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

Summary Report of the First Research Coordination Meeting

IAEA Headquarters, Vienna, Austria

10 – 12 December 2008

Prepared by

R.E.H. Clark
International Atomic Energy Agency, Vienna, Austria

March 2009

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or to:
Nuclear Data Section
International Atomic Energy Agency
PO Box 100
Wagramer Strasse 5
A-1400 Vienna
Austria

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Abstract

Nine experts on dust formation and their physical and behavioural characteristics attended the first Research Coordination Meeting (RCM) on Characterization of Size, Composition and Origins of Dust in Fusion Devices held at IAEA Headquarters on 10–12 December 2008. Participants summarized recent relevant developments related to dust in fusion devices. The specific objectives of the CRP and a detailed work plan were formulated. Discussions, conclusions and recommendations of the RCM are briefly described in this report.

March 2009

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1. Introduction

The first Research Coordination Meeting (RCM) dedicated to "Characterization of Size, Composition and Origins of Dust in Fusion Devices" was held on 10–12 December 2008 at IAEA Headquarters, Vienna. On the advice of the A&M Data for Fusion Subcommittee of the International Fusion Research Council, this RCM was organised to review known relevant research activities, identify data needs related to dust in fusion devices, and formulate and agree an appropriate work plan for the initial phase of the Coordinated Research Project (CRP).

All nine invited participants of the first RCM are experts in various aspects of dust formation and transport in fusion devices, including dust formation and removal techniques, their impact on tritium retention, and related safety issues. The list of participants is given in Appendix A. Each participant presented a summary of their areas of expertise and on-going research activities. A detailed work plan was subsequently formulated after detailed discussions of the needs to determine and understand quantitatively the processes involving dust formation and behaviour in current and future fusion machines.

2. Presentations and Discussion

A.L. Nichols (Section Head, Nuclear Data Section) welcomed the participants on behalf of the International Atomic Energy Agency (IAEA). With plane moving forward to build and operate large-scale machines, the demand for detailed knowledge of all aspects of dust in such devices has greatly increased. He expressed confidence that the participants would together contribute substantial new knowledge and data inputs to quantify dust production and removal in such facilities. R.E.H. Clark (Scientific Secretary) reviewed the proposed agenda; one change was necessitated because C. Grisolia was unable to attend the meeting (see Appendix B).

<u>Research Activities</u>

Participants presented their current research activities of relevance to the formation, detection and removal of dust, and related safety issues. A number of potential collaborations on specific topics were identified during the course of subsequent discussions. All presentations were distributed electronically to the participants.

S. Ciattaglia from the ITER Project described the safety concerns related to dust accumulation. The safety analysis and related design safety targets for the ITER design recognize that in vacuum vessel (VV) dust will be the main radioactive source term for transportation in an accident because of the radioactive content in dust itself and of the fact that most of the tritium is adsorbed in dust. Dust can also represent a possible explosive source (and therefore a possible challenge for the dust confinement systems, primarily the VV) under particular accident conditions: directly, in case of ingress of air into the VV or indirectly contributing to the H_2 production in case of Loss Of Coolant Accident (LOCA) inside the VV . Specific aims within the ITER are for the total dust accumulation to be limited to one tonne and total tritium to one kilogram. There is a need to develop the means to measure the amount of dust and tritium and for the introduction of removal procedures to maintain these limits. Removal of dust will be especially important with respect to the tritium inventory. Inaccuracies in estimates of in-VV tritium and dust inventories will have an adverse effect on the operational limits of the machine. Removal of dust is complicated by the possibility of dust accumulation in areas to which there is limited access with the divertor installed. Assumptions have been made that the VV will be opened every 2000 pulses, approximately every 15 to 16 months, and divertor replacement will take place after 6000 pulses. Dust accumulation and collection during the opening of the VV were discussed. Estimates of the tritium retention during DT operation were presented. Tritium release through baking of the divertor, where most of the dust should be accumulated, at 350°C was recently approved into the ITER baseline - baking with gas at 350°C would appear to be more effective than the previous baking at 240 C (with water). A further problem is dust accumulation on hot surfaces, which can give rise to explosive reactions: in particular the relevant safety limits are small and the relevant measurement could be difficult. However, dust does not remain on hot surfaces for long periods, making significant accumulation unlikely. There are needs in ITER for the development of diagnostic techniques to determine in-VV dust accumulation, especially on hot surfaces, and for methods of ensuring dust explosion prevention/mitigation. Research is on-going, and further studies will be launched in 2009.

V. Rohde of the Max-Planck-Institut für Plasmaphysik presented recent work on ASDEX-Upgrade (AUG). AUG is a medium size tokamak which has made a transition from carbon to tungsten plasma-facing components through a gradual step-by-step process of tungsten coatings. Due to restricted resources, dust has not been a primary research interest on AUG. However, AUG now is in “open” mode, and cooperation on dust investigation has been initiated in collaboration of Sharpe (INL, USA). Dust distribution analyses were carried out in 2000 and 2006, at different phases of operation. A distinction has been made between dust and debris, dust being produced by plasma interactions and debris originating mainly from other sources. These studies revealed that debris dominates the samples collected below the divertor structure. Dust collectors allow analysis of the amount and size distribution of dust - particles consisting of tungsten in a boron-carbon matrix have been detected. The role of plasma arcs as a dust production mechanism in fusion machines was discussed. A number of methods for monitoring dust in machines were compared, including electrostatic grids as proposed by Skinner, quartz microbalances, video signals, thermography and high-speed cameras. Evaluation of video signals yields dust speeds of 10 to 100 m/s. The movement of suspended dust drops after a vent, indicating the effectiveness of such a conditioning and removal process. However, all participants emphasized that there is still much research needed to quantify and understand such behaviour in fusion devices.

J. Winter of Ruhr University, Bochum, described research on dust production mechanisms and properties. The team working in the plasma physics group at Bochum possesses a wide range of experience of value in performing such disparate work. Dust formation in fusion devices encompasses such facets as plasma-dust interactions, safety issues and engineering challenges. The main dust production mechanisms of flaking, agglomeration, particle ejection from thermal transients and growth from hydrocarbon precursors were discussed in detail. An analysis of forces acting on dust particles was presented, from which some dust collection methods have evolved. The accumulation of electrical charge on dust particles from tritium radioactivity was discussed, including estimates of the degree and resulting levitation in a magnetic field. Existing problems include the development of tools to locate and quantify dust, implementation of effective removal systems, and understanding of dust transport and dust-plasma interactions.

C. Castaldo of ENEA, Frascati, presented work on hypervelocity dust grains in fusion devices. Uncertainties exist in the quantification of dust characteristics that define their behaviour, and proposed diagnostic procedures need to cover the full parameter range. He discussed diagnostic methods for dust particles. Visible imaging with a single camera can give a lower bound of particle velocity by projection on to a plane, as well as an estimate of particle size from the intensity of the scattered light. Multiple cameras with intersecting views can provide a 3D trajectory. Adoption of a suitable laser beam can give information on particle size through Thomson scattering; Mie scattering can also be used to study the larger dust particles by application of a higher-power laser and observation of the ablation region around the particle. Hypervelocity particles can cause pressures sufficient to give rise to vaporization and ionization for diagnostic purposes. Aerogels have p-roved to be useful in the capture of dust without destruction - these highly porous, low density materials can even capture hypervelocity particles.

N. Ashikawa of NIFS, Japan, outlined recent work on the characterisation of dust and their dynamics in LHD, JT-60U and TRIAM-1M. The Large Helical Device (LHD) has a first wall of stainless steel with a carbon divertor, JT-60U has mainly carbon for the first wall, and the small TRIAM-1M tokamak uses high-Z material on the first wall. Dusts collected from these machines have been analysed, and the results were summarized. LHD dust was collected from tile surfaces, and from under the tiles and divertor plates. The amount of dust collected was less than the estimated wall erosion. A visible camera was used in TRIAM-1M to record dust movement from the limiter; a higher-speed camera system in JT-60U recorded dust transport outward from the divertor. Infrared images showed that the movement of the heated dust was not uniform. A theoretical model of dust dynamics is being developed to estimate dust size, which is difficult to measure from the camera images. Comparisons are being made with dust injected into LHD. Measurements of dust size distributions in JT-60U were made by means of Mie scattering. Work on dust removal was also reported. Future studies will include multi-machine experiments in which dust with known properties will be injected into these facilities in order to test various proposed analysis techniques.

L. Khimchenko of Kurchatov Institue, Russia, presented work on dust morphology, composition and growth mechanisms under ITER-relevant energy loads. The facilities are able to carry out a number of experiments that can readily be extrapolated to conditions in ITER. Motivation for the work comes from the T-10 graphite limiter tokamak, which was discovered to contain a large amount of dust and flakes after a four-year operational cycle. The QSPA facility is now being used to simulate ELMs and disruptions, which are judged to be important processes for ITER. Analyses of the particles as well as their angular distribution of deposition can be carried out, along with the determination of surface crystallisation and subsequent modification caused by high-energy loads. Plasma-focus experiments and dust formation studies will be performed, including evaporation and condensation, flaking, melt splashing and cracking. Surfaces have been examined, as well as the determination of the size distributions of particles; sputtering as a result of dusty surfaces is being investigated, along with electron emission effects. Several edge-modelling codes are under development.

A. Widdowson of UKAEA Fusion reported on studies of dust generated within the JET facility, Culham Laboratory, UK. JET was initially a limiter machine, and changed to a divertor after 20 years of operation. A number of investigations have been carried out on dust collected as aerosols, by swabs and from debris found on the floor of the facility. Data from a number of collection and analysis procedures were summarized. After the DT phase, radioactive dusts were analysed and shown to be potentially highly radiotoxic, depending on their origin. Recent work on erosion/deposition shows that the layer spalls and gives rise to flakes when deposits exceed a critical thickness. A dust collection plan is being formulated for JET during the ITER-like wall shutdown in 2009-10. The percentage erosion and re-deposited material leading to dust is an open question for future machines such as ITER, and research initiated through this CRP will be important in addressing this issue.

P. Sharpe of Idaho National Laboratory (INL), USA, described dust research and development activities at INL. Dust generation mechanisms such as blistering and fracturing of deposited layers, generation of reactive species, arcing, off-normal events and maintenance activities were discussed. Work undertaken to model intense plasma-surface interactions was summarized and assessed. Analytical results of dust collected from a number of fusion machines were presented, and studies on beryllium dust behaviour and chemical reactivity were summarized. Progress on mobilization experiments and models was also reported.

C. Skinner of Princeton Plasma Physics Laboratory discussed advances in electrostatic dust detection and removal. Experience with previous machines was summarized, including flaking in TFTR and thick "micro-seismology" films in NSTX. Tritiated dust in TFTR was observed to levitate due to the electrostatic charge resulting from beta decay - such behaviour is viewed as more hazardous than HTO because the dust can stick in the lungs and cause long-term damage. An electrostatic grid for dust detection was described that has been tested in NSTX - impact of a dust particle results in a short circuit which heats and can evaporate or eject the particle. Such an event results in an electronic signal which is dependent on the initial size of the particle. This device has been tested in NSTX. A capacitive dust detection system was described and compared with the electrostatic device. The introduction of pre-characterized dust to benchmark models was proposed. An electrostatic grid for dust removal was described.

3. Formulation of Work Plan

After the data needs had been identified and discussed in detail, the participants assessed the possible means of addressing the most pressing requirements. Each participant indicated areas in which they could contribute, and a work plan was proposed. Specific tasks were agreed to be within the scope and capability of the CRP, and these studies are summarized in the table.

4. Concluding Remarks

Extensive discussions during the course of the first RCM on “Characterization of size, composition and origins of dust in fusion devices” resulted in a comprehensive list of data needs for the assessment and design of fusion devices, and the formulation of an agreed work plan for the initial activities of participants and co-workers. A number of collaborations were identified and specific studies were proposed. Definitive objectives were agreed for the Coordinated Research Project (CRP), and will be reported at the second RCM in approximately 18 months.

Characterization of size, composition and origins of dust in fusion devices: Agreed tasks to be undertaken by CRP participants.

CRP objective	Specific tasks	Year of CRP	Responsible participant	Motivation
Consistent collection and characterization	Analysis of ALCATOR, DIII-D NSTX ASDEX FTU dust	1, 2	Sharpe	Allow cross comparisons
Dust generation modelling	Plan experimental validation on suitable devices (QSPA, PISCES)	2, 3	Sharpe, Kimchenko	Validate modelling
Correlation dust production with erosion and deposition	Planning dust collection and tile survey	1, 2	Widdowson	Improve dust estimates
	Analysis of dust and tiles	3-5	Widdowson	
Basic physics investigations	Charging of particles; levitation; growth from hydrocarbons; condensation; removal by thermophoretic probes	1, 2	Winter	Understand behaviour of radioactive dust
	Co-deposition of W-H-C layers?	3	Winter	Assess dust contribution of mixed material layers
Role of arcs in dust production	Observe arcs in AUG	1-5	Rohde	Assess dust production from arcs
Characterization of mixed material dust	Collection and analysis by SEM, EDX and FIB	1, 2	Rohde, Kimchenko	Understand dust formation
Identify dust production scenarios	Observation with fast camera	1, 2	Rohde	Possible dust reduction methods
Role of transient load in dust production	Collection and analysis by SEM, AFM and SR; material testing - CFC, W and Be	1-3	Kimchenko	Improve estimates of dust production; BeT licensing
Dust dynamics	Analysis of movement with 3-dimensional position in LHD	1-3	Ashikawa	Understand dust transport in plasmas
	Optimization of modelling for dynamics	3-5	Ashikawa	
Detection of nanoparticles and search for hypervelocity dust	Introduction of aerogel samples in fusion devices, and collection of nanoparticles and hypervelocity dust	1, 2	Castaldo	Estimate nano-dust distribution, potential for erosion
	Development of diagnostics for hypervelocity dust (electro-optical probe)	3-5	Castaldo	
Local dust detection	Apply electrostatic dust detection in tokamaks	1-3	Skinner	Dust diagnostics
Dust removal	Apply electrostatic dust conveyors in NSTX	1-3	Skinner	Dust removal techniques

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10–12 December 2008, IAEA Headquarters, Vienna, Austria

Scientific Secretary: R.E.H. Clark

LIST OF PARTICIPANTS

Dr Sergio Ciattaglia *(Observer)*
ITER Organization
Building 519
Cadarache
F-13108 St. Paul-lez-Durance Cedex
FRANCE
Tel.: +33-4-4225-6328; Fax: +33-4-4225-2600
E-mail: sergio.ciattaglia@iter.org

Dr Christian Grisolia
Commissariat a l'energie atomique (CEA)
Batiment 168
13108 Saint Paul-lez-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
Institute 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 Leonid Khimchenko
Nuclear Fusion Institute
Russian Research Centre "Kurchatov Institute"
Kurchatov sq. 1
123182 Moscow
RUSSIAN FEDERATION
Tel.: +7-499-196-7808; Fax: +7-499-943-0073
E-mail: lkhimch@nfi.kiae.ru

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 Phil Sharpe
Idaho National Laboratory
2525 N. Fremont Avenue
P.O. Box 1625
Idaho Falls, ID 83415-3840
UNITED STATES OF AMERICA
Tel.: +1-208-533-4185; Fax: +1-208-526-2930
E-mail: sharjp@inel.gov

Dr Charles Skinner
Princeton Plasma Physics Laboratory
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

Dr. A.L. Nichols
IAEA Nuclear Data Section
Wagramerstrasse 5
P.O. Box 100
A-1400 Vienna
AUSTRIA
Tel.: +43-1-2600-21709; Fax: +43-1-26007
E-mail: a.nichols@iaea.org

Dr. R.E.H. Clark
IAEA Atomic and Molecular Data Unit
Wagramerstrasse 5
P.O. Box 100
A-1400 Vienna
AUSTRIA
Tel.: +43-1-2600-21731; Fax: +43-1-26007
E-mail: r.e.h.clark@iaea.org

Dr. D. Humbert
IAEA Atomic and Molecular Data Unit
Wagramerstrasse 5
P.O. Box 100
A-1400 Vienna
AUSTRIA
Tel.: +43-1-2600-21729; Fax: +43-1-26007
E-mail: d.humbert@iaea.org

Appendix 2

IAEA First Research Co-ordination Meeting on Characterization of Size, Composition and Origin of Dust in Fusion Devices

10–12 December 2008, IAEA Headquarters, Vienna, Austria

Scientific Secretary: R.E.H. Clark

AGENDA

Wednesday, 10 December **Meeting Room: F-07-04**

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

Session 1: Reports I

Chairman: C. Grisolia

10:00 – 10:45 S. Ciattaglia
The integrated approach to in-vacuum vessel dust (and tritium) inventory control in ITER

10:45 – 11:15 *Coffee Break*

11:15 – 12:00 V. Rohde
Dust investigations at ASDEX Upgrade

12:00 – 14:00 *Lunch*

Session 2: Reports II

Chairman: V. Rohde

14:00 – 14:45 C. Grisolia
Tore Supra Dust Work Program

14:45 – 15:30 J. Winter
Dust in fusion devices and in laboratory plasmas: A summary of production mechanisms and of dust properties

15:30 – 16:00 *Coffee Break*

16:00 – 16:45 C. Castaldo
Nanoparticles and hypervelocity dust grains in fusion devices

Thursday, 11 December

Session 3: Reports III

Chairman C. Castaldo

09:30 – 10:15	N. Ashikawa Characterization of dust and its dynamics in LHD, JT-60U and TRIAM-1M
10:15 – 10:45	*Coffee Break*
10:45 – 11:30	L. Khimchenko Study of dust morphology, composition and growth mechanism under ITER-relevant energy load
11:30 – 12:15	A. Widdowson Dust studies at JET: Past and future
12:15 – 14:00	*Lunch*

Session 4: Reports IV

Chairman: N. Ashikawa

14:00 – 14:45	P. Sharpe Dust R&D activities at INL
14:45 – 15:15	*Coffee Break*
15:15 – 16:00	C. Skinner Electrostatic dust detection and removal

Friday, 12 December

Session 5: Review of Current Status

Chairman: A. Widdowson

09:30 – 12:30	All Comprehensive review of current status, including proposed areas of data needs
12:30 – 14:00	*Lunch*

Session 6: Formulation of Work Plan for CRP

Chairman: C. Skinner

14:00 – 17:00	All Formulation of work plan for first two years of CRP
17:00 –	*Adjourn*

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