Available online at www.sciencedirect.com
SCIENCE DIRECT®
ELSEVIER
Journal of Nuclear Materials 337–339 (2005) 1000–1004
journal of nuclear materials
www.elsevier.com/locate/jnucmat

Characterization of dust collected from NSTX and JT-60U

J. Phillip Sharpe [a,*], P.W. Humrickhouse [a], C.H. Skinner [b], the NSTX Team, T. Tanabe [c], K. Masaki [d], N. Miya [d], the JT-60U Team, A. Sagara [e]

[a] *Idaho National Engineering and Environmental Laboratory, Mail stop 3860, Idaho Falls, ID, United States*
[b] *Princeton Plasma Physics Laboratory, Princeton, NJ, United States*
[c] *Department of Nuclear Engineering, Graduate School of Engineering, Nagoya University, Nagoya, Japan*
[d] *Department of Fusion Facilities, Naka Fusion Research Establishment, Japan Atomic Energy Research Institute, Ibaraki, Japan*
[e] *National Institute for Fusion Science, Toki, Japan*

Abstract

Dust has been collected and analyzed from NSTX at PPPL and JT-60U at JAERI-Naka. A total quantity of 39 mg of dust was collected from NSTX, and 170 mg was obtained from sampling areas in JT-60U. Particle sizes determined by count-based measurements from all locations in NSTX averaged 3.27 μm, and JT-60U dust has a similar average size of 3.08 μm. Dust from both devices was composed mainly of carbon. Specific surface areas of two dust samples from JT-60U are 1.18 m^2/g and 0.28 m^2/g. NSTX samples contained insufficient mass for measuring specific surface area. Details from the analysis of each dust collection activity in NSTX and JT-60U are described in this paper.

PACS: 52.55.F; 52.40.H
Keywords: NSTX; JT60U; Dust; Tokamak dust

1. Introduction

Investigation of dust in fusion plasma research devices continues with the collection and analysis of particulate from the National Spherical Torus Experiment (NSTX) at the Princeton Plasma Physics Laboratory (PPPL), USA, and from the JT-60 Upgrade tokamak at the Japan Atomic Energy Research Institute-Naka (JAERI-Naka). Both machines present unique configurations for the generation and transport of dust, thereby contributing valuable insight into dust's impact on the safety and operational performance of future fusion reactors. Dust is collected from current fusion plasma experiments and analyzed to determine physical, chemical, and radiological properties (e.g. dust from machines that use tritium). Identifying locations of dust deposits within the device chamber is important because associated areas in larger reactor systems may require periodic cleaning to minimize dust inventories.

2. Dust collection in NSTX

Dust was collected from NSTX during a scheduled maintenance period in June 2001. Sources of dust generally include erosion of plasma-exposed surfaces, such as plasma-facing components and protective coatings on

* Corresponding author. Tel.: +1 208 526 9830; fax: +1 208 526 2930.
E-mail address: jpsharpe@ida.net (J.P. Sharpe).

0022-3115/$ - see front matter
doi:10.1016/j.jnucmat.2004.09.058

antennae and diagnostics. Carbon is used as the primary plasma-facing material. The effort to collect dust early in the operation of NSTX allows development of a baseline for continued studies of dust generation and transport within the experiment.

2.1. Collection locations within NSTX

Sampling locations in the NSTX vessel were selected from regions expected to have measurable quantities of dust. Twenty-two locations were sampled via the filtered vacuum collection technique [2]. Surfaces of carbon tiles exposed to plasma were sampled in various regions of the device, including lower divertor and passive plates, along center-stack surfaces, and upper divertor and passive plates. Locations beneath the protective tiles were sampled by removing the tiles, and exposed locations on the vacuum vessel surface were also sampled. Dust was collected from auxiliary locations, such as the RF antenna surface and the neutral-beam dump. Pumping ducts and ports were also sampled to investigate dust transport in the vacuum system. The total dust mass collected during this campaign was 38.9 mg.

2.2. Particle morphology and size distributions

Scanning electron microscopy (SEM) is used to investigate particulate morphology, and a representative image is shown in Fig. 1. Dust particles shown in the figure were collected from the surfaces of plasma-facing tiles in the upper divertor region. The majority of particles appeared irregular in shape and many clusters of very small particles were found. Existence of these small particles and their growth into larger groupings indicates that aerosol nucleation from plasma-eroded material [1] may play an important role in dust generation within NSTX.

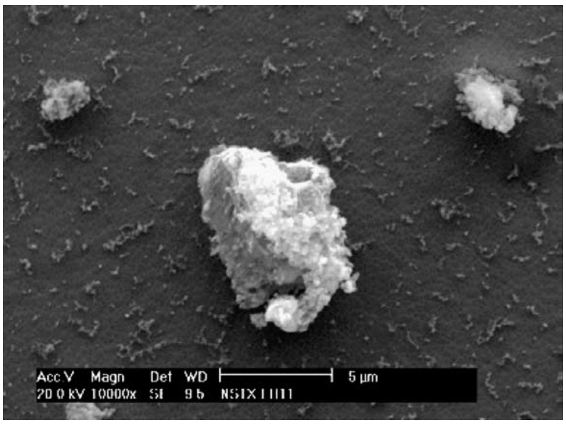

Fig. 1. SEM image of dust obtained from plasma-exposed surfaces in the upper divertor region of NSTX.

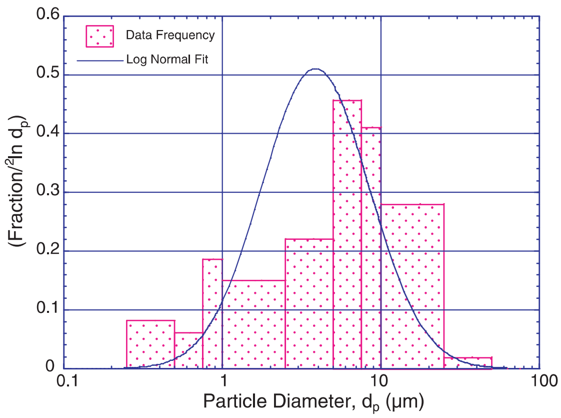

Fig. 2. Count-based size distribution of NSTX dust shown in Fig. 1.

Count-based size distributions were obtained for all dust sampling locations based on optical microscopy imaging and particle counting using the analysis protocol described in [2]. The estimated sizing limit of this technique is 0.3 µm, such that the smallest constituents of the clusters in Fig. 1 may not be counted. Fig. 2 shows the resulting size distribution for dust collected at the location from which Fig. 1 was obtained. This distribution appears bi-modal when compared to the log-normal fit. Although most sampling locations have distributions that reasonably fit log-normal distributions ($R^2 > 0.95$), several locations display similar bimodal features. Future dust collection campaigns in NSTX could address the longevity of these small clusters.

Measured count-median diameters (CMDs) ranged from 2.10 µm to 4.60 µm with an average value of 3.27 µm, and the geometric standard deviations (GSDs) ranged from 2.19 to 3.09. There are no significant position-dependent trends of the CMD and associated GSD values among all sampled toroidal locations. The average CMD for the lower poloidal region is slightly larger (3.68 µm) than those of the middle (3.21 µm) and upper (2.75 µm) poloidal regions.

2.3. Dust composition

Qualitative elemental composition of dust collected from NSTX was obtained from energy dispersive X-ray (EDX) analysis. All particles investigated contain carbon, and a few particles have detectable quantities of boron.

2.4. Distribution of surface mass density

The total mass of dust collected by each filter, determined as the difference of filter mass before and after dust collection, divided by the sampled area gives the

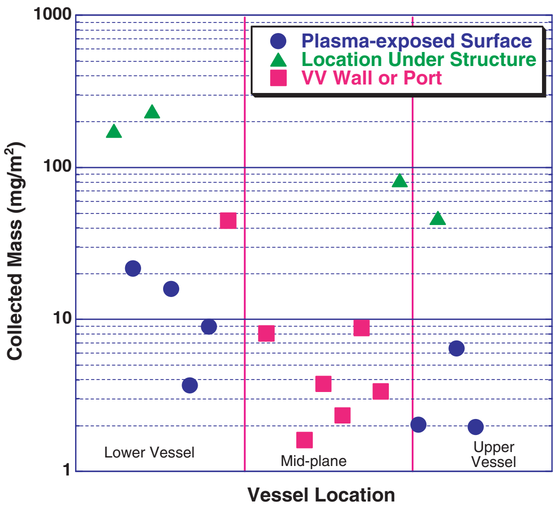

Fig. 3. Distribution of surface mass density of dust collected from NSTX.

surface mass density at each sampling location. Fig. 3 shows the distribution of surface mass density for the lower, middle, and upper poloidal regions of the NSTX plasma chamber. Within each region, collection was performed for three types of surfaces: plasma exposed surfaces that have direct contact or view of discharge plasmas (e.g. tile surfaces), locations under structures (e.g. supporting structure onto which tiles are mounted), and vacuum vessel (VV) or port locations (e.g. horizontal pumping port, diagnostic ports, and VV wall positions underneath or around support structures). The highest levels of surface mass density (up to ~200 mg/m^2) are found underneath tiles in the lower regions. Surface mass density values are similar for all plasma-exposed surfaces, with an average value of 6 mg/m^2. The average surface mass density for the entire chamber (i.e. all samples and a total sampled area of 27805 cm^2) is 33.4 mg/m^2. Assuming a total area of 15 m^2 for the plasma chamber, the estimated amount of dust in the NSTX vessel is ~0.5 g.

3. Dust collection in JT-60U

A scheduled shutdown of the JT-60U tokamak in August 2003 provided an opportunity to collect and examine dust from within the vacuum vessel. Plasma-facing materials for JT-60U are composed of graphitic carbon on the first wall and carbon–fiber composite on the divertor. The collected dust had accumulated over the operational history of JT-60U, with dust being generated and distributed over many experiment campaigns.

3.1. Collection locations within JT-60U

Locations for dust sampling in the JT-60U vessel were selected from regions expected to have sufficient quantities of dust. Twenty-two locations were selected for sampling via the filtered vacuum collection technique. Measurements were obtained underneath plasma-facing structures, on top of tile surfaces, on the lower surfaces of ports accessing the plasma region of the vacuum vessel, and around the ion-cyclotron-resonance-heating antenna. The total dust mass collected during this collection campaign was 170 mg.

3.2. Particle morphology and size distributions

SEM and optical microscopy were used to investigate the details of particulate morphology. Fig. 4 shows an SEM image of dust collected from the plasma-facing surface of the upper first wall. Although particle resolution is greater with the SEM, the optical microscope accurately images the size range of collected particles [2,3]. The vast majority of particles from JT-60U appeared generally round in shape. There were very few noticeable agglomerates or clusters of particles.

Measured CMDs were found to be alike for all collection locations, ranging from 1.32 μm to 4.38 μm with an average value of 3.08 μm. GSDs ranged from 2.32 to 3.25. Median particle diameters for dust in JT-60U are similar to values found in other fusion devices where dust has been investigated [1–3]. There are no identifiable position-dependent trends of the particle size data among all sampled locations. Average sizes of particles from plasma-exposed and non-plasma-exposed surfaces vary no more than 2 μm, and surface orientation does not appear to effect particle size.

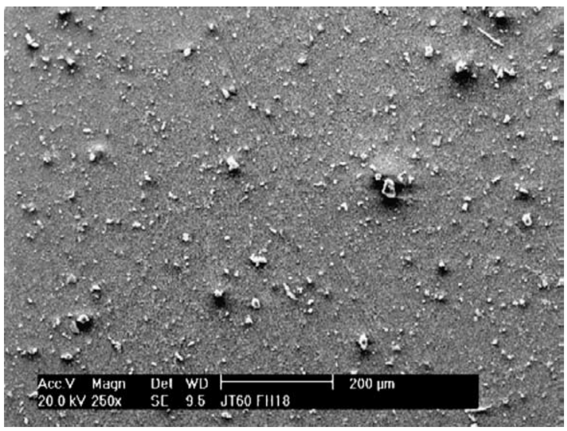

Fig. 4. Representative images of dust collected on the upper first wall tiles of JT-60U.

3.3. Dust composition and tritium content

Qualitative elemental composition analysis of dust collected from JT-60U was obtained with an EDX instrument. Carbon was found as the predominate element for all particles analyzed with the electron beam, although a few particles had small quantities of silicon. In addition to vacuum collection of dust, smear measurements for tritium were obtained at several locations on the JT-60U vacuum vessel. Measurable quantities of tritium were obtained at the very bottom of the vacuum vessel; 423 Bq/cm^2, 137 Bq/cm^2, 45 Bq/cm^2, and 26 Bq/cm^2 were the highest values, whereas all other sampled locations were <10 Bq/cm^2.

3.4. BET surface area analysis

Specific surface area (SSA) measurements were performed on dust samples from JT-60U. Individual samples did not contain sufficient mass quantities (∼20 mg transferable) for BET analysis, therefore samples from similar locations were added together. Two samples were analyzed, and the resulting isotherms are shown in Fig. 5. Analysis of the samples was performed using both nitrogen and krypton. Hysteresis is observed for Sample 1 analyses with nitrogen (see Fig. 5(a)), indicating the presence of some surface-connected porosity [4]. Desorption analysis of Sample 2 in nitrogen failed and is not shown in Fig. 5(b). The bend observed at $P/P_0 \sim 0.3$ indicates the presence of sizeable pores, likely leading to the significant outgasing observed during desorption runs with nitrogen. Further analysis is required to determine the pore size distribution of the samples.

Sample 1, consisting of dust collected from underneath the divertor plates (57.7 mg), has an average SSA of 1.18 ± 0.15 m^2/g. Dust from underneath the divertor dome and pumping port (34.4 mg) comprised Sample 2, with an average SSA of 0.28 ± 0.1 m^2/g. Specific surface area measurements for dust in JT-60U are consistent in magnitude with average SSA values obtained from other fusion experiments [3,4].

3.5. Distribution of surface mass density

Fig. 6 shows the distribution of surface mass density for dust collected in JT-60U. The data are presented by collection location within the vessel for positions similar to those described for NSTX. Locations without direct plasma exposure have greater dust mass than positions exposed to plasma. Assuming uniform surface mass density derived from the total mass collected and total area sampled (170 mg/45360 cm^2 = 37.4 mg/m^2), and estimating the inner surface area of the JT-60U chamber as

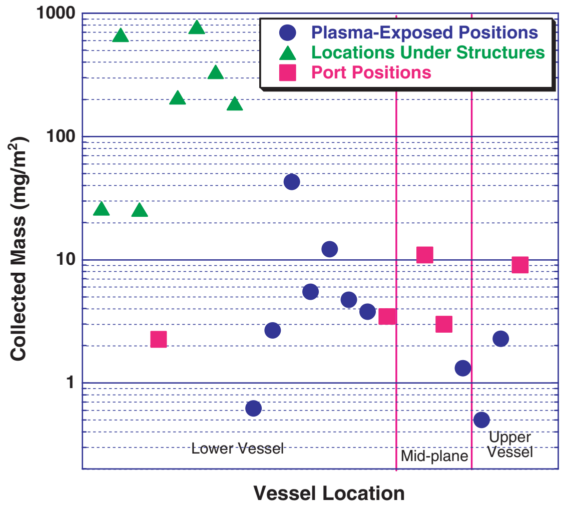

Fig. 6. Distribution of surface mass density of dust collected from JT-60U.

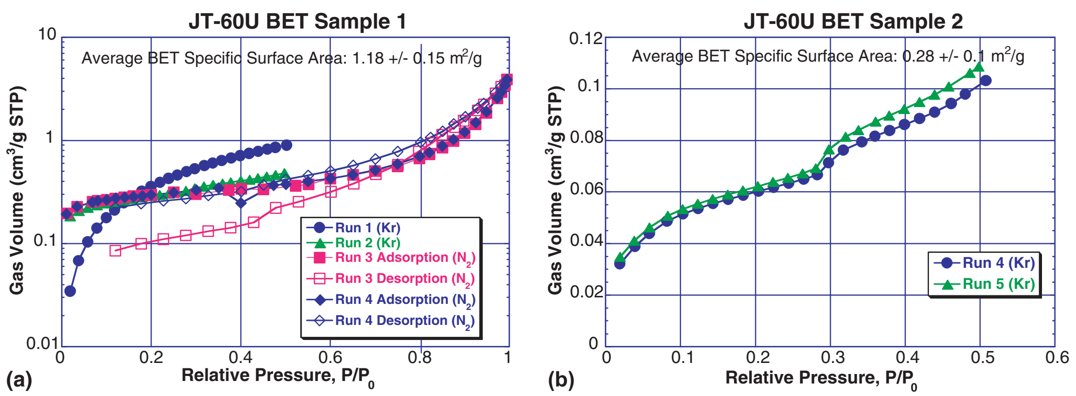

Fig. 5. Isotherms used to calculate BET specific surface area for JT-60U dust samples: (a) Sample 1- beneath lower divertor plates and (b) Sample 2- beneath divertor dome and pumping port.

200 m^2, the total dust inventory may be on the order of 7.5 g. The accuracy of this estimate is unknown. Significantly changing operational conditions, for example longer plasma discharges and greater heating, may lead to increased dust production.

4. Conclusions

Dust was collected from NSTX during an outage in June 2001. The predominant particle size determined by count-based measurements from all locations averaged 3.27 μm. Particles of this size are of considerable importance for safety analysis because they are transportable and respirable (i.e. efficiently deposit in the lungs). The total mass collected in this campaign was 39 mg. Chamber-average surface mass density is 33.4 mg/m^2, comparable to many other fusion devices. The dust was composed mainly of carbon, and numerous clusters of small particles were found on plasma-exposed surfaces. Future studies of dust in NSTX should examine the origin and fate of these particles.

In August 2003, dust was collected and examined from JT-60U. The total amount of dust collected was 170 mg. Dust particles analyzed with SEM/EDX were found to contain mostly carbon, as expected from the graphitic carbon and carbon–fiber composite materials used for plasma-exposed surfaces. The average surface mass density was 37.4 mg/m^2 for all surface types; a value comparable to other fusion research devices (compare to LHD at 40.5 mg/m^2 [3]). Average count-based particle size from all locations is 3.08 μm. BET specific surface area measurements were obtained for two groups of samples: the grouping of samples from underneath the divertor plate has a SSA of 1.18 m^2/g, whereas samples from underneath the divertor dome and pump port have a SSA of 0.28 m^2/g. Minute quantities of tritium were also detected in smears obtained at the bottom of the vacuum vessel. Continued collection and analysis of dust will aid in understanding the role of JT-60U's operation history on dust production and behavior.

Acknowledgment

This work was performed for the US Department of Energy (DOE), Office of Fusion Energy Sciences, under the DOE Idaho Operations Office contract number DE-AC07-99ID13727.

References

[1] J.P. Sharpe, D.A. Petti, H.-W. Bartels, Fus. Eng. Design 63&64 (2002) 153.

[2] J.P. Sharpe, Ph. Chappuis, D.A. Petti, Fus. Technol. 39 (2001) 1061, Volume contains Proceedings of the 14th Topical Meeting on the Technology of Fusion Energy, Park City Utah 15–19 October 2000.

[3] J.P. Sharpe et al., J. Nucl. Mater. 313–316 (2003) 455.

[4] R.A. Anderl et al., BET surface area measurements of materials for fusion safety studies, ITER Engineering Design File, ITER/US/97/TE/SA-20, January 1998.