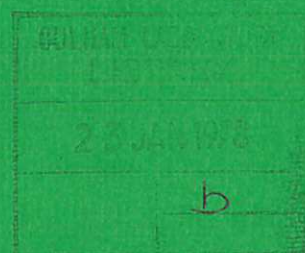




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# THE ROLE OF ARCING IN PRODUCING METAL IMPURITIES IN TOKAMAKS

G M McCracken  
D H J Goodall

CULHAM LABORATORY  
Abingdon Oxfordshire

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G M McCracken and D H J Goodall

Culham Laboratory, Abingdon, Oxon OX14 3DB U.K.

(Euratom/UKAEA Fusion Association)

## ABSTRACT

Measurements have been made of the rate of deposition of metal on collectors near the wall in the DITE tokamak. The rate is too high to be explained by hydrogen ion sputtering. However, unipolar arcing has been observed on probes and limiters and it has been shown that the rate of removal of metal from surfaces by arcing is consistent with the amount deposited on the collectors.

The predominant arc tracks are 10 $\mu$ m wide and run at right angles to the toroidal field. Many arcs appear to occur in each discharge, but the depth of the arc track is dependent on the type of discharge and is shallower in those discharges which have low metal concentrations.

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Arcing was considered to be the principal method of introducing metals into early pinch discharges<sup>(1)</sup>. Although the externally applied voltages are small, it is possible for unipolar arcing to occur between the plasma and the wall driven by the sheath potential<sup>(2)</sup>. Local electron emission from a cathode spot is balanced by a uniform flow back to the surface of energetic electrons in the tail of the Maxwellian distribution. In tokamaks, however, this mechanism appears to have been ignored and sputtering or evaporation are normally invoked as the mechanism to explain the metal impurities observed in the plasma. In the present letter we put forward the experimental evidence for arcing as the dominant mechanism for introducing metals in the DITE tokamak<sup>(3)</sup>.

It has previously been shown that under normal discharge conditions in DITE, as in many other tokamaks, the radiated power from metal impurities dominates the power balance<sup>(4)</sup>. The evidence comes from V.U.V. spectroscopy, from the radial distribution of the total radiation and from X-ray diagnostics. The metals observed are predominantly iron from the stainless steel wall, and molybdenum from the limiters. When the torus has been exposed to atmosphere, oxygen and carbon impurities are initially important. After a few weeks of operation and the use of hydrogen discharge cleaning, the low Z impurities are reduced and the metal impurities are responsible for radiating more than 50% of the ohmic power<sup>(3)</sup>. The amount of metal removed from the wall per discharge has been estimated by chemical analysis of the thin metal films collected on the torus windows. These windows have shutters which are opened only during tokamak discharges. The result of this analysis for four windows is shown in Table 1. The metal film thickness over the 0.45m length of the window sometimes varies by up to a factor 3 indicating some local sources of metal. However, two windows W1 and L1 70° apart azimuthally around the torus gave results agreeing within a factor of 2 over the lifetime of the experiment to date, indicating that the number of sources is sufficient to ensure the uniform deposition of metal over the whole internal surface of the machine. Thus, the total amount of metal removed from the walls per discharge is  $\sim 3 \times 10^{18}$  atoms. From Columns 1 and 2 it is seen that the metal deposited on two windows

at the surface. However, if only a small fraction of the heavy ions are in highly ionized states, unreasonably large sheath potentials would be required. Further information on the energy distribution and charge state of ions arriving at the wall is required before the question of self sputtering of the wall can be resolved. We have dismissed evaporation as a possible source of metal impurities, since measurements of time resolved surface temperatures in DITE<sup>(12)</sup> have indicated wall and limiter temperatures of less than 310K under normal stable discharge conditions.

We have therefore been led to consider arcing as the method by which metal impurities are produced. In a thorough investigation of the surface of the torus, we have found overwhelming evidence of the presence of arcs, on the torus wall, on the fixed limiters, on movable limiters and on specially prepared probes which have been inserted in the vacuum vessel<sup>(13)</sup>. A summary of the probes used for observation, and the plasma conditions to which they were exposed, are shown in Table 2. The arcs are of two types; one is fern-like, similar to that observed in the diffuse pinches<sup>(1)</sup>, the other consists of narrow linear tracks. Both types run in a direction orthogonal to the local magnetic field. Examples are shown in Figure 1. The fern arc has occurred on the face of only one probe so far and this probe was exposed to so many different discharge conditions that no conclusions can be drawn. Fern arcs of a more random nature have also been observed in large numbers on the probe supports and on the divertor target where the magnetic field lines intersect the surface at near normal incidence. On the other hand, only linear arcs have been observed on the test probes A1-A4 which have been exposed near the wall at minor radii (a) of 0.23m to 0.27m.

Observations with the scanning electron microscope (SEM) show that the linear arcs are typically  $\sim 10\mu\text{m}$  wide and consist of a series of overlapping melted regions  $\sim 10\mu\text{m}$  diameter, Figure 2. They are sometimes discontinuous and small craters are observed at irregular intervals, Figure 3. The number of tracks observed per discharge determined from the probes exposed to a small number of discharges at  $a = 0.27\text{m}$  is  $\sim 10$ . Using an average track length of 0.01m a track width of  $10\mu\text{m}$ , and assuming a layer is evaporated of 0.2 times the track width, the number of atoms removed per discharge is  $\sim 10^{17}$  atoms - sufficient to explain the thickness of the thin films when account is taken of the other probes and limiters at the same radius. The material removed during arcing is typically quoted as  $10^{17}$  atoms/C<sup>(14)</sup>, thus the amount of metal evaporated corresponds to a charge of  $\sim 30\text{C}$  or  $300\text{A}$  during a discharge of length 0.1s. The material removed from the surface during an arc is ejected in the form of

However, the theoretical threshold is at  $T_e \approx 3\text{eV}$  so it will be difficult to eliminate it completely. Nevertheless, the use of hydrogen gas puffing has been effective both in reducing  $Z_{\text{eff}}$  and in decreasing the depth of the observed arc tracks; the mechanism is most probably due to cooling the plasma boundary. The use of divertors would also be expected to be effective both by reducing the plasma density near the walls as well as by screening impurities entering the discharge from the wall.

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TABLE 2

## PROBE HISTORY

Probe	++ Position of vertical port (all at R=113cm)	Radial setting	Gas current	Arcs Fern Linear	Craters unassociated with arc tracking	Exposure to rapid cleaning	No. shots
Energy flux probe Mk I	13/14	26-18cm	50-100kA	No Yes	No	Yes	
Energy flux probe Mk II	7/8	26-18cm	50-200kA	Yes Yes	Yes	Yes	
B <sub>θ</sub> probe	13/14	26-16cm	100kA	No Yes	Yes	Yes	
Arc probe A1	15/16	27cm	50-250kA	No Yes	No	No	33 @ 200kA
Arc probe A2	15/16	23cm	200kA*	No Yes	No	No	5
Arc probe A3	15/16	26cm	150kA*	No Yes	No	No	35
Arc probe A4	15/16	26cm	200kA <sup>+</sup>	No Yes	No	No	7

++ The probe is situated between a pair of the 16 numbered toroidal coils.

<sup>+</sup>D<sub>2</sub> + 2% Ne

\*High density gettered discharges

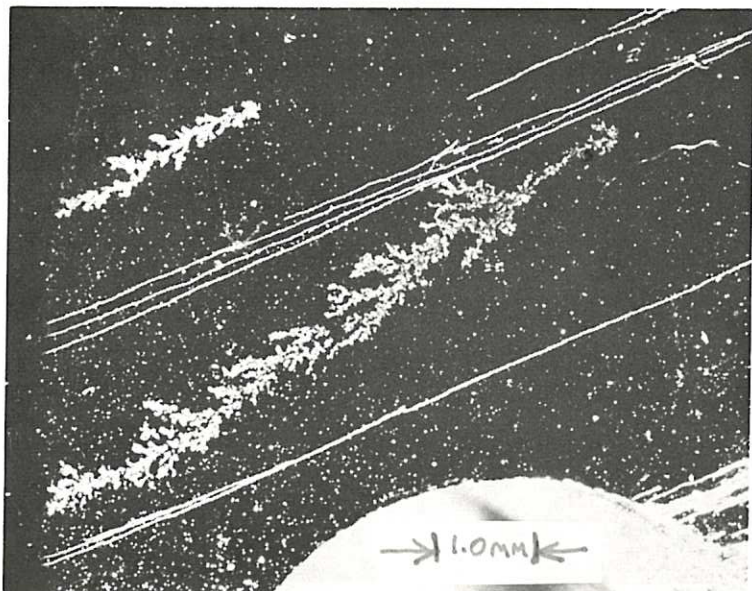
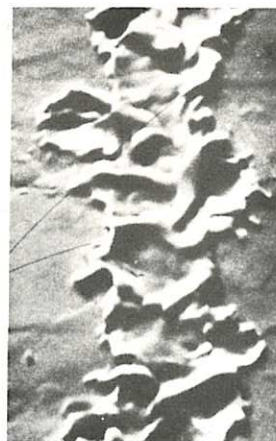
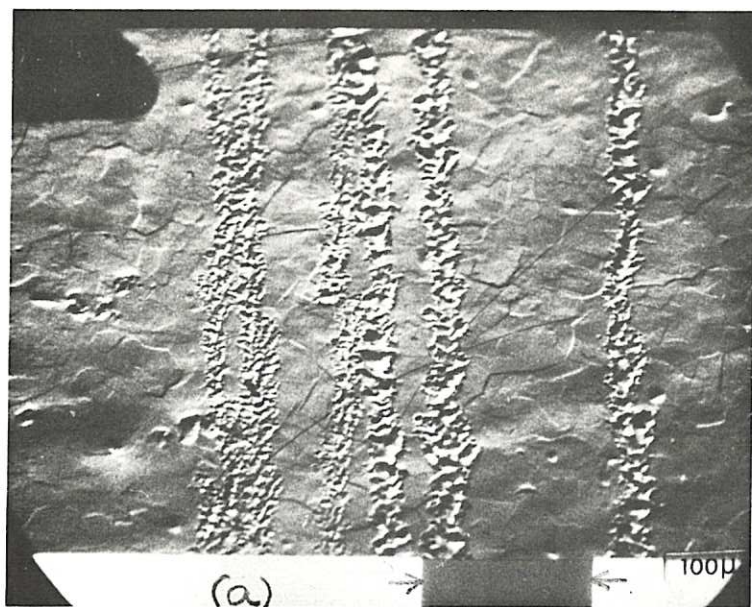


Fig.1 Linear and fern arcs on the surface of energy flux probe Mk II.



(b)

Fig.2 (a) Scanning electron microscope photograph of linear arc tracks on the energy flux probe Mk II.  
(b) Insert: detail of linear tracks.



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