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Deposits/Flakes in the JET MkIIa Divertor – A Major Source of Tritium and Deuterium Inventory

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1. INTRODUCTION

After the initial operation of the JET MKIIa divertor deposits/flakes of material were discovered on the inner leg of the divertor which had not been seen before in previous divertors at JET. The flakes were found to contain significant quantities of hydrogenic material. After the DTE1 a much higher long term tritium retention was found than was expected based upon pre-MKIIa experimental data. The outgassing rate of tritium from the JET vessel after venting was also higher than expected. Both the higher than expected retention and the high outgassing rates are attributed to the deposits/flakes.

The retention of significant quantities of tritium in tokamaks represents a major concern for the operation of machines like JET and for future machines such as ITER. If the retention is too high then methods are needed to remove the tritium before it reaches unacceptable levels.

The aim of this work was to locate and quantify the material present in these deposits/flakes and to characterise the deposits/flakes present. In addition methods of removing these flakes/deposits during the Remote Tile Exchange (RTE) were sought. The analysis of the material collected will provide the data base for future machines to deal with these deposits/flakes, either by design modifications to stop the films being formed or to identify potential methods of removal of the films.

2. OBSERVATION OF THE DEPOSITS/FLAKES

During the October 1996 shutdown at JET a poloidal row of divertor tiles was removed from the structure for analysis. When the tiles and their carriers were moved it was noticed that in the inner leg of the divertor there were flakes of material upon the divertor structure floor.

These flakes of material appeared to have fallen off the water cooled louvres of the structure. Fig 1 shows a section of the JET MkIIa divertor, showing where the flakes were found. No comparable deposits or flakes were found in the outer leg of the divertor.

The end of tile 3 was also found to be covered with a deposit. Figure 2 shows the end of this tile were the deposits were found. On the end of the tile are Inconel 718 fixtures used for mounting the tiles and to stop delamination of the carbon-carbon fibre composite[1]. On the metal parts there was a film that was partially removed.

These observations suggest that deposition had occurred in the inner leg of the divertor in regions shadowed from the plasma. These deposits were different from the normal co-deposited films previously seen which tend to be adjacent to erosion areas. The observations also suggest that the deposits are adherent to carbon substrates but tend to fall off metal substrates. Analysis of the films that had fallen off the metal parts of the tiles show that they are as thick as deposits found on the tiles. This would indicate that the deposits fall off the metal pieces only once, probably on venting of the JET machine.

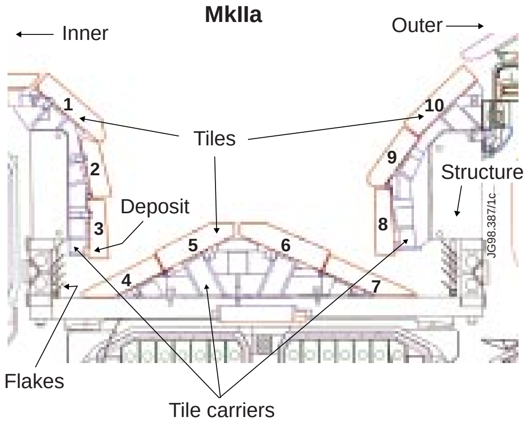

Figure 1: Cross-section of the JET MkIIa

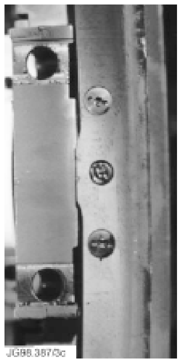

Figure 2: End of tile 3 showing deposits/flakes

3. ANALYSIS OF THE FLAKES/DEPOSITS

Samples of the flakes were manually collected from the region where the tiles were removed for analysis. Later a vacuum cleaner was used to remove all the flakes toroidally. This vacuum cleaner had a head fitted with a stainless steel brush to remove the flakes from the louvres. The limited access to the area around the louvres with the tiles in place limited the effectiveness of this cleaning process.

3.1 Ion beam analysis

Rutherford backscattering (RBS) and Nuclear reaction analysis (NRA) were performed upon the films and it immediately became clear that the films were heavily loaded with deuterium. Preliminary analysis with NRA showed that the films were predominantly carbon and deuterium with a deuterium/carbon ration of 0.4 but more detailed analysis with RBS showed that this ratio could be as high as 0.7 [2]. Normally ion implanted films have a limit of D/C of 0.4. The composition of the films was the same on both sides indicating that the composition was uniform throughout. The films measured were thicker than the range of the ion beam techniques used (~ 8 microns). The ion beam techniques could not detect the presence of hydrogen.

3.2 SEM analysis

SEM analysis was performed upon the both the flakes and the deposits. The deposits and flakes were typically 40 microns thick. Figure 3 shows the flake material that had been collected with the vacuum cleaner. The action of vacuum cleaning had broken up the flake material from typical 5mm lateral dimensions to sub-millimetre pieces.

3.3 Other analyses

A number of other analysis techniques were used to characterise the deposits/films. These showed that the chemical composition of these films was as follows:

Table 1 Chemical composition of the flake material.

Elements present	Carbon	Beryllium	Metals	Oxygen
Flakes/Deposits	96 wt%	0.5 wt%	0.6 wt%	3 wt%

The amount of oxygen present would seem high to have been obtained from the JET tokamak and from the fact that it greatly exceeds the level of Be. The chemical composition also does not include the effects of hydrogenic material. Therefore it is important to realise that what is being analysed is not the material that was produced in the tokamak but the material as it was after several months exposure to air.

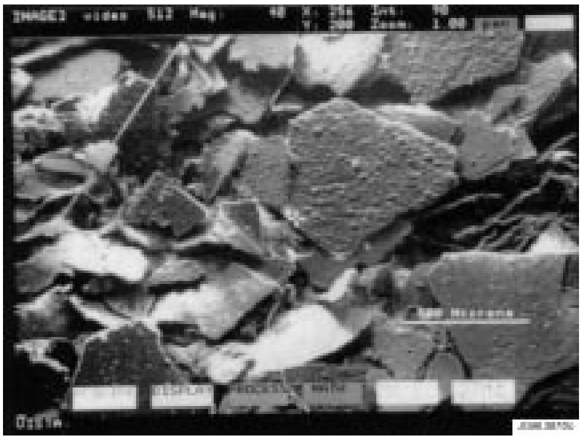

Figure 3: Flakes collected by vacuuming

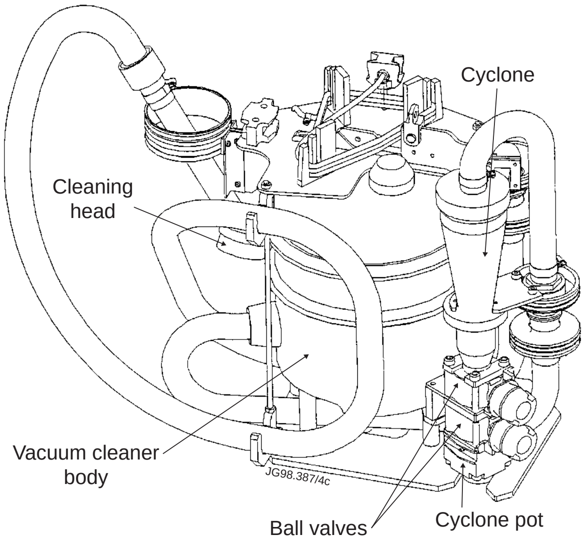

Figure 4: DTE1 flake collection equipment

3.4 Tritium inventory

The flakes/deposits were shown to contain approx 4% of the deuterium and tritium in the JET machine prior to DTE. Taking into account outgassing effects the amount of tritium in the flakes/ deposits could have been as high as 10% of the total fuelling, explaining nearly all of the anomalous retention.

4. REMOVAL OF THE FLAKES/DEPOSITS AFTER THE DTE1

At the end of operations following the DTE1 17% of the tritium introduced into the torus was still present[3]. This was much higher than had been expected following the preliminary tritium experiment (PTE). It was recognized that the flakes/deposits represented a significant inventory of tritium. It was therefore originally planned to collect the flakes to determine the tritium inventory present. This collection exercise then became important as a tritium inventory reduction exercise given the high amount of tritium present in the JET machine, 6g, at the end of operations.

The Remote Tile Exchange (RTE) [4] had as its object the removal of the MkIIa carriers and tiles. Therefore, the deposits present on the tiles would be removed along with the tiles. An interesting observation was the asymmetry observed in the outgassing rate of an inner and outer tile carrier and their associated tiles. This differed by a factor of 100. Given that the temperature histories of an inner and outer tile carrier are very similar then this suggests that the inner tile carrier and tiles contains a factor of 100 times more tritium than the outer carrier and tiles. This is to be confirmed by further analysis.

Removal of the tiles and carriers allowed greater access to the region were the flakes were present. This eased the problem of removing the flakes and allowed a better in-vessel inspection of the flakes than had previously been possible. This remote inspection revealed that the flakes were present upon the back surfaces of the louvres as well as on those facing towards the centre of the machine, however these did not extend over the entire back surface of the louvres, just the top edges. In addition to the normal camera view an endoscope was used to examine the back surface of the louvres.

4.1 Equipment Used

To allow collection of the flakes a vacuum cleaner fitted with cyclone attachment was used. The cyclone device collected material down to 2 microns in size. The cyclone collection pot was fitted with 2 ball valves so that the cyclone pot could be closed prior to its removal from the JET vessel. Flakes were present on the louvres and on the bottom of the support structure. A stiff nylon bristle vacuum cleaner head was chosen after a number of trials as the best compromise for the flake collection. This assessment included such factors as damage to the louvres, ease of remote handling operation and collection efficiency.

All operations inside the JET vessel to operate the vacuum cleaner were performed remotely. This included the positioning of the vacuum cleaner at suitable positions inside the machine, the operation of the vacuum cleaner head, the closure of the cyclone pot, the removal of the cyclone pot from the vacuum cleaner and the positioning of the pot into secondary containment before removal from the vessel. The full 360 degrees of the structure were vacuumed in this manner.

Observation of louvres after cleaning suggests that approximately 90% of the visible flakes were recovered by the vacuum cleaner. The uncollected material present still attached to the louvres, behind the louvre or having fallen through holes in the structure could be up to 50% of the total.

5. CONCLUSIONS

A significant fraction of the tritium retained in the JET vessel appears to be present as flakes/ deposits. A large fraction of this tritium inventory has been removed either with the divertor tiles or by vacuuming of flakes. The exact amount still requires further clarification by analysis of tiles and flakes removed after the DTE1.

The Remote handling equipment at JET has shown itself to be extremely useful in the performance of the complex tasks required for the removal of these flakes/deposits.

6. REFERENCES

[1] Altmann, H et al, "Design of the MkII divertor with large carbon fibre composite tiles" 18th SOFT, Karlsruhe 1994.

[2] Maier, M private communication

[3] Andrew, P., "Tritium Recycling and Retention at JET". In Proceedings of 13th Int. Conf. On Plasma Surface Interactions 1998.

[4] Rolfe, A.et al. "The Exchange of JET Divertor Modules using Remote Handling Techniques". In Proceedings of the IEEE Conference on Robotics and Automation, May 1998.