, convex area, convex perimeter and many others and then various derived parameters such as circularity, convexity and again many others. On top of that is a higher classification as, for example, W-, Cu- or Fe-dominated spheroids and flakes, C flakes, B agglomerates, contaminants. The images in the database come from “experiments” which in the present context means a specific dust collection: a well-defined location on the machine at a particular time.

The automated analysis can handle 100s of thousands of particles. A pilot database interface exists and was demonstrated; however, many details of the classification and processing are yet to be worked out before the system can be used in a compatible manner across multiple experiments.

The data sources are diverse and include microscopy images (SEM, LM, ...) and element spectra (EDX, XPS, AES, RBS, ...). Desired outputs include tables of morphological information based on image analysis and elemental composition based on spectrum analysis. For the image analysis the open source program ImageJ was selected and for the spectrum analysis commercial standard software; at IPP the INCA software. The integration between image and spectrum analysis is to be done as part of the dust database project; this is not off-the-shelf.

Various measures of shape and size were described; these can be obtained from the ImageJ analysis. A preliminary dust particle classification scheme was developed. The important next steps are to provide broader user access for prototyping and to set up the practical database including security and backup. The database parameters and the classification scheme need to obtain agreement from the community so that the system will be accepted by users.

At Garching the preliminary database already includes more than 100 000 particles from four experimental campaigns including the full-tungsten first wall. The present classification scheme contains 8 dominant classes identified in AUG: W-, Cu- and Fe-dominated spheroids and flakes, C flakes, B agglomerates and Contaminants.

3. Discussion and Conclusions

Dust remains a major concern for ITER and all studies of dust on present devices are motivated by the needs of ITER. During the operation of ITER the production of dust and the uptake of tritium in dust must remain within specified limits (roughly 1000 kg total dust and 1 kg tritium in dust) and it has to be guaranteed that these amounts can be measured and the limits verified throughout the operation of the device.

For ITER the interest is in beryllium dust more than anything else. Tungsten dust is not mobilizable and does not take up tritium. Beryllium dust is light, mobilizable and absorbs tritium; besides, most of the ITER wall will be made of beryllium. Carbon dust is worse than beryllium for tritium uptake, but it is now not likely that carbon will be used in ITER. At the same time, due to its toxicity beryllium dust is much more difficult to study than C or W dust.

With respect to tungsten dust the experience on AUG must be noted that this dust is often associated with arcing and this is a real concern for ITER. Due to the high light intensity there may be significant parasitic plasma under the dome or elsewhere away from the regular plasma, and arcs can form there easily.

The discussion provided several recommendations for ITER.

- A full-size mock-up of the divertor cassette is needed for dust removal studies. There is one in Naka for remote handling training and in Finland there is a mock-up of one sector. The mock-up must have realistic size and realistic surfaces (Be, C, W) in order to scale up laboratory dust removal experiments. It must be under vacuum and it must be possible to heat it to the relevant temperature.
- The properties of radioactive and thereby electrostatically charged dust need a new look. How does the mobilization behaviour depend on the charging? How does it affect surface reactivity? The activity in Be would be due to tritium; in tungsten also activation products play a role.
- Besides the activation of dust there is also the issue of activation of the surface. Could that influence mobilization?
- It is stressed that ITER will need a clear chain of command for dust diagnostics.

Some technical questions were raised for which detailed scenario studies may be needed. In particular the meeting participants asked for the expected surface temperature as a function of location and time under various operating scenarios.

The limits of 1000 kg of dust and 1 kg of tritium in dust are understood: the former is for the explosion hazard and the latter for the activity hazard. Nevertheless the question is raised, is it conceivable that one would have 1000 kg of dust and only 1 kg of T in dust? In other words, is it accepted that in practice the limit on T is the more severe one? It should be noted that dust from melt layers may not have much tritium.

The topic of arcing needs new studies; at present it is not possible to predict the locations and extent of arcing damage in ITER. One should note earlier work by K. Behrisch and G. McCracken, and much work on arcing by the AUG team at the recent PSI meeting.

EFDA work on dust continues with studies on wall conditioning and on arcing and new work on radioactive dust. Within the EFDA programme Jülich is at present the only laboratory that would study radioactive dust.

The interest in possible future IAEA activities was discussed. The role of the IAEA in hosting a dust database is emphasized and this would fit quite naturally with the traditional role of the A+M Data Unit. The A+M Unit should consider to organize some time a meeting or other activity on wall conditioning for ITER; useful experience could be provided by KSTAR, EAST and the JET ILW experiment. It has at times been suggested that the A+M Data Unit might organize a meeting or even a CRP on diagnostic mirrors, but this issue is also covered by ITPA diagnostics.

List of Participants

PARTICIPANTS

Dr Christian Grisolia
Commissariat a l'energie atomique (CEA)
Batiment 168
13108 Saint Paul Les Durance Cedex
FRANCE
Tel.: +33-4-4225-4378; Fax: +33-4-4225-4990
E-mail: christian.grisolia@cea.fr

Dr Volker Rohde
Max-Planck-Institut für Plasmaphysik
Boltzmannstrasse 2
85478 Garching, GERMANY
Tel.: +49-89-3299-1833; Fax: +49-89-3299-1812
E-mail: rohde@ipp.mpg.de

Dr Jörg Winter
Institue of Experimental Physics II
Faculty of Physics and Astronomy
Ruhr-University Bochum
44780 Bochum, GERMANY
Tel.: +49-234-32-23693; Fax: +49-234-32-14171
E-mail: joerg.winter@rub.de

Dr Carmine Castaldo
ENEA – Agency for New Technologies, Energy and the Environment
Lungotevere Thaon di Revel, 76
00196 Roma
ITALY
Tel.: +39-69-400-5193; Fax: +39-69-400-5735
E-mail: castaldo@frascati.enea.it

Dr Naoko Ashikawa
National Institute for Fusion Science (NIFS)
Toki, Gifu 509-5292, JAPAN
Tel.: +81-57-258-2150; Fax: +81-57-258-2618
E-mail: ashikawa@lhd.nifs.ac.jp

Dr Suk-Ho Hong
National Fusion Research Institute
113 Gwahangno, YuSung-Gu
DaeJeon 305-333
KOREA, REPUBLIC OF
Tel.: +82-42-879-5124; Fax: +82-42-879-5119
E-mail: sukhhong@nfri.re.kr

Dr Anna Widdowson
United Kingdom Atomic Energy Authority (UKAEA)
Culham Science Centre
Abingdon, Oxfordshire OX14 3DB
UNITED KINGDOM
Tel.: +44-1235-464874; Fax: +44-1235-464554
E-mail: anna.widdowson@jet.uk

Dr Paul Humrickhouse
Idaho National Laboratory
2525 N. Fremont Avenue
P.O. Box 1625
M.S. 3840
Idaho Falls, ID 83415-3840
UNITED STATES OF AMERICA
Tel.: +1-208-526-7496; Fax: +1-208-526-2930
E-mail: paul.humrickhouse@inel.gov

Dr Charles Skinner
Princeton Plasma Physics Laboratory (PPPL)
MS 15
Route North
P.O. Box 451
Princeton NJ 08543
UNITED STATES OF AMERICA
Tel.: +1-609-243-2214; Fax: +1-609-243-2665
E-mail: cskinner@pppl.gov

OBSERVERS

Dr Sergio Ciattaglia
ITER Organization
Building 519
CS 90 046, Cadarache
F-13108 St. Paul-lez-Durance Cedes
FRANCE
Tel.: +33-4-4225-6328; Fax: +33-4-4225-2600
E-mail: sergio.ciattaglia@iter.org

Dr Roman Zagorski
EFDA-RO Plasma Wall Interaction
Boltzmannstrasse, 2
D-85748 Garching bei München
GERMANY
Tel.: +49-893-299-4314; Fax: +49-893-299-4312
E-mail: roman.zagorsky@efda.org

Dr Marek Rubel
KTH Royal Institute of Technology
School of Electrical Engineering
Alfvén Laboratory
Teknikringen 31
Stockholm 100 44
SWEDEN
Tel.: +46-8-790-6093
E-mail: rubel@kth.se

IAEA

Dr Bastiaan J. Braams
IAEA Atomic and Molecular Data Unit
Vienna International Centre, P.O. Box 100
A-1400 Vienna
AUSTRIA
Tel.: +43-1-2600-21731; Fax: +43-1-26007
E-mail: bastiaan.j.braams@iaea.org

Dr Hyun-Kyung Chung
IAEA Atomic and Molecular Data Unit
Vienna International Centre, P.O. Box 100
A-1400 Vienna
AUSTRIA
Tel.: +43-1-2600-21729; Fax: +43-1-26007
E-mail: h.k.chung@iaea.org

Mr Khalid Sheikh
IAEA Atomic & Molecular Data Unit
Vienna International Centre, P.O. Box 100
A-1400 Vienna
AUSTRIA
Tel.: +43-1-2600-21730; Fax: +43-1-26007-21730
E-mail: k.sheikh@iaea.org

Agenda

Wednesday 30 November

09:30 – 09:40	R. Forrest, B. Braams: Welcome
09:40 – 10:20	C. Grisolia: The French contribution to dust in fusion and current perspectives
10:20 – 11:00	S.-H. Hong: Statistics on dusts in KSTAR and dust transport and removal experiments in TReD
11:00 – 11:20	*Coffee*
11:20 – 12:00	V. Rohde: Dust investigations at IPP: Statistically relevant dust collection in AUG and LHD, F4E dust monitor and fast camera evaluation
12:00 – 13:40	*Lunch*
13:40 – 14:20	N. Ashikawa: Recent investigations of dust particles in LHD and JT-60U
14:20 – 15:00	S. Ciattaglia: Strategy and plan for in-vessel dust (and tritium retention) control in ITER. Status November 2011
15:00 – 15:40	A. Widdowson: Update on dust activities at JET
15:40 – 16:00	*Coffee*
16:00 – 16:40	C. Skinner: Advances in electrostatic dust detection and removal
16:40 – 17:20	J. Winter: Fundamental aspects of dusty plasmas

Thursday 01 December 2011

09:00 – 09:40	C. Castaldo: Researches on the dust component in FTU plasmas: diagnostics and modelling
09:40 – 10:20	P. Humrickhouse: ASDEX dust particle size distributions, and the beryllium dust explosion experiment
10:20 – 10:40	*Coffee*
10:40 – 11:20	M. Rubel: Overview of recent progress in studies of dust in tokamaks
11:20 – 12:00	V. Rohde: Status of the dust database: demonstration of software and definition of first dust classes
12:00 – 12:30	B. Braams and All: Plans for CRP final report
12:30 – 14:00	*Lunch*
14:00 – 15:30	All: Review status of Dust research
15:30 – 16:00	*Coffee*
16:00 – 17:30	V. Rohde, S.-H. Hong et al., Prospects and plans for Dust database

Friday 02 December 2011

09:00 – 12:00	All: Draft of meeting report
12:00 – 13:30	*Lunch*
13:30 – 16:00	Plans for CRP final report and Dust database
16:00 –	*Close of meeting*

List of Publications

(Articles co-authored by CRP participants that were published between 2008 and early 2013 and that are related to the subject matter of the CRP.)

N. Asakura, T. Hayashi, N. Ashikawa, and M. Fukumoto, "Investigation of carbon dust accumulation in the JT-60U tokamak vacuum vessel," Journal of Nuclear Materials, Jan. 2013. http://dx.doi.org/10.1016/j.jnucmat.2013.01.139.

N. Ashikawa, N. Asakura, M. Fukumoto, T. Hayashi, Y. Ueda, and T. Muroga, "Characteristics of tungsten and carbon dusts in JT-60U and evaluation of hydrogen isotope retention," Journal of Nuclear Materials, Jan. 2013. http://dx.doi.org/10.1016/j.jnucmat.2013.01.140.

M. Balden, N. Endstrasser, V. Rohde, M. Rasinski, S. Lindig, R. Neu and the ASDEX Upgrade Team, "Dust collection Strategy and Inner Morphology of Dust Particles in ASDEX Upgrade," Paper EXD/P3-03, 23rd IAEA Fusion Energy Conference, Daejeon, Korea, 2010. http://www-pub.iaea.org/mtcd/meetings/PDFplus/2010/cn180/cn180_papers/exd_p3-03.pdf.

M. Balden, V. Rohde, S. Lindig, A. Manhard, and K. Krieger, "Blistering and re-deposition on tungsten exposed to ASDEX upgrade divertor plasma," Journal of Nuclear Materials, Jan. 2013. http://dx.doi.org/10.1016/j.jnucmat.2013.01.031.

H. Bergsåker, P. Petersson, I. Bykov, G. Possnert, J. Likonen, S. Koivuranta, J. P. Coad, and A. M. Widdowson, "Microanalysis of deposited layers in the divertor of JET following operations with carbon wall," Journal of Nuclear Materials, Jan. 2013. http://dx.doi.org/10.1016/j.jnucmat.2013.01.141.

J. Berndt, E. Kovazević, I. Stefanović, O. Stepanović, S. H. Hong, L. Boufendi, and J. Winter, "Some Aspects of Reactive Complex Plasmas," Contrib. Plasma Phys., vol. 49, no. 3, pp. 107–133, 2009. http://dx.doi.org/10.1002/ctpp.200910016.

J. Berndt, O. Stepanović, E. Kovazević, I. Stefanović, and J. Winter, "Plasma chemical aspects of dust formation in hydrocarbon plasmas," AIP Conference Proceedings, vol. 1041, no. 1, pp. 27–30, 2008. http://dx.doi.org/10.1063/1.2997089.

D. P. Boyle, C. H. Skinner, and A. L. Roquemore, "Electrostatic dust detector for fusion devices with improved sensitivity," Journal of Nuclear Materials, vol. 390-391, pp. 1086–1089, June 2009. http://dx.doi.org/10.1016/j.jnucmat.2009.01.295.

A. Campos and C. H. Skinner, "Advances in Dust Detection and Removal for Tokamaks", Journal of Undergraduate Research vol. IX (2009) 30. http://www.scied.science.doe.gov/scied/JUR_v9/default.htm.

C. Castaldo, "Novel diagnostics for dust in space, laboratory and fusion plasmas," Contrib. Plasma Phys., vol. 51, no. 2-3, pp. 207–217, Mar. 2011. http://dx.doi.org/10.1002/ctpp.201000064.

C. Castaldo, S. Ratynskaia, M. De Angeli, and U. de Angelis, "On the feasibility of electro-optical detection of dust-impact ionization in tokamaks," Plasma Physics and Controlled Fusion, vol. 52, no. 10, pp. 105 003+, October 2010. http://dx.doi.org/10.1088/0741-3335/52/10/105003.

S. G. Cho, S. H. Hong, H. J. Woo, S. J. Park, E. K. Park, Y. S. Oh, J. W. Kim, and K. S. Chung, “Characterization and calibration of a capacitive diaphragm gauge manometer for the measurement of dust particles in vacuum,” Journal of Nuclear Materials, Jan. 2013.
http://dx.doi.org/10.1016/j.jnucmat.2013.01.207.

J. W. Davis, B. W. N. Fitzpatrick, J. P. Sharpe, and A. A. Haasz, “Thermo-oxidation of tokamak carbon dust,” Journal of Nuclear Materials, vol. 386-388, pp. 764–767, April 2009.
http://dx.doi.org/10.1016/j.jnucmat.2008.12.212.

M. De Angeli, C. Castaldo, S. Ratynskaia, G. Grosso, S. Almaviva, L. Caneve, F. Colao, and G. Maddaluno, “Note: Simultaneous electrical and optical detection of expanding dense partially ionized vapour clouds,” Review of Scientific Instruments, vol. 82, no. 10, pp. 106 101+, 2011.
http://dx.doi.org/10.1063/1.3646463.

Denysenko, I. Stefanovic´, B. Sikimic´, J. Winter, N. A. Azarenkov, and N. Sadeghi, “A global model for the afterglow of pure argon and of argon with negatively charged dust particles,” Journal of Physics D: Applied Physics, vol. 44, no. 20, pp. 205 204+, May 2011.
http://dx.doi.org/10.1088/0022-3727/44/20/205204.

N. Endstrasser, F. Brochard, V. Rohde, M. Balden, T. Lunt, S. Bardin, J. L. Briançon, and R. Neu, “Video tracking and post-mortem analysis of dust particles from all tungsten ASDEX-Upgrade,” Journal of Nuclear Materials, August 2010.
http://dx.doi.org/10.1016/j.jnucmat.2010.07.045.

N. Endstrasser, V. Rohde, M. Balden, P. Humrickhouse, U. von Toussaint, B. J. Braams, H.-K. Chung, R. Neu, and the ASDEX Upgrade team, “Comparative study of the dust particle population sampled during four consecutive campaigns in full-tungsten ASDEX upgrade,” Physica Scripta, vol. 2011, no. T145, pp. 014 021+, Dec. 2011. http://dx.doi.org/10.1088/0031-8949/2011/T145/014021.

F. Q. L. Friesen, B. John, C. H. Skinner, A. L. Roquemore, and C. I. Calle, “Evaluation of an electrostatic dust removal system with potential application in next-step fusion devices,” Review of Scientific Instruments, vol. 82, no. 5, pp. 053 502–053 502–4, May 2011.
http://dx.doi.org/10.1063/1.3587619.

P. Gąsior, F. Irrek, P. Petersson, H. J. Penkalla, M. Rubel, B. Schweer, P. Sundelin, E. Wessel, J. Linke, V. Philipps, B. Emmoth, J. Wolowski, and T. Hirai, “Laser-induced removal of co-deposits from graphitic plasma-facing components: Characterization of irradiated surfaces and dust particles,” *Journal of Nuclear Materials*, vol. 390-391, pp. 585–588, Jun. 2009.
http://dx.doi.org/10.1016/j.jnucmat.2009.01.115.

E. Giovannozzi, C. Castaldo, G. Apruzzese, G. Maddaluno, S. Ratynskaia, and A. Rydzy, “Dust in FTU with the thomson scattering diagnostic,” AIP Conference Proceedings, vol. 1041, no. 1, pp. 213–214, 2008. http://dx.doi.org/10.1063/1.2996900.

E. Giovannozzi, C. Castaldo, G. Maddaluno, S. Ratynskaia, and A. Rydzy, “Dust measurement with thomson scattering in FTU,” AIP Conference Proceedings, vol. 988, no. 1, pp. 148–151, 2008.
http://dx.doi.org/10.1063/1.2905058.

C. Godde, J. Berndt, E. Kovacevic, I. Stefanovic, J. Winter, and L. Boufendi, “Controlled sampling of nanoparticles in reactive plasmas,” Plasma Science, IEEE Transactions on, vol. 39, no. 11, pp. 2766–2767, Nov. 2011. http://dx.doi.org/10.1109/TPS.2011.2157980.

C. Grisolia, S. Rosanvallon, P. Sharpe, and J. Winter, “Micro-particles in ITER: A comprehensive review,” Journal of Nuclear Materials, vol. 386-388, pp. 871–873, April 2009.
http://dx.doi.org/10.1016/j.jnucmat.2008.12.192.

C. Grisolia, S. Rosanvallon, A. Loarte, P. Sharpe, and C. Arnas, “From eroded material to dust: An experimental evaluation of the mobilised dust production in Tore Supra,” Journal of Nuclear Materials, vol. 390-391, pp. 53–56, June 2009. http://dx.doi.org/10.1016/j.jnucmat.2009.01.045.

F. Hempel, D. Lopatik, B. Sikimic, I. Stefanovic, J. Winter, and J. Röpcke, “Monitoring of hydrocarbon concentrations in dust-producing RF plasmas,” Plasma Sources Science and Technology, vol. 21, no. 5, pp. 055 001+, Aug. 2012. http://dx.doi.org/10.1088/0963-0252/21/5/055001.

C. Hernandez, H. Roche, C. Pocheau, C. Grisolia, L. Gargiulo, A. Semerok, A. Vatry, P. Delaporte, and L. Mercadier, “Development of a Laser Ablation System Kit (LASK) for Tokamak in vessel tritium and dust inventory control,” Fusion Engineering and Design, vol. 84, no. 2-6, pp. 939–942, June 2009. http://dx.doi.org/10.1016/j.fusengdes.2008.12.033.

C. Hernandez, H. Roche, C. Pocheau, M. Naiim-Habib, J. C. Patterlini, R. Sibois, M. Lapeyre, A. Semerok, L. Doceul, and C. Grisolia, “Integration of laser techniques in a remote handled compact system for tokamak in vessel tritium and dust inventory, control and removal,” Jun. 2009, pp. 1–4. http://dx.doi.org/10.1109/FUSION.2009.5226378.

C. Hernandez, H. Roche, C. Pocheau, M. Naiim-Habib, J. C. Patterlini, R. Sibois, M. Lapeyre, C. Grisolia, and L. Doceul, “Integration of Laser Techniques in a Remote-Handled System for Tokamak Using and Dust Management,” IEEE Transactions on Plasma Science, vol. 38, no. 3, pp. 237–241, March 2010. http://dx.doi.org/10.1109/TPS.2009.2035503.

C. Hernandez, H. Roche, C. Pocheau, M. Naiim-Habib, J. C. Patterlini, R. Sibois, M. Lapeyre, A. Semerok, L. Doceul, and C. Grisolia, “Integration of laser techniques in a remote handled compact system for tokamak in vessel tritium and dust inventory, control and removal,” June 2009, pp. 1–4. http://dx.doi.org/10.1109/FUSION.2009.5226378.

A. Herrmann, M. Balden, M. Laux, K. Krieger, H. W. Müller, R. Pugno, and V. Rohde, “Arcing in ASDEX Upgrade with a tungsten first wall,” Journal of Nuclear Materials, vol. 390-391, pp. 747–750, June 2009. http://dx.doi.org/10.1016/j.jnucmat.2009.01.296.

A. Herrmann, O. Gruber, U. Seidel , T. Lunt, G. Pautasso, V. Rohde and the ASDEX Upgrade Team, “Plasma induced arcs in remote areas of ASDEX Upgrade,” Paper/Poster P2.134, 37th EPS Conference on Plasma Physics, Dublin, Ireland, 2010.

S.-H. Hong, K.-R. Kim, Y.-U. Nam, J. Chung, C. Grisolia, V. Rohde, K. Team, T. S. Team, and A. U. Team, “Statistical analysis of temporal and spatial evolution of in-vessel dust particles in fusion devices by using CCD images,” Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, Dec. 2012. http://dx.doi.org/10.1016/j.nima.2012.12.024.

S.-H. Hong, C. Grisolia, and P. Monier-Garbet, “Development of automatic data extraction technique from visible CCD images for in-vessel dust study in tore supra,” Plasma Physics and Controlled Fusion, vol. 51, no. 7, pp. 075 013+, Jul. 2009. http://dx.doi.org/10.1088/0741-3335/51/7/075013.

S.-H. Hong, C. Grisolia, and P. Monier-Gabet, “Investigation of temporal evolution and spatial distribution of dust creation events in DITS campaign using visible CCD cameras in Tore Supra,” Journal of Nuclear Materials, vol. 390-391, pp. 100–102, June 2009. http://dx.doi.org/10.1016/j.jnucmat.2009.01.120.

S.-H. Hong, C. Grisolia, V. Rohde, P. Monier-Garbet, Tore Supra Team, and Asdex Upgrade Team, “Temporal evolution and spatial distribution of dust creation events in Tore Supra and in ASDEX Upgrade studied by CCD image analysis,” Nuclear Fusion, vol. 50, no. 3, pp. 035 002+, March 2010.

http://dx.doi.org/10.1088/0029-5515/50/3/035002.

S.-H. Hong, C. Grisolia, and P. Monier-Garbet, “Development of automatic data extraction technique from visible CCD images for in-vessel dust study in Tore Supra,” Plasma Physics and Controlled Fusion, vol. 51, no. 7, pp. 075 013+, July 2009. http://dx.doi.org/10.1088/0741-3335/51/7/075013.

P. W. Humrickhouse and J. P. Sharpe, “Dust mobilization and transport modeling for loss of vacuum accidents,” Fusion Engineering and Design, vol. 83, no. 10-12, pp. 1721–1724, Dec. 2008. http://dx.doi.org/10.1016/j.fusengdes.2008.05.005.

D. Ivanova, M. Rubel, V. Philipps, M. Freisinger, Z. Huang, H. Penkalla, B. Schweer, G. Sergienko, P. Sundelin, and E. Wessel, “Survey of dust formed in the TEXTOR tokamak: structure and fuel retention,” Physica Scripta, vol. 2009, no. T138, pp. 014025+, Dec. 2009. http://dx.doi.org/10.1088/0031-8949/2009/T138/014025.

D. Ivanova, M. Rubel, V. Philipps, B. Schweer, M. Freisinger, A. Huber, N. Gierse, H. Penkalla, P. Petersson, and T. Dittmar, “Laser-based and thermal methods for fuel removal and cleaning of plasma-facing components,” Journal of Nuclear Materials, vol. 415, no. 1, pp. S801–S804, Aug. 2011. http://dx.doi.org/10.1016/j.jnucmat.2011.01.119.

M. Kantor, M. Tsalas, A. Litnovsky, D. Rudakov, S. Bozhenkov, S. Ratynskaia, N. Ashikawa, A. Pospieszczyk, and V. Philipps, “Characterization of dust particles in the TEXTOR tokamak with thomson scattering diagnostic,” Journal of Nuclear Materials, Jan. 2013. http://dx.doi.org/10.1016/j.jnucmat.2013.01.150.

K.-R. Kim, S.-H. Hong, Y.-U. Nam, J. Jung, and W.-C. Kim, “Statistical analysis of temporal and spatial evolution of in-vessel dust particles in KSTAR,” Journal of Nuclear Materials, Jan. 2013. http://dx.doi.org/10.1016/j.jnucmat.2013.01.152.

N. Klimov, V. Podkovyrov, A. Zhitlukhin, D. Kovalenko, J. Linke, G. Pintsuk, I. Landman, S. Pestchanyi, B. Bazylev, G. Janeschitz, A. Loarte, M. Merola, T. Hirai, G. Federici, B. Riccardi, I. Mazul, R. Giniyatulin, L. Khimchenko, and V. Koidan, “Experimental study of PFCs erosion and eroded material deposition under ITER-like transient loads at the plasma gun facility QSPA-t,” Journal of Nuclear Materials, vol. 415, no. 1, pp. S59–S64, Aug. 2011. http://dx.doi.org/10.1016/j.jnucmat.2011.01.013.

K. Koga, S. Iwashita, S. Kiridoshi, M. Shiratani, N. Ashikawa, K. Nishimura, A. Sagara, A. Komori, and LHD Experimental Group, “Characterization of Dust Particles Ranging in Size from 1 nm to 10 µm Collected in the LHD,” Plasma and Fusion Research, vol. 4, p. 034, 2009. http://dx.doi.org/10.1585/pfr.4.034.

K. Koga, K. Nishiyama, Y. Morita, G. Uchida, D. Yamashita, K. Kamataki, H. Seo, N. Itagaki, M. Shiratani, N. Ashikawa, S. Masuzaki, K. Nishimura, and A. Sagara, “Effects of DC substrate bias voltage on dust flux in the large helical device,” Journal of Nuclear Materials, Jan. 2013. http://dx.doi.org/10.1016/j.jnucmat.2013.01.154.

R. D. Kolasinski, M. Shimada, D. A. Buchenauer, R. A. Causey, T. Otsuka, W. M. Clift, J. M. Shea, T. R. Allen, P. Calderoni, and J. P. Sharpe, “Characterization of surface morphology and retention in tungsten materials exposed to high fluxes of deuterium ions in the tritium plasma experiment,” Physica Scripta, vol. 2009, no. T138, pp. 014 042+, December 2009. http://dx.doi.org/10.1088/0031-8949/2009/T138/014042.

B. N. Kolbasov, V. G. Stankevich, Svechnikov, V. S. Neverov, A. B. Kukushkin, Y. V. Zubavichus, A. A. Veligzhanin, L. P. Sukhanov, K. A. Menshikov, A. M. Lebedev, D. Rajarathnam, and L. N. Khimchenko, “Nano-scale structural features of stratified hydrocarbon films formed at interaction of plasma with surface in t-10 tokamak," Journal of Nuclear Materials, vol. 415, no. 1, pp. S266–S269, Aug. 2011. http://dx.doi.org/10.1016/j.jnucmat.2011.01.005.

E. Kovacević, J. Berndt, I. Stefanović, H. W. Becker, C. Godde, T. Strunskus, J. Winter, and L. Boufendi, "Formation and material analysis of plasma polymerized carbon nitride nanoparticles," Journal of Applied Physics, vol. 105, no. 10, pp. 104 910+, 2009. http://dx.doi.org/10.1063/1.3129318.

S. I. Krasheninnikov, A. Y. Pigarov, R. D. Smirnov, M. Rosenberg, Y. Tanaka, D. J. Benson, T. K. Soboleva, T. D. Rognlien, D. A. Mendis, B. D. Bray, D. L. Rudakov, J. H. Yu, W. P. West, A. L. Roquemore, C. H. Skinner, J. L. Terry, B. Lipschultz, A. Bader, R. S. Granetz, C. S. Pitcher, N. Ohno, S. Takamura, S. Masuzaki, N. Ashikawa, M. Shiratani, M. Tokitani, R. Kumazawa, N. Asakura, T. Nakano, A. M. Litnovsky, R. Maqueda, and the LHD Experimental Group, "Recent progress in understanding the behavior of dust in fusion devices," Plasma Physics and Controlled Fusion, vol. 50, no. 12, pp. 124 054+, Nov. 2008. http://dx.doi.org/10.1088/0741-3335/50/12/124054.

V. I. Krauz, Y. V. Martynenko, N. Y. Svechnikov, V. P. Smirnov, V. G. Stankevich, and L. N. Khimchenko, "Nanostructures in controlled thermonuclear fusion devices," Physics-Uspekhi, pp. 1015+, Oct. 2010. http://dx.doi.org/10.3367/UFNe.0180.201010c.1055.

A. Kreter, S. Brezinsek, J. P. Coad, H. G. Esser, W. Fundamenski, V. Philipps, R. A. Pitts, V. Rohde, T. Tanabe, and A. Widdowson, "Dynamics of erosion and deposition in tokamaks," Journal of Nuclear Materials, vol. 390-391, pp. 38–43, June 2009. http://dx.doi.org/10.1016/j.jnucmat.2009.01.041.

K. Krieger, T. Lunt, R. Dux, A. Janzer, A. Kallenbach, H. W. Müller, R. Neu, T. Pütterich, and V. Rohde, "Induced tungsten melting events in the divertor of ASDEX upgrade and their influence on plasma performance," Journal of Nuclear Materials, vol. 415, no. 1, pp. S297–S300, Aug. 2011. http://dx.doi.org/10.1016/j.jnucmat.2010.12.229.

M. Laux, P. Siemroth, M. Marx, R. Neu, V. Rohde, M. Balden, and N. Endstrasser, "Laboratory investigations of arcing on w-coated graphite components," Journal of Nuclear Materials, Jan. 2013. http://dx.doi.org/10.1016/j.jnucmat.2013.01.162.

E. Lazzaro, I. Proverbio, F. Nespoli, S. Ratynskaia, C. Castaldo, U. deAngelis, M. DeAngeli, J. P. Banon, and L. Vignitchouk, "Transport and effects of ferromagnetic dust in a tokamak with a metallic vessel," Plasma Physics and Controlled Fusion, vol. 54, no. 12, pp. 124 043+, Nov. 2012. http://dx.doi.org/10.1088/0741-3335/54/12/124043.

F. Le Guern, W. Gulden, S. Ciattaglia, G. Counsell, A. Bengaouer, J. Brinster, F. Dabbene, A. Denkevitz, T. Jordan, M. Kuznetsov, M. T. Porfiri, R. Redlinger, P. Roblin, J. Roth, J. Segré, K. Sugiyama, I. Tkatschenko, and Z. Xu, "F4E R&D programme and results on in-vessel dust and tritium," Fusion Engineering and Design, vol. 86, no. 9-11, pp. 2753–2757, Oct. 2011. http://dx.doi.org/10.1016/j.fusengdes.2010.12.029.

F. Le Guern, S. Ciattaglia, G. Counsell, J. Kim, M. Walsh, A. Denkevitz, N. Endstrasser, H. Eixenberger, E. Gauthier, T. Jordan, L. Kammerloher, M. Kuznetsov, R. Neu, R. Redlinger, B. Reiter, V. Rohde, and Z. Xu, "R&D on in-vessel dust and tritium management in ITER," in Fusion Engineering (SOFE), 2011 IEEE/NPSS 24th Symposium, IEEE, Jun. 2011, pp. 1–5. http://dx.doi.org/10.1109/SOFE.2011.6052249.

A. Litnovsky, D. Rudakov, S. Bozhenkov, R.D. Smirnov, S. Ratynskaia et al., and TEXTOR Team, "Dust investigations in TEXTOR: impact of dust on plasma-wall interactions and on plasma performance," Journal of Nuclear Materials, Jan. 2013. http://dx.doi.org/10.1016/j.jnucmat.2013.01.020.

A. Litnovsky, D. L. Rudakov, S. Bozhenkov, R. D. Smirnov, S. Ratynskaia, H. Bergsåker, I. Bykov, N. Ashikawa, G. De Temmerman, Y. Xu, S. I. Krasheninnikov, W. Biel, S. Brezinsek, J. W. Coenen, A. Kreter, M. Kantor, H. T. Lambertz, V. Philipps, A. Pospieszczyk, U. Samm, G. Sergienko, O. Schmitz, and H. Stoschus, "Dust investigations in TEXTOR: Impact of dust on plasma-wall interactions and on plasma performance," Journal of Nuclear Materials, Jan. 2013. http://dx.doi.org/10.1016/j.jnucmat.2013.01.020.

T. Lunt, J. C. Fuchs, K. Mank, Y. Feng, F. Brochard, A. Herrmann, V. Rohde, and N. Endstrasser, "A new 3D viewer as an interface between the ASDEX upgrade CAD models and data from plasma modelling and experiment," Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, vol. 623, no. 2, pp. 812–814, Nov. 2010. http://dx.doi.org/10.1016/j.nima.2010.04.150.

M. Mayer, M. Andrzejczuk, R. Dux, E. Fortuna-Zalesna, A. Hakola, S. Koivuranta, K. Krieger, K. J. Kurzydlowski, J. Likonen, G. Matern, R. Neu, G. Ramos, M. Rasinski, V. Rohde, K. Sugiyama, A. Wiltner, W. Zielinski, and Asdex-Upgrade team, "Tungsten erosion and redeposition in the all-tungsten divertor of ASDEX Upgrade," Physica Scripta, vol. 2009, no. T138, pp. 014 039+, December 2009. http://dx.doi.org/10.1088/0031-8949/2009/T138/014039.

M. Mayer, V. Rohde, K. Sugiyama, J. L. Chen, X. Gong, C. Hopf, J. Likonen, S. Lindig, R. Neu, G. Ramos, E. Vainonen-Ahlgren, and A. Wiltner, "Carbon balance and deuterium inventory from a carbon dominated to a full tungsten ASDEX upgrade," Journal of Nuclear Materials, vol. 390-391, pp. 538–543, Jun. 2009. http://dx.doi.org/10.1016/j.jnucmat.2009.01.087.

B. J. Merrill and P. W. Humrickhouse, "Aerosol Resuspension Model for MELCOR for Fusion and Very High Temperature Reactor Applications," Report INL/EXT-10-19683, Idaho National Laboratory, Jan. 2011. http://www.inl.gov/technicalpublications/documents/4781577.pdf.

J. Merrill, P. W. Humrickhouse, and J. P. Sharpe, "An aerosol resuspension model for MELCOR for fusion," Fusion Engineering and Design, vol. 86, no. 9-11, pp. 2686–2689, Oct. 2011. http://dx.doi.org/10.1016/j.fusengdes.2011.01.012.

B. J. Merrill, R. L. Moore, and J. P. Sharpe, "A preliminary assessment of beryllium dust oxidation during a wet bypass accident in a fusion reactor," Fusion Engineering and Design, vol. 84, no. 7-11, pp. 1285–1288, June 2009. http://dx.doi.org/10.1016/j.fusengdes.2008.11.065.

J. Nichols, A. L. Roquemore, W. Davis, D. K. Mansfield, C. H. Skinner, E. Feibush, W. Boeglin, R. Patel, D. Abolafia, K. Hartzfeld, and R. Maqueda, "3-D reconstruction of pre-characterized lithium and tungsten dust particle trajectories in NSTX," Journal of Nuclear Materials, vol. 415, no. 1, pp. S1098–S1101, Aug. 2011. http://dx.doi.org/10.1016/j.jnucmat.2010.10.049.

K. Nishiyama, Y. Morita, G. Uchida, D. Yamashita, K. Kamataki, H. Seo, N. Itagaki, K. Koga, M. Shiratani, N. Ashikawa, S. Masuzaki, K. Nishimura, A. Sagara, S. Bornholdt, and H. Kersten, "Discharge power dependence of carbon dust flux in a divertor simulator," Journal of Nuclear Materials, Jan. 2013. http://dx.doi.org/10.1016/j.jnucmat.2013.01.169.

F. Onofri, K. F. Ren, and C. Grisolia, "Development of an in situ ITER dust diagnostic based on extinction spectrometry: Dedicated light scattering models," Journal of Nuclear Materials, vol. 390-391, pp. 1093–1096, June 2009. http://dx.doi.org/10.1016/j.jnucmat.2009.01.272.

L. I. Proverbio, E. Lazzaro, S. Ratynskaia, C. Castaldo, U. de Angelis, G. Grosso, and M. De Angeli, "The dynamics of ferromagnetic dust particles in the FTU tokamak," Plasma Physics and Controlled Fusion, vol. 53, no. 11, pp. 115 013+, Oct. 2011. http://dx.doi.org/10.1088/0741-3335/53/11/115013.

B. Rais, C. H. Skinner, and A. L. Roquemore, "Note: He puff system for dust detector upgrade," Review of Scientific Instruments, vol. 82, no. 3, pp. 036 102+, 2011. http://dx.doi.org/10.1063/1.3545841.

Y. Raitses, C. H. Skinner, F. Jiang, and T. S. Duffy, "Raman spectroscopy of carbon dust samples from NSTX," Journal of Nuclear Materials, vol. 375, no. 3, pp. 365–369, Apr. 2008. http://dx.doi.org/10.1016/j.jnucmat.2008.01.012.

S. Ratynskaia, C. Castaldo, H. Bergsåker, and D. Rudakov, "Diagnostics of mobile dust in scrape-off layer plasmas," Plasma Physics and Controlled Fusion, vol. 53, no. 7, pp. 074 009+, May 2011. http://dx.doi.org/10.1088/0741-3335/53/7/074009.

S. Ratynskaia, C. Castaldo, E. Giovannozzi, D. Rudakov, G. Morfill, M. Horanyi, J. H. Yu, and G. Maddaluno, "In situ dust detection in fusion devices," Plasma Physics and Controlled Fusion, vol. 50, no. 12, pp. 124 046+, Nov. 2008. http://dx.doi.org/10.1088/0741-3335/50/12/124046.

S. Ratynskaia, C. Castaldo, K. Rypdal, G. Morfill, U. de Angelis, V. Pericoli-Ridolfini, A. Rufoloni, and E. Giovannozzi, "Hypervelocity dust impacts in FTU scrape-off layer," Nuclear Fusion, vol. 48, no. 1, pp. 015 006+, Jan. 2008. http://dx.doi.org/10.1088/0029-5515/48/1/015006.

S. Ratynskaia, M. De Angeli, E. Lazzaro, C. Marmolino, U. de Angelis, C. Castaldo, A. Cremona, L. Laguardia, G. Gervasini, and G. Grosso, "Plasma fluctuation spectra as a diagnostic tool for submicron dust," Physics of Plasmas, vol. 17, no. 4, pp. 043 703+, 2010. http://dx.doi.org/10.1063/1.3374035.

H. Roche, A. Barbuti, J. Bucalossi, L. Ducobu, C. Grisolia, T. Loarer, B. Pegourié, S. Rosanvallon, P. Spuig, C. H. Skinner, S. Vartanian, and B. Vincent, "First results from dust detection during plasma discharges on tore supra," Physica Scripta, vol. 2011, no. T145, pp. 014 022+, Dec. 2011. http://dx.doi.org/10.1088/0031-8949/2011/T145/014022.

H. Roche, X. Courtois, P. Delaporte, T. Dittmar, D. Farcage, E. Gauthier, C. Hernandez, P. Languille, T. Loarer, and L. Mercadier, "Optimization of laser ablation technique for deposited layer removal on carbon plasma facing components," Journal of Nuclear Materials, August 2010. http://dx.doi.org/10.1016/j.jnucmat.2010.08.033.

V. Rohde, M. Balden, N. Endstrasser, and U. von Toussaint, "Arc erosion on w plasma facing components in ASDEX upgrade," Journal of Nuclear Materials, Jan. 2013. http://dx.doi.org/10.1016/j.jnucmat.2013.01.172.

V. Rohde, M. Balden, T. Lunt, and the Asdex Upgrade Team, "Dust investigations at ASDEX Upgrade," Physica Scripta, vol. 2009, no. T138, pp. 014 024+, December 2009. http://dx.doi.org/10.1088/0031-8949/2009/T138/014024.

V. Rohde, N. Endstrasser, Toussaint, M. Balden, T. Lunt, R. Neu, A. Hakola, and J. Bucalossi, "Tungsten erosion by arcs in ASDEX upgrade," Journal of Nuclear Materials, vol. 415, no. 1, pp. S46–S50, Aug. 2011. http://dx.doi.org/10.1016/j.jnucmat.2010.11.045.

L. Roquemore, D. K. Mansfield, R. I. Patel, W. Boeglin, R. J. Maqueda, and C. H. Skinner, "Dynamic behavior of li dust in NSTX," p. 1, Jun. 2009. http://dx.doi.org/10.1109/PLASMA.2009.5227234.

S. Rosanvallon, C. Grisolia, P. Andrew, S. Ciattaglia, P. Delaporte, D. Douai, D. Garnier, E. Gauthier, W. Gulden, and S. H. Hong, "Dust limit management strategy in tokamaks," Journal of Nuclear Materials, vol. 390-391, pp. 57–60, June 2009. http://dx.doi.org/10.1016/j.jnucmat.2009.01.048.

S. Rosanvallon, C. Grisolia, P. Delaporte, J. Worms, F. Onofri, S. H. Hong, G. Counsell, and J. Winter, "Dust in ITER: Diagnostics and removal techniques," Journal of Nuclear Materials, vol. 386-388, pp. 882–883, April 2009. http://dx.doi.org/10.1016/j.jnucmat.2008.12.195.

S. Rosanvallon, C. Grisolia, P. Sharpe, P. Andrew, S. Ciattaglia, J. Furlan, C. S. Pitcher, and N. Taylor, "Control of dust inventory in tokamaks," AIP Conference Proceedings, vol. 1041, no. 1, pp. 51–54, 2008. http://dx.doi.org/10.1063/1.2997271.

S. Rosanvallon, C. Grisolia, F. Onofri, J. Worms, and S. H. Hong, "Diagnostics for dust monitoring in tokamak environment," AIP Conference Proceedings, vol. 988, no. 1, pp. 349–356, 2008. http://dx.doi.org/10.1063/1.2905097.

S. Rosanvallon, C. Grisolia, G. Counsell, S. H. Hong, F. Onofri, J. Worms, J. Winter, B. M. Annaratone, G. Maddaluno, and P. Gasior, "Dust control in tokamak environment," Fusion Engineering and Design, vol. 83, no. 10-12, pp. 1701–1705, Dec. 2008. http://dx.doi.org/10.1016/j.fusengdes.2008.04.001.

J. Roth, E. Tsitrone, A. Loarte, T. Loarer, G. Counsell, R. Neu, V. Philipps, S. Brezinsek, M. Lehnen, and P. Coad, "Recent analysis of key plasma wall interactions issues for ITER," Journal of Nuclear Materials, vol. 390-391, pp. 1–9, June 2009. http://dx.doi.org/10.1016/j.jnucmat.2009.01.037.

M. Rubel, G. De Temmerman, P. Sundelin, J. P. Coad, A. Widdowson, D. Hole, F. L. Guern, M. Stamp, and J. Vince, "An overview of a comprehensive First Mirror Test for ITER at JET," Journal of Nuclear Materials, vol. 390-391, pp. 1066–1069, June 2009. http://dx.doi.org/10.1016/j.jnucmat.2009.01.257.

M. Rubel, J. P. Coad, G. De Temmerman, A. Hakola, D. Hole, J. Likonen, I. Uytdenhouwen, and A. Widdowson, "First Mirrors Test in JET for ITER: An overview of optical performance and surface morphology," Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, vol. 623, no. 2, pp. 818–822, November 2010. http://dx.doi.org/10.1016/j.nima.2010.01.069.

M. Rubel, D. Ivanova, J. P. Coad, G. De Temmerman, J. Likonen, L. Marot, A. Schmidt, A. Widdowson, and J.-E. Contributors, "Overview of the second stage in the comprehensive mirrors test in JET," *Physica Scripta*, vol. 2011, no. T145, pp. 014070+, Dec. 2011. http://dx.doi.org/10.1088/0031-8949/2011/T145/014070.

M. Rubel, D. Ivanova, V. Philipps, M. Zlobinski, A. Huber, P. Petersson, and B. Schweer, "Efficiency of fuel removal techniques tested on plasma-facing components from the TEXTOR tokamak," *Fusion Engineering and Design*, vol. 87, no. 5-6, pp. 935–940, Aug. 2012. http://dx.doi.org/10.1016/j.fusengdes.2012.02.054.

D. L. Rudakov, A. Litnovsky, W. P. West, J. H. Yu, J. A. Boedo, B. D. Bray, S. Brezinsek, N. H. Brooks, M. E. Fenstermacher, M. Groth, E. M. Hollmann, A. Huber, A. W. Hyatt, S. I. Krasheninnikov, C. J. Lasnier, A. G. McLean, R. A. Moyer, Yu, V. Philipps, A. Pospieszczyk, R. D. Smirnov, J. P. Sharpe, W. M. Solomon, J. G. Watkins, and C. P. C. Wong, "Dust studies in DIII-d and TEXTOR," Nuclear Fusion, vol. 49, no. 8, pp. 085 022+, Jul. 2009. http://dx.doi.org/10.1088/0029-5515/49/8/085022.

D. L. Rudakov, J. H. Yu, J. A. Boedo, E. M. Hollmann, S. I. Krasheninnikov, R. A. Moyer, S. H. Muller, Pigarov, M. Rosenberg, R. D. Smirnov, W. P. West, R. L. Boivin, B. D. Bray, N. H. Brooks, A. W. Hyatt, C. P. C. Wong, A. L. Roquemore, C. H. Skinner, W. M. Solomon, S. Ratynskaia, M. E. Fenstermacher, M. Groth, C. J. Lasnier, A. G. McLean, and P. C. Stangeby, "Dust measurements in tokamaks (invited)," Review of Scientific Instruments, vol. 79, no. 10, pp. 10F303–10F303–6, Oct. 2008. http://dx.doi.org/10.1063/1.2969422.

Semerok, F. Jaubert, S. V. Fomichev, P. Y. Thro, and C. Grisolia, “Tokamak active laser pyrometry for tungsten deposited layer characterisation,” Fusion Engineering and Design, vol. 87, no. 3, pp. 267–274, Mar. 2012. http://dx.doi.org/10.1016/j.fusengdes.2011.12.021.

M. Shimada, R. A. Pitts, S. Ciattaglia, S. Carpentier, C. H. Choi, G. Dell Orco, T. Hirai, A. Kukushkin, S. Lisgo, J. Palmer, W. Shu, and E. Veshchev, “In-vessel dust and tritium control strategy in ITER,” *Journal of Nuclear Materials*, Jan. 2013. http://dx.doi.org/10.1016/j.jnucmat.2013.01.217.

C. H. Skinner, J. P. Allain, M. G. Bell, F. Q. L. Friesen, B. Heim, M. A. Jaworski, H. Kugel, R. Maingi, B. Rais, and C. N. Taylor, “Lithium wall conditioning and surface dust detection on NSTX, and dust removal,” Physica Scripta, vol. 2011, no. T145, pp. 014 020+, Dec. 2011. http://dx.doi.org/10.1088/0031-8949/2011/T145/014020.

C. H. Skinner, R. Hensley, and A. L. Roquemore, “Large aperture electrostatic dust detector,” Journal of Nuclear Materials, vol. 376, no. 1, pp. 29–32, May 2008. http://dx.doi.org/10.1016/j.jnucmat.2008.02.001.

C. H. Skinner, B. Rais, A. L. Roquemore, H. W. Kugel, R. Marsala, and T. Provost, “First real-time detection of surface dust in a tokamak,” Review of Scientific Instruments, vol. 81, no. 10, pp. 10E102+, 2010. http://dx.doi.org/10.1063/1.3464465.

R. D. Smirnov, S. I. Krasheninnikov, Pigarov, T. D. Rognlien, D. K. Mansfield, C. H. Skinner, and A. L. Roquemore, “Impurity seeding with dust injection in tokamak edge plasmas,” Contrib. Plasma Phys., vol. 52, no. 5-6, pp. 435–439, Jun. 2012. http://dx.doi.org/10.1002/ctpp.201210029.

R. D. Smirnov, S. I. Krasheninnikov, A. Y. Pigarov, A. L. Roquemore, D. K. Mansfield, and C. H. Skinner, “Modeling of dust transport and impact on fusion edge plasmas,” in Plasma Science (ICOPS), 2011 Abstracts IEEE International Conference on, IEEE, Jun. 2011, p. 1. http://dx.doi.org/10.1109/PLASMA.2011.5993151.

R. D. Smirnov, Yu, Y. Tanaka, S. I. Krasheninnikov, D. A. Mendis, T. D. Rognlien, M. Rosenberg, T. K. Soboleva, P. K. Shukla, B. D. Bray, D. Rudakov, W. P. West, A. L. Roquemore, and C. H. Skinner, “Dust in fusion plasmas: theory and modeling,” AIP Conference Proceedings, vol. 1041, no. 1, pp. 59–62, 2008. http://dx.doi.org/10.1063/1.2997273.

I. Stefanović, N. Sadeghi, and J. Winter, “The influence of C2H2 and dust formation on the time dependence of metastable argon density in pulsed plasmas,” Journal of Physics D: Applied Physics, vol. 43, no. 15, pp. 152 003+, April 2010. http://dx.doi.org/10.1088/0022-3727/43/15/152003.

M. Tang, J. S. Hu, J. G. Li, Y. F. Li, G. Morfill, and N. Ashikawa, “Recent researches on dust in EAST and HT-7 tokamaks,” Journal of Nuclear Materials, vol. 415, no. 1, pp. S1094–S1097, Aug. 2011. http://dx.doi.org/10.1016/j.jnucmat.2011.01.001.

N. Taylor, D. Baker, S. Ciattaglia, P. Cortes, J. Elbez-Uzan, M. Iseli, S. Reyes, L. Rodriguez-Rodrigo, S. Rosanvallon, and L. Topilski, “Updated safety analysis of ITER,” Fusion Engineering and Design, vol. 86, no. 6-8, pp. 619–622, Oct. 2011. http://dx.doi.org/10.1016/j.fusengdes.2010.11.037.

N. Taylor, S. Ciattaglia, P. Cortes, M. Iseli, S. Rosanvallon, and L. Topilski, “ITER safety and licensing update,” Fusion Engineering and Design, vol. 87, no. 5-6, pp. 476–481, Aug. 2012. http://dx.doi.org/10.1016/j.fusengdes.2012.01.001.

C. N. Taylor, B. Heim, S. Gonderman, J. P. Allain, Z. Yang, R. Kaita, A. L. Roquemore, C. H. Skinner, and R. A. Ellis, “Materials analysis and particle probe: A compact diagnostic system for in situ analysis of plasma-facing components (invited),” Review of Scientific Instruments, vol. 83, no. 10, pp. 10D703–10D703–6, Oct. 2012. http://dx.doi.org/10.1063/1.4729262.

M. Tokitani, Y. Ohtawa, N. Yoshida, K. Tokunaga, T. Fujiwara, N. Ashikawa, S. Masuzaki, H. Yamada, A. Sagara, and N. Noda, “Micro/nano scale modification of plasma facing components in LHD and its impact on the metal dust generations,” Journal of Nuclear Materials, vol. 390-391, pp. 156–159, June 2009. http://dx.doi.org/10.1016/j.jnucmat.2009.01.156.

M. Tokitani, N. Yoshida, S. Masuzaki, N. Ashikawa, A. Sagara, N. Noda, and H. Yamada, “Micro/nano structural analysis of mixed-material deposition layer formed on the first walls of large helical device,” Journal of Nuclear Materials, vol. 417, no. 1-3, pp. 668–672, Oct. 2011. http://dx.doi.org/10.1016/j.jnucmat.2010.12.185.

A. Vatry, M. N. Habib, P. Delaporte, M. Sentis, D. Grojo, C. Grisolia, and S. Rosanvallon, “Experimental investigation on laser removal of carbon and tungsten particles,” Applied Surface Science, vol. 255, no. 10, pp. 5569–5573, March 2009. http://dx.doi.org/10.1016/j.apsusc.2008.09.045.

A. Vatry, M. Naiim Habib, P. Delaporte, C. Grisolia, D. Grojo, S. Rosanvallon, and M. Sentis, “Characterization of carbon and tungsten micro-particles mobilized by laser irradiation in order to develop an ITER dust removal technique,” Journal of Nuclear Materials, vol. 390-391, pp. 144–147, June 2009. http://dx.doi.org/10.1016/j.jnucmat.2009.01.151.

A. Vatry, A. Marchand, P. Delaporte, C. Grisolia, C. Hernandez, H. Roche, and M. Sentis, “Tokamak-like dust removal induced by laser irradiation,” Journal of Nuclear Materials, September 2010. http://dx.doi.org/10.1016/j.jnucmat.2010.08.055.

A. Vatry, A. Marchand, P. Delaporte, D. Grojo, C. Grisolia, and M. Sentis, “Studies of laser-induced removal mechanisms for tokamak-like particles,” Applied Surface Science, vol. 257, no. 12, pp. 5384–5388, Apr. 2011. http://dx.doi.org/10.1016/j.apsusc.2010.09.075.

A. Vatry, C. Grisolia, P. Delaporte, and M. Sentis, “Removal of in vessel tokamak dust by laser techniques,” Fusion Engineering and Design, vol. 86, no. 9-11, pp. 2717–2721, Oct. 2011. http://dx.doi.org/10.1016/j.fusengdes.2011.01.027.

A. Widdowson, C. F. Ayres, S. Booth, J. P. Coad, A. Hakola, K. Heinola, D. Ivanova, S. Koivuranta, J. Likonen, M. Mayer, and M. Stamp, “Comparison of JET main chamber erosion with dust collected in the divertor,” Journal of Nuclear Materials, Jan. 2013. http://dx.doi.org/10.1016/j.jnucmat.2013.01.179.

J. Winter, J. Berndt, S. H. Hong, E. Kovazević, I. Stefanović, and O. Stepanović, “Dust formation in Ar/CH¬4 and Ar/C2H2 plasmas,” Plasma Sources Science and Technology, vol. 18, no. 3, pp. 034 010+, August 2009. http://dx.doi.org/10.1088/0963-0252/18/3/034010.

Z. Yang, K. Krieger, T. Lunt, F. Brochard, J. L. Briancon, R. Neu, R. Dux, A. Janzer, S. Potzel, and T. Pütterich, “3D trajectories re-construction of droplets ejected in controlled tungsten melting studies in ASDEX upgrade,” Journal of Nuclear Materials, Jan. 2013. http://dx.doi.org/10.1016/j.jnucmat.2013.01.183.

Y. Yu, S.-H. Hong, S.-W. Yoon, K.-P. Kim, W.-C. Kim, J.-M. Park, Y.-S. Oh, H.-K. Na, J.-G. Bak, K.-S. Chung, and the KSTAR Team, “First comprehensive particle balance study in KSTAR with a full graphite first wall and diverted plasmas,” Plasma Physics and Controlled Fusion, vol. 54, no. 10, pp. 105 006+, Aug. 2012. http://dx.doi.org/10.1088/0741-3335/54/10/105006.

Nuclear Data Section
International Atomic Energy Agency
P.O. Box 100
A-1400 Vienna
Austria

e-mail: services@iaeand.iaea.org
fax: (43-1) 26007
telephone: (43-1) 2600-21710
Web: http://www-nds.iaea.org