Tritium efflux from TFTR during a vacuum vessel vent[1]

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Operation of TFTR with deuterium-tritium fuel has resulted in retention of tritium in the in-vessel hardware. Measurements of deuterium retention in TFTR made prior to tritium fueling indicate that 45 % of the injected deuterium was retained. The fraction of injected tritium retained in TFTR prior to efforts to remove the tritium was 52 %. The techniques used to remove tritium were glow discharge cleaning (GDC) with a mixture of 10 % oxygen in He or deuterium as the working gas, pulse discharge cleaning and vessel vents. These techniques were successful in removing 9.2 kCi of the 16.4 kCi of tritium trapped in the in vessel hardware. During the upcoming vacuum vessel opening for installation of new ICRF antennas, after initial tritium removal techniques are completed and the vessel is purged with air, it is expected that tritium will continue to evolve from the walls at a low rate. Based on the 1987 measurements of the outgassing rate of the tritium produced by D-D reactions, 34 Ci/day with a 4 day time constant are expected. The results found during the upcoming vent are presented.

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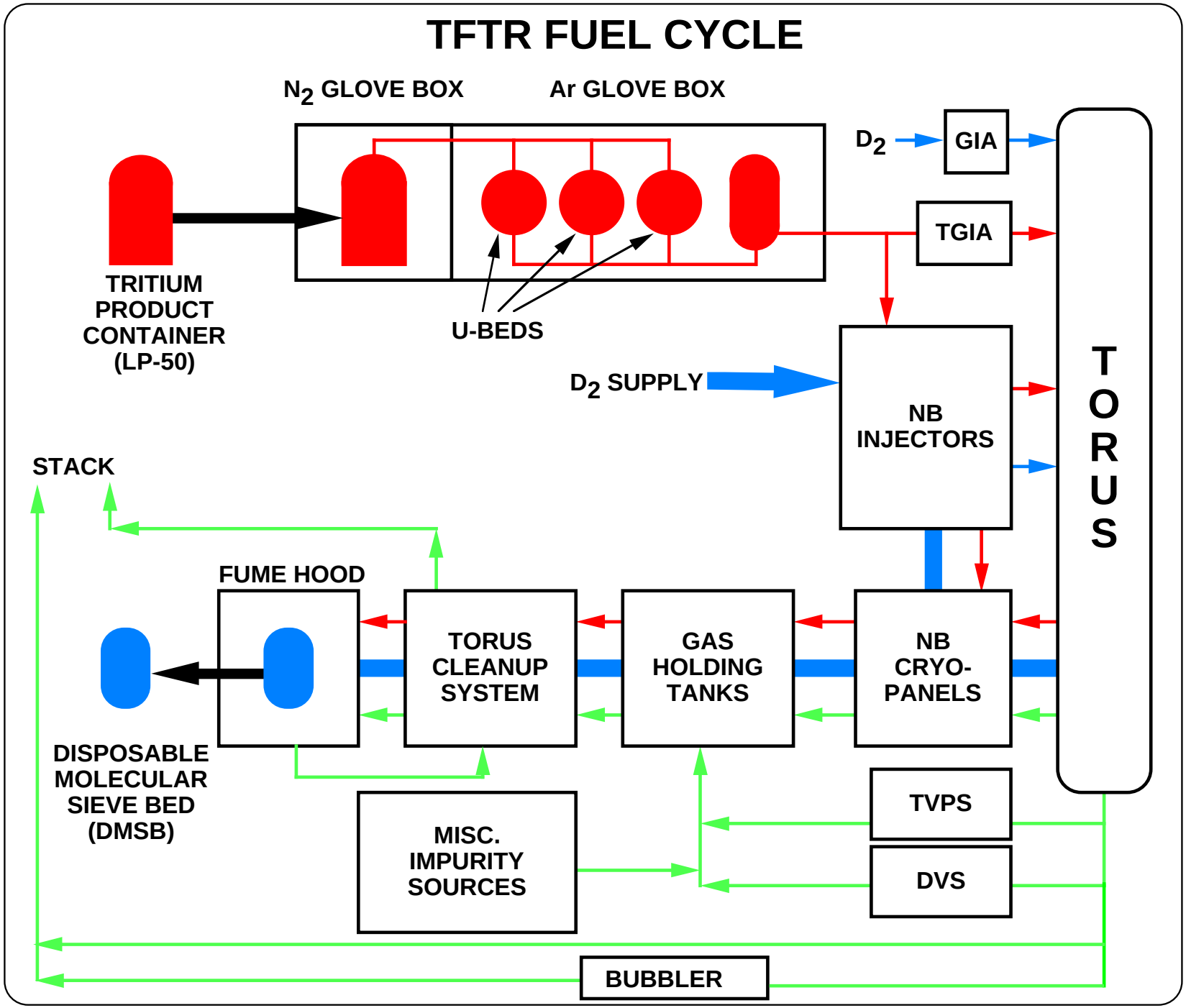
PURPOSE

- It is expected from studies made during the deuterium phase of TFTR that 45 +/- 15 % of the tritium injected into TFTR will be retained on the wall surfaces and in codeposited carbon on the limiter.

- TFTR has a site limit of 50 kCi and an in vessel limit of 20 kCi. At the end of the 1995 run, the in-vessel limit was approached and various techniques were employed to reduce the inventory.

- The issue of tritium retention and removal techniques are important for ITER which will have much higher inventories.

- The issue of tritium evolution from the walls and internal hardware is an important topic for any maintenance that requires a vessel opening.


TFTR FUEL CYCLE
N_2 GLOVE BOX
Ar GLOVE BOX
D_2
GIA
TGIA
TRITIUM PRODUCT CONTAINER (LP-50)
U-BEDS
D_2 SUPPLY
NB INJECTORS
TORUS
STACK
FUME HOOD
TORUS CLEANUP SYSTEM
GAS HOLDING TANKS
NB CRYO-PANELS
DISPOSABLE MOLECULAR SIEVE BED (DMSB)
MISC. IMPURITY SOURCES
TVPS
DVS
BUBBLER

TRITIUM MEASUREMENT

Input -

PVT measurement of plenum pressures before and after pulse.

Recovered -

Effluent from pumping systems goes to Gas Holding Tanks
PVT measurement for total gas.

Ionization chambers and quadrupole mass spectrometer measure the tritium content.

During the period when the vessel was open, a flow of between 4 and 1500 CFM was maintained and the exhaust gas was handled in three ways.

At low flow (4 CFM) during the early stage of purging, the effluent gas was handled through the gas holding tanks. Later, the effluent was passed over a bubbler system to remove tritium before exhausting the remainder up the stack.

During the high flow period and later in the process,the effluent gas was exhausted up the stack.

In both cases, the tritium content was measured.

Retained -

The difference between input and recovered tritium during normal high power operation is typically 2 %. While the error on this difference is not well known, it is reasonable to expect the uncertainty in the measured difference to be on the order of 1 % of the total or 50% of the difference.

PERIOD 09-01-93 TO 09-30-95

HIGH POWER OPERATION

Total Number of discharges	14724
Number of Discharges with neutral beam injection (NBI)	6134
Number of Discharges with tritium neutral beam injection (TNBI)	500
Amount of tritium processed	700 kCi
Amount of tritium injected	31.4 kCi
Amount of tritium retained in TFTR	16.4 kCi

TRITIUM FUELING IN TFTR

12 TRITIUM NEUTRAL BEAM SOURCES

Source parameters:	Normal Range	Typical values
Duration:	< 5 sec.	1 sec
Voltage	85 to 120 kV	105 kV
Power	2 to 3 .2 MW	2.8 MW
Tritium consumed	< 750 Ci	250 Ci
Tritium injected	< 50 Ci	10 Ci

2 TRITIUM PIEZOELECTRIC GAS VALVES

Flow rate up to 2 x 150 Tl/s

TOTALS INJECTED INTO TFTR FROM 09/01/93 TO 09/30/95

TRITIUM

Energetic tritons	4.03×10^{23}	19.4 kCi
Cold gas from NB sources	0.24×10^{23}	1.2 kCi
Gas Puffing	2.24×10^{23}	10.8 kCi
Total tritons	6.51×10^{23}	31.4 kCi

DEUTERIUM

Energetic deuterons	1.57×10^{25}
Cold gas from NB sources	0.16×10^{25}
Estimated gas puffing	0.08×10^{25}
Total Deuterons	1.81×10^{25}

TRITIUM RETENTION BEFORE REMOVAL TECHNIQUES 09-01-93 TO 09-30-95

At the end of the 1993-1995 run, the total tritium retained in TFTR torus, neutral beam boxes and appendages was 16.4 kCi.

This gives a run averaged retention of 52 +/- 15 %. This is the total retention, including tritium trapped in the neutral beam boxes, and other vacuum hardware. Purges of various beam and other enclosures suggest about 2 kCi were trapped in places other than the torus structures.

For reference, the measured deuterium retention on TFTR by post-run analysis of limiter tiles and wall samples was 45 +/- 20 %.

PERIOD 09-30-95 TO 01-01-96

TRITIUM REMOVAL

Tritium Removed **9.2 kCi**

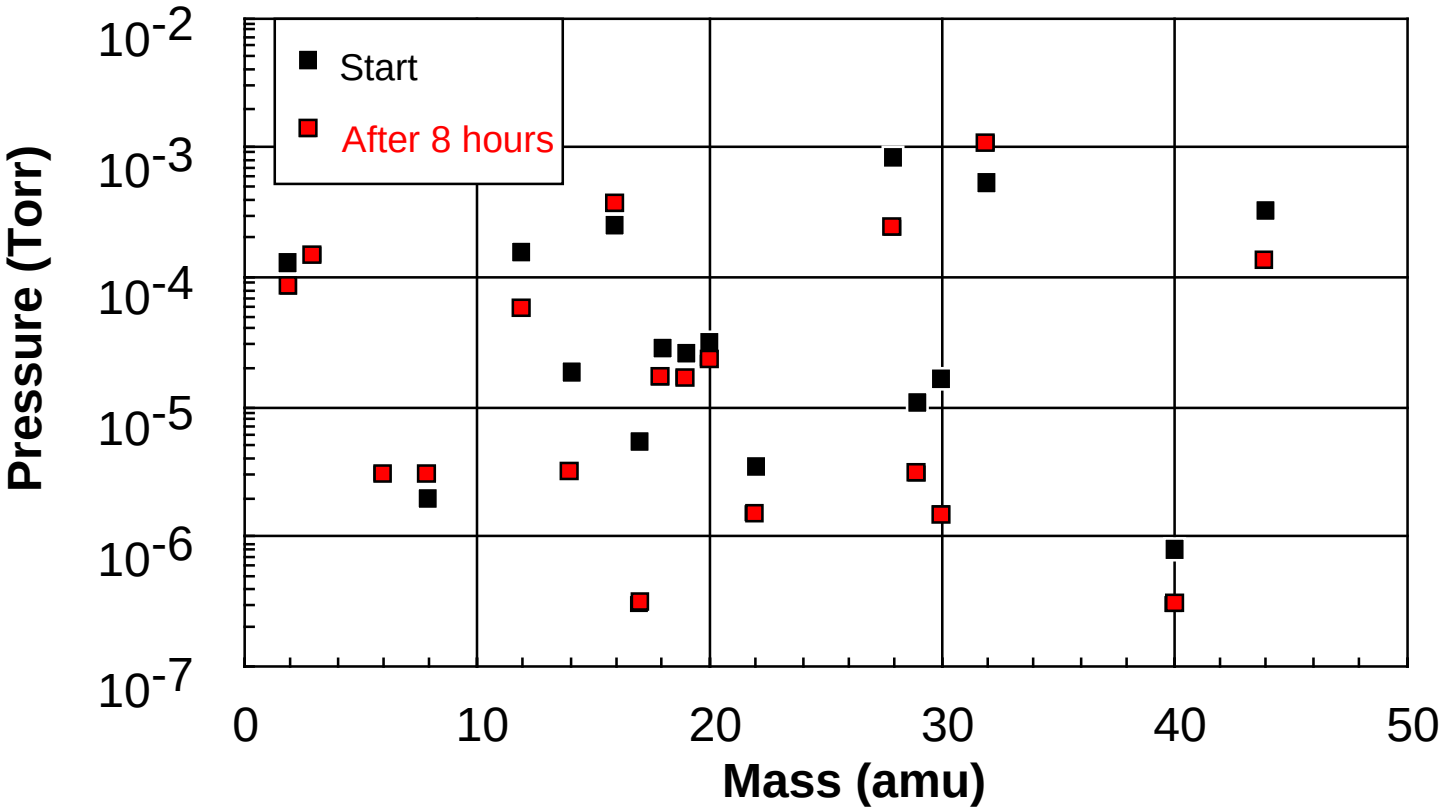
Removal Techniques:

D_2GDC @150°C	Effective, but rate decreases
D_2GDC @25°C	Effective, but rate decreases
He GDC	Ineffective
He-O GDC	Effective, but low ~ constant rate
PDC @150°C	Effective, but labor intensive
Air Purge	Effective for "loosely bound" T
N_2 Purge	Ineffective

GLOW CHARACTERISTICS

Gasses used	**He** **D_2** **90% He /10% O_2 mixture** **88% He /2% CD_4 /10% B_2D_6**
Gas pressure	**20 mTorr**
Probe Voltage	**~200 Volts**
Probe Current	**2 X 7 Amp.**

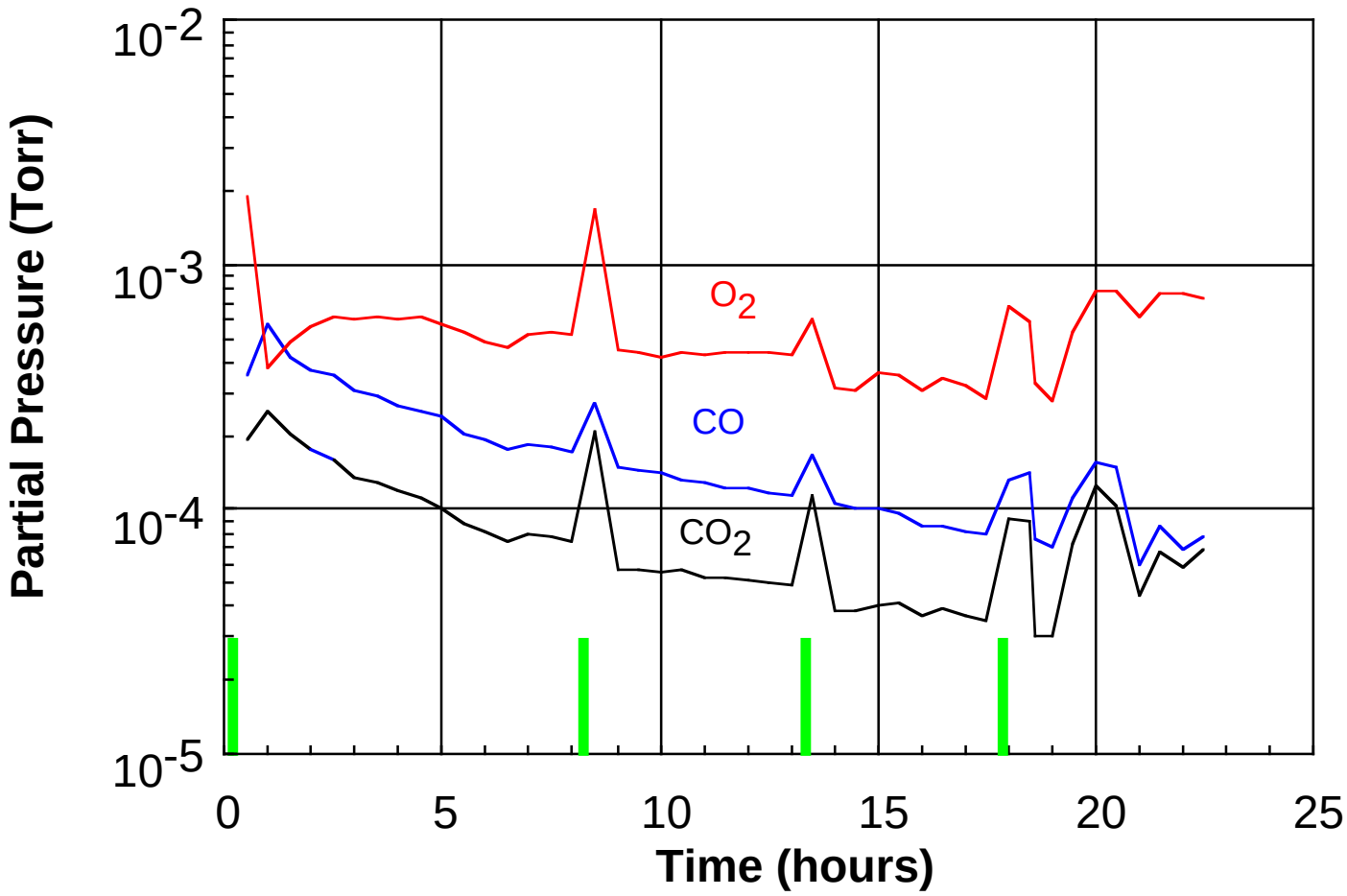
RGA spectra during He-O GDC



RGA spectra taken during He-O glow about 1/2 hour after the start and after about 8 hours of glow.

Note the deuterated methanes are an order of magnitude smaller than CO and CO_2.

Partial Pressure versus time during He-O GDC

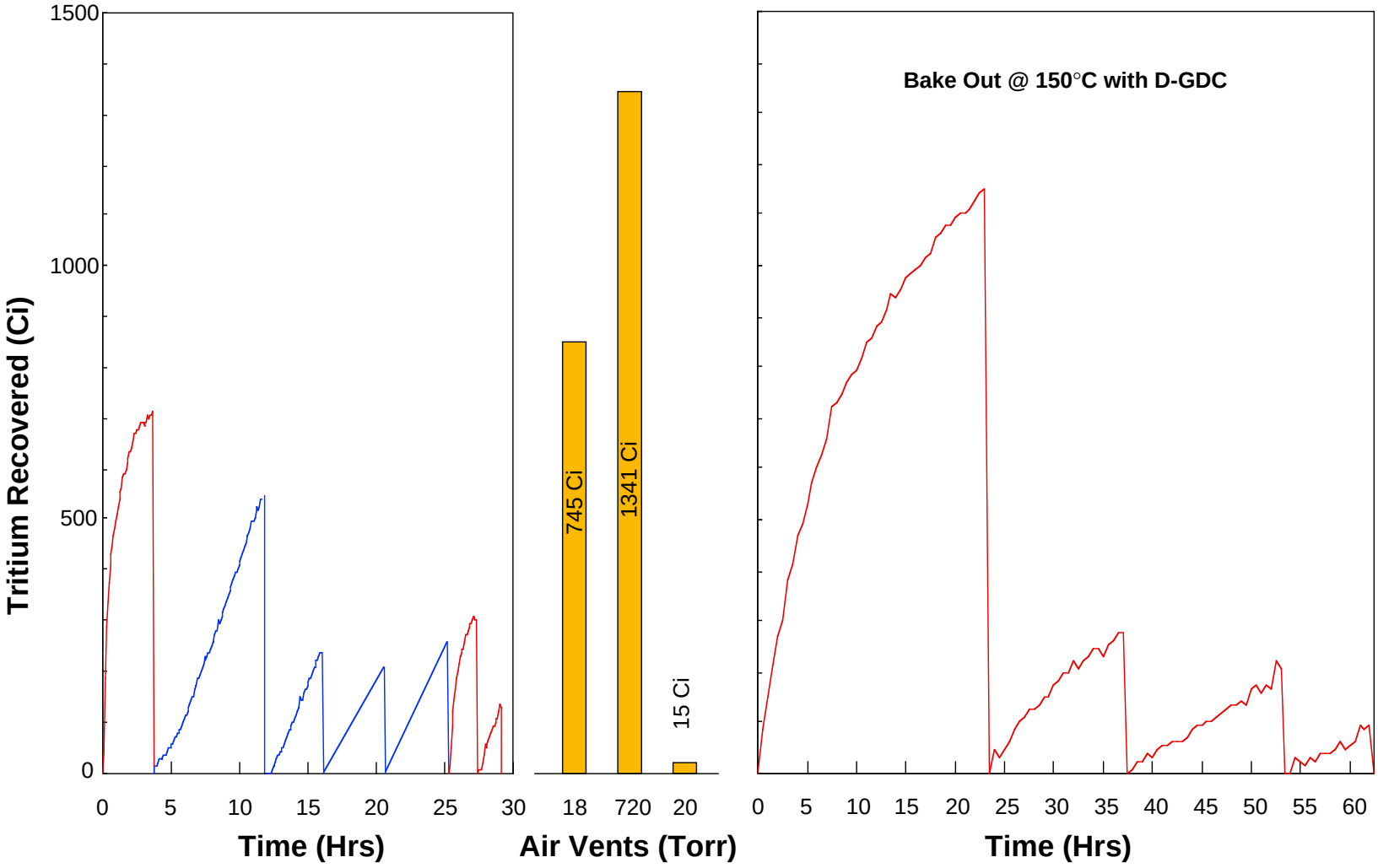


Partial pressures during He-O GDC. The data has been concatenated to remove the non-glow periods. The start times of the periods are indicated by green bars at the bottom of the graph.

The ratio of C to O for the entire glow was 0.2 and 225 g of oxyger were used in performing the glow. This then implies removal of 33.7 g of carbon or 0.34 μm assuming a surface area of 100 m^2.

Further since 1250 Ci of tritium were removed this implies 0.011T/C, consistent with D/C ~ .3 and the T/D fuelling ratio for entire D-T run period of 0.036.

TFTR Tritium Recovery during deuterium and helium-oxygen glow discharge and room air vent



- At the end of September, 1995, 16.4 kCi were in the TFTR vessel and beamlines. This was ~52% of the tritium injected during the preceding 2 years.
- At the end of the cleanup campaign, 8.1 kCi remained.
- He GDC and D_2 soaks were ineffectual in removing tritium.

MEASURED TRITIUM REMOVAL FROM TFTR

9-30-95 to 01-02-96

Activity	Tritium Removed (Ci)	In-vessel Account (Ci)
End of operation	0	16,399
D-GDC	687	15,713
He-O GDC	1249	14,463
D-GDC	495	13,968
Torus vent to 18 Torr air, 20 Torr N_2	745	13,223
Torus vent: to 718 Torr air	1341	11,882
Torus vent to 20 Torr air	15	11,867
150°C Bake + D-GDC	1609	10,258
150°C Bake + boronization	169	10,089
150°C Bake + PDC	956	9,133
NB vent to 720 Torr air	467	8,666
Miscellaneous pumps and purges of volumes and outgassing during the period 10/06 to 11/17/95	524	8,141
Operations and outgassing from 11/17/95 to 01/02/96	978	7,163

PERIOD 01-02-96 TO 08-02-96

HIGH POWER OPERATION

Total Number of discharges	5324
Number of Discharges with neutral beam injection (NBI)	2167
Number of Discharges with tritium neutral beam injection (TNBI)	124
Amount of tritium processed	161 kCi
Amount of tritium injected	5.58 kCi
Amount of tritium retained in TFTR	14.1 kCi
Increment of tritium inventory in TFTR	6.9 kCi

TRITIUM FUELING IN TFTR

12 TRITIUM NEUTRAL BEAM SOURCES

Source parameters:	Normal Range	Typical values
Duration:	< 5 sec.	1 sec
Voltage	85 to 120 kV	105 kV
Power	2 to 3 .2 MW	2.8 MW
Tritium consumed	< 750 Ci	250 Ci
Tritium injected	< 50 Ci	10 Ci

2 TRITIUM PIEZOELECTRIC GAS VALVES

Flow rate up to 2 x 150 Tl/s

TOTALS INJECTED INTO TFTR FROM 01/02/96 TO 08/02/96

TRITIUM

Energetic tritons	1.08×10^{23}	5.20 kCi
Cold gas from NB sources	0.06×10^{23}	0.31 kCi
Gas Puffing	0.01×10^{23}	0.07 kCi
Total tritons	1.16×10^{23}	5.58 kCi

DEUTERIUM

Energetic deuterons	5.68×10^{24}
Cold gas from NB sources	0.57×10^{24}
Estimated gas puffing	0.28×10^{24}
Total Deuterons	6.53×10^{24}

TRITIUM RETENTION
01-01-96 TO 08-02-96

At the end of the 1996 run, the increase in the total tritium retained in TFTR torus, neutral beam boxes and appendages was 6.9 kCi.

This gives an averaged retention of 63 % for the entire DT experimental run, if the effects of active tritium removal techniques and the tritium trapped in the various beam and vacuum appendages are ignored.

PERIOD 08-03-96 TO 10-30-96

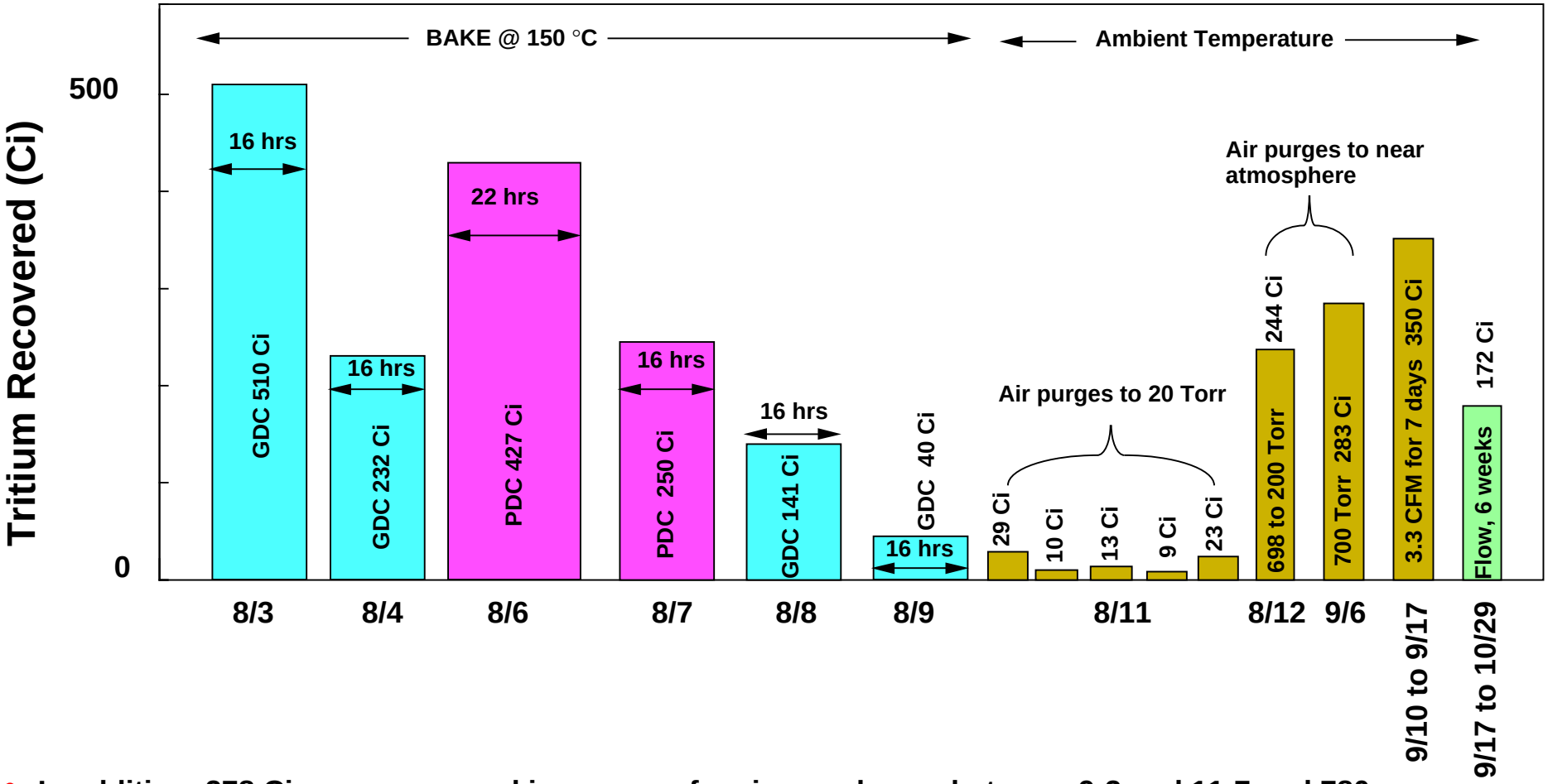
TRITIUM REMOVAL

Tritium Removed **3.9 kCi**

Removal Techniques:

D_2GDC @150°C	Effective, but rate decreases
PDC @150°C	Effective, but labor intensive
Air Purge	Effective for "loosely bound" T
Continuous Air Purge	Slow declining release

Tritium recovery August 3 through November 4, 1996



- In addition, 278 Ci were recovered in purges of various volumes between 9-3 and 11-7 and 780 Ci were recovered from purges of NB volumes.

SUMMARY

On average, 63 % of the tritium injected into TFTR was retained in the torus, neutral beams and appendages prior to efforts to remove it.

D_2 GDC had a high initial rate of removal (1600 Ci/hr) which fell to < 15 Ci/hr over tens of hours.

He-O GDC had a more constant removal rate (50 Ci/hr) and removed approximately 0.34 μm of the graphite surface in 23 hours. This is about 20 times slower than reported in lab experiments.

PDC at 150°C removed tritium at a rate of 15 to 20 Ci/hour.

D_2 soak, He GDC and boronization were not effective tritium removal techniques.

The first two air vents removed 2100 Ci total, while the third removed only 15 Ci in 1995. In 1996, less tritium (~1000 Ci) was removed by the air vents.

The effectiveness of air vents fell quickly, indicating that while tritium removal by venting with air works quickly, however, ~ 80% of the retained tritium is not available for release to room temperature air.

Tritium continued to evolve from the walls over the entire opening. The average rate of tritium release during the period air flow was maintained was 4.1 Ci /day.

The flow rate was not constant and the actual rate at which tritium was vented up the stacked varied by orders of magnitude up 9 Ci/hr during brief periods of high flow. It is thought that the peak values are due to turbulent mixing of tritium and air that had stratified during much longer periods of low flow.