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Detritiation of the JET Carbon Tiles by Flame Heating

Fuel Retention in the Gas Box Divertor of JET

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ABSTRACT

Operation with tritium plasma led to contamination of the JET in-vessel components with tritium at a level exceeding 12kBq/g, which is the Low Level Waste (LLW) threshold in the UK. Carbon tiles used at JET for protecting the pumped divertor and inner wall against heat and neutron flux create one of the Intermediate Level Waste (ILW) streams to deal with during the JET decommissioning in the future. To reduce quantity and cost of ILW disposal from JET, the study has been initiated for development of detritiation techniques. This paper presents a brief description of the study of the JET carbon tiles detritiation using flame heating.

1. INTRODUCTION

As a result of operation with tritium plasma, the vacuum vessel of the JET machine has become contaminated with tritium. The level of contamination often exceeds the Low Level Waste threshold, which is 12kBq/g in the UK. To reduce the amount and cost of disposal of the in-vessel components as ILW during JET decommissioning in the future, a study of detritiation processes was initiated with a purpose to reduce the level of waste contamination from ILW to LLW. Carbon tiles used at JET to protect the pumped divertor and the wall of the vacuum vessel against heat and neutron flux present one of the ILW streams. Carbon Fibre Composite (CFC) tiles of the pumped divertor MKIIA removed from the vessel after the DTE1 experiment [1] have been used for development of the detritiation methods. Tritium distribution along and across tiles of the JET divertor MKIIA was found to be inhomogeneous [2,3,4]. In some tiles, a large fraction of tritium inventory retains in the bulk [3,4]. Several techniques, such as ultrasonic bath treatment, purging with moist gases at elevated temperature, treatment with moist ozone, purging with noble gas under radio frequency heating, flame heating, have been tested [5] for tritium removal from carbon tiles. Some of the techniques tested on a laboratory scale demonstrated removal of 96% to more than 98% of tritium inventory. Flame heating, which demonstrated good capacity for tritium removal from solids [5,6], has been developed in this study for testing of detritiation of JET tiles on a pilot scale whereby a whole tile can be treated. The purpose of the study was to demonstrate if flame heating would reduce tritium concentration in the JET CFC tiles to a level below 12kBq/g. UKAEA has developed the gas burner for detritiation of the JET tiles. Operation of the burner has been tested and optimised with respect to desired tile temperature, type and flow rate of the fuel, and heating procedures. Uniform temperature distribution within $\pm 10\text{K}$ range along and across the part of the tile being heated was observed. Such a quite uniform distribution was achieved due to powerful heating and the large heat conductivity of the CFC material. This paper gives a brief review of study of the JET CFC tiles detritiation using flame heating.

2. EXPERIMENTAL

The tile to be heated was moved at the fixed speed along the stationary gas burner. The burner provided heating of part of the tile only, but from the bottom to the top. The gas burner was operated in pulsing mode, which allows control of the desired tile temperature. Figure 1 illustrates temperatures

measured at the ends and in the middle point of the tile during heating run. Figure 1 refers to the test carried out with non-tritiated JET tile. The maximum temperature (T_{MAX}) and the temperature average (T_{AV}) for the whole tile during the last 5 minutes of the heating are presented in Figure 2 as function of the total heating time in the heating run. The tile made four passes along the burner in each heating run. Temperature in the tile was monitored using the thermocouples inserted in the tile. Tritium depth profile was measured by coring of the tile, slicing the core followed with complete combustion of the obtained disks. Two tiles, tile 4 and tile 7, which have the largest tritium contamination level among tiles of the divertor MKIIA [3] and also a large fraction of tritium inventory retained in the bulk of the tile, were used for the tests.

3. REVIEW OF RESULTS

Because of inhomogeneous tritium distribution in the JET tiles, the decontamination factor, such as ratio of the tritium inventory of the tile before the treatment to that after the treatment, was not considered here as a parameter expressing the effectiveness of the decontamination process. Achieving residual tritium concentration below 12kBq/g in the decontaminated tile was chosen as the target. The first series of tests was devoted to finding the heating procedure and the tile temperature, which achieved a residual tritium concentration in the decontaminated tile that was as low as possible. In these tests pieces of the tile 7 were used. The tritium inventory of the tile 7, which has a mass of 3.5kg, was calorimetrically measured at 132.8GBq. This gives an average tritium concentration of 38MBq/g. Both the tritium inventory and concentration are larger than 107GBq and 31MBq/g measured [3] for another tile 7 of divertor MKIIA. The tritium depth profile measured in the piece of the tile before treatment is shown in Fig.3. For a decontamination test, a piece of tritium-contaminated tile was fixed in a cut made in graphite matrix of shape similar to the JET tile 7. The pieces to be treated for detritiation with approximate size of 80mm*70mm and the thickness the same as the tile, were cut out of the tile 7. The results of the tests are given in Table 1. The tests 1 to 3 were performed each with its own heating run. Tests 4 to 6 included decontamination with three consecutive heating runs. In each test the same piece of tile 7 was used for all heating runs. Tritium depth profile in the detritiated piece was evaluated via withdrawing the core sample for analysis after each heating run. Tritium depth profiles measured for tests with three consecutive heating runs are shown in Figures 4, 5, 6. Table 1 shows that even a single heating run allows removal of more than 99% of tritium inventory. However, none of single heating runs resulted in reduction of tritium concentration sufficient to reach the target value of 12kBq/g. Tests 1 and 4 in Table 1 and Fig.4 indicate that the detritiation run with an average temperature around 800K was less effective for achieving a small residual tritium concentration than runs at an average temperature of 900K or larger. Some tests with three consecutive heating runs brought average tritium concentration near to or below 12kBq/g. Quite uniform tritium distribution across the decontaminated tile with “flat” tritium depth profile was also observed.

Figure 5 presenting tritium depth profiles measured after test 5 with average tile’s temperature of 1100K shows tritium concentrations larger than presented in Fig.6 for the test 6 performed at smaller

average temperature. Figure 5 also demonstrates an obvious increase of tritium concentration from the rare surface of the detritiated tile to the plasma-faced surface, which was flame treated. In test 6, performed at temperature lower than test 5, tritium depth profiles measured after second and third heating runs show quite a small gradient of tritium concentration across the detritiated tile. The explanation for this result could be that heating at large temperature causes tritium transport from the contaminated plasma-faced sub-surface (as shown in Fig.3) not only to the gas phase but also to the bulk of the tile. Alternative explanation might be that the level of contamination of the piece of the tile used for the test 5 was much larger than that for the piece of the tile used in the test 6.

Table 1 and Figures 4 and 6 show that multi-heating runs with the gas burner operated in pulsed mode are effective in removing even “bulk tritium”. Such detritiation technique might allow the reduction of tritium concentration in the carbon tile below 12kBq/g threshold.

Figure 7 shows a photo of tile 7 before and after heating runs in the test 4. A white deposit, which appeared on the surface of the tile during the first and second heating, was burned out and disappeared after the third heating. A similar phenomenon was observed for all the tests with three consecutive heating runs. The combustion of the “white deposit” in the flame heating might eliminate the difficulty with detritiation of the co-deposited layer observed in earlier study [5].

To check the effectiveness of the multi-heating technique for removal of the small residual concentration of “bulk tritium”, a multi-heating test was carried out using a whole tile. Tile 4 of the JET divertor MKIIA was used for this test. The tritium inventory of the tile was measured calorimetrically at 199.8GBq. With tile’s mass of 2.7kg this gives an average tritium concentration of 74MBq/g. Both the tritium inventory and concentration are smaller than 231GBq and 85.5MBq/g measured [3] for another tile 4 of the divertor MKIIA. The tile was decontaminated in 6 consecutive heating runs. The maximum temperature observed during each heating was 1010K, the average temperature for the whole tile during last 5 minutes of each heating run was 920K. Tritium depth profiles measured after runs 2, 4 and 6 are present in Fig.8. The average residual tritium concentrations in the tile after those runs were evaluated at 56, 27 and 50kBq/g. The fluctuation in average residual tritium concentration measured after the heating runs might be attributed to very inhomogeneous tritium distribution in the tile 4.

The driving force for tritium migration from the bulk of the tile to the decontaminated surface is low at small residual concentration in the bulk. Therefore removal of this small quantity of residual tritium from the bulk of tile would require an extended time of the tile’s exposure to flame. Long total heating time or simultaneous heating both plasma-faced and rear sides of the tile might be needed to reduce tritium inventory of tiles with a large fraction of tritium retained in the bulk to level below LLW threshold. Testing with tile 4 also clearly indicates that flame heating will allow detritiation of the vast majority of the JET CFC tiles down to level of LLW.

All tritium released from the tiles during the tests was collected as tritiated water. Most of this tritiated water was condensed in a trap cooled with liquid nitrogen. The rest was collected in a molecular sieve bed operated at room temperature.

CONCLUSIONS

Detritiation of the CFC tiles of the JET divertor MKIIA using flame heating has shown that more than 99% of the tritium inventory can be removed both from the surface and from the bulk in a short single heating. Decontamination factor of several thousands was observed for tiles having the largest tritium inventory among tiles of the diveror MKIIA and a large fraction of this inventory retained in the bulk of the tiles. Consecutive flame heating allowed reduction of the tritium concentration in the tiles close to or below 12kBq/g which is the LLW threshold in the UK.

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Test	Temperature, K		Average residual tritium Concentration ^{c)} , kBq/g
	T _{AV}	T _{MAX}	
1 ^{a)}	840	915	73
2 ^{a)}	1070	1195	40
3 ^{a)}	960	1030	32
4 ^{b)}	780	890	170
	990	1130	34
	1100	1300	10
5 ^{b)}	1100	1300	43
	1100	1300	30
	1100	1300	30
6 ^{b)}	900	1130	27
	900	1130	16
	900	1130	10

a) Single heating run

b) Three consecutive heating runs

c) Average tritium concentration before the treatment was 38MBq/g

TABLE 1. Results of the test with pieces of tile 7

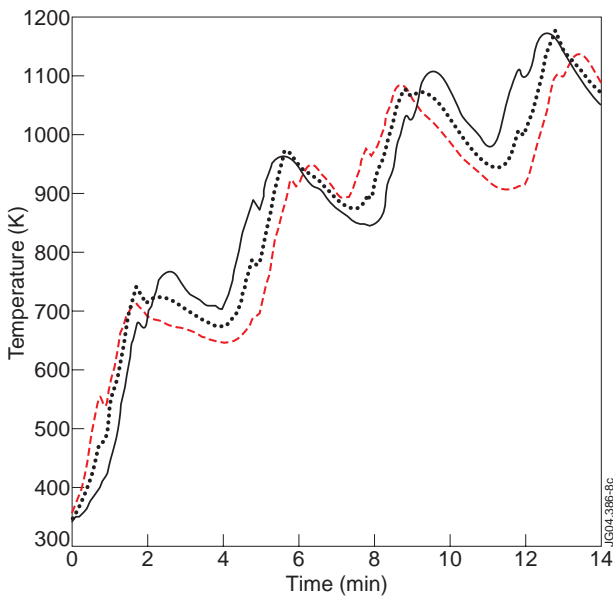


Figure 1: Temperature in different points of the tile during the heating run.

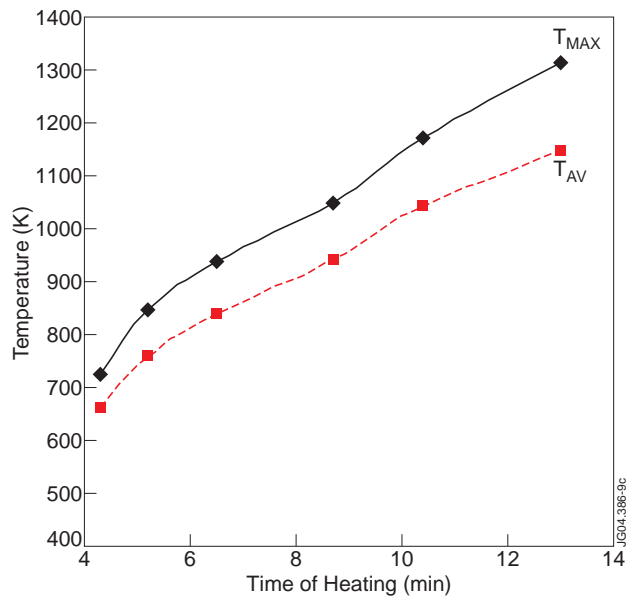


Figure 2: Temperature of the CFC tile which can be achieved in flame heating in a single heating run

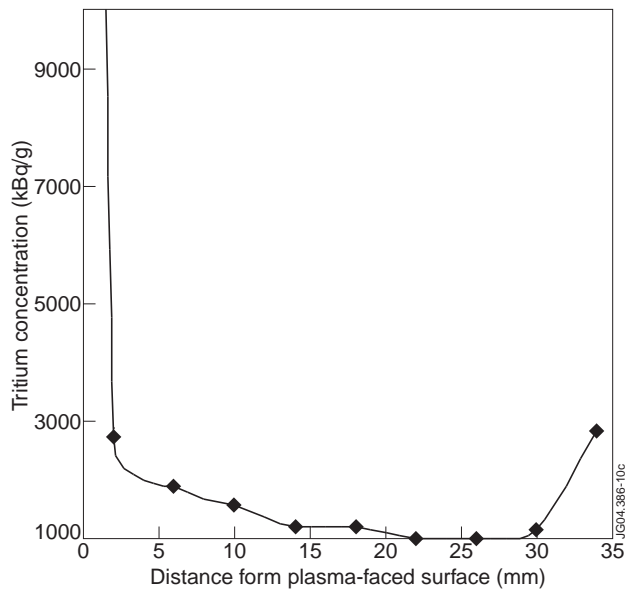


Figure 3: Tritium depth profile in the piece of the tile 7 before treatment.

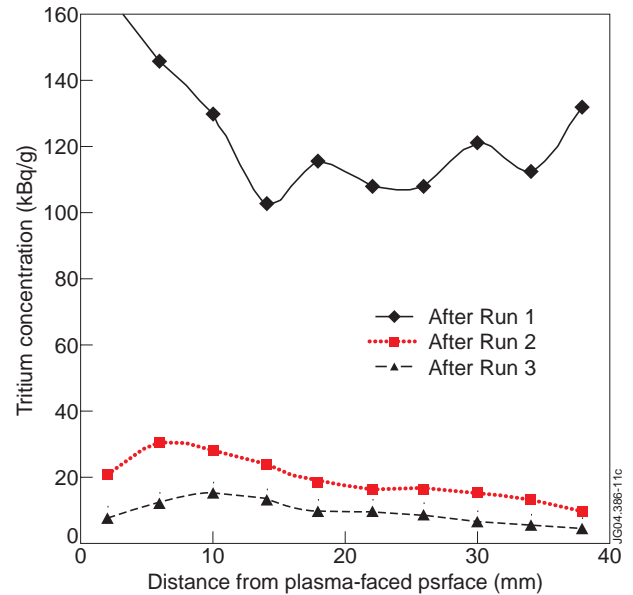


Figure 4: Tritium depth profiles measured in test 4 (tritium concentration in near to surface after first heating run was 640kBq/g).

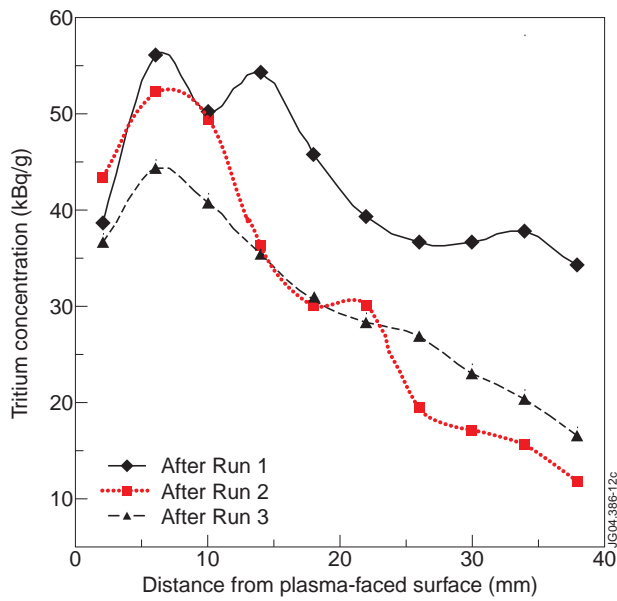


Figure 5: Tritium depth profiles measured in test 5.

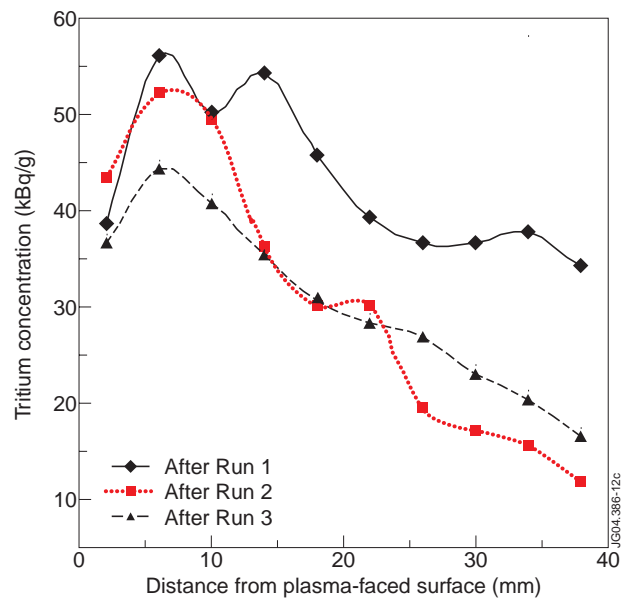


Figure 6: Tritium depth profiles measured in test 6.



Figure 7: Photo of tile 7 after heating runs in test 4 (left top corner - before the heating, left bottom corner - after the first heating run, right top corner - after second heating run, right bottom corner - after third heating run)

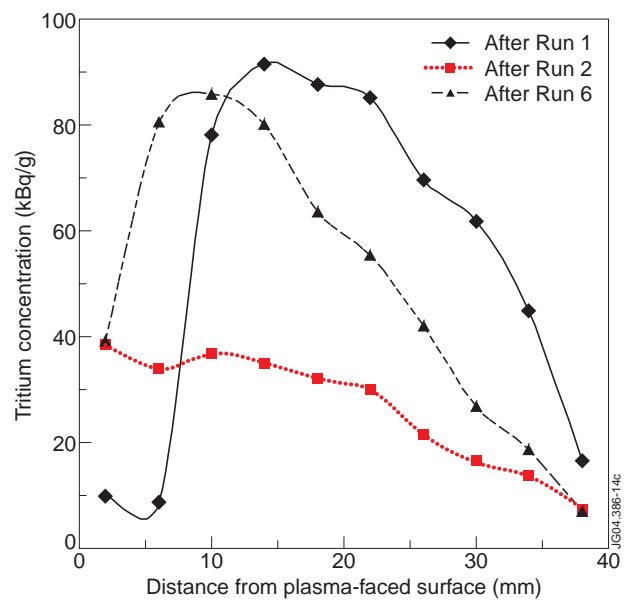


Figure 8: Tritium depth profile in tile 4 after heating runs 2, 4 and 6