TRACER TECHNIQUES IN STUDIES OF MATERIAL MIGRATION in TOKAMAKS

DIAGNOSTIC TOOLS and RESULTS from TEXTOR and JET

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Workshop Agenda

Key Questions in Studies of Material Migration: What? Where? Why? How?

- ***What** is the distribution of erosion and deposition zones ?*
- ***Where and why** fuel is stored ?*
- ***How** does the material erosion and transport mechanism influence the fuel inventory ?*
- ***What** are the implications for ITER operation?*
- ***How** can we deal with the problem?*

O U T L I N E

- Tracers
- Tungsten transport and mixing: TEXTOR
- Carbon transport and re-deposition:
    - TEXTOR
    - JET
- New diagnostic tools at JET.

Tracers (Transport Markers)

Definition

Tracer: an alien agent introduced deliberately to a studied system in minute quantities.

The introduced agent must be reasonably harmless to the system under examination.

In fusion experiments, tracers are used to study material migration: e.g. erosion and re-deposition.

Experimental Approach: Dedicated Experiments and Diagnostic Tools

Dedicated marker experiments

- Gas injection
  CD_4, $^{13}CH_4$, SiH_4, $B(CH_3)_3$
- Deuterium - Tritium experiments
- Test tiles (limiter, divertor)
- Marker coated tiles and probes

In-vessel diagnostic

- *In-situ* (real time)
  - spectroscopy, cameras
  - quartz micro-balance (QMB)
  - electrical probes
  - laser ablation
- Diagnostic for *ex-situ* studies:
  - passive deposition monitors
  - surface collector probes

Various material analysis techniques for surface and bulk studies

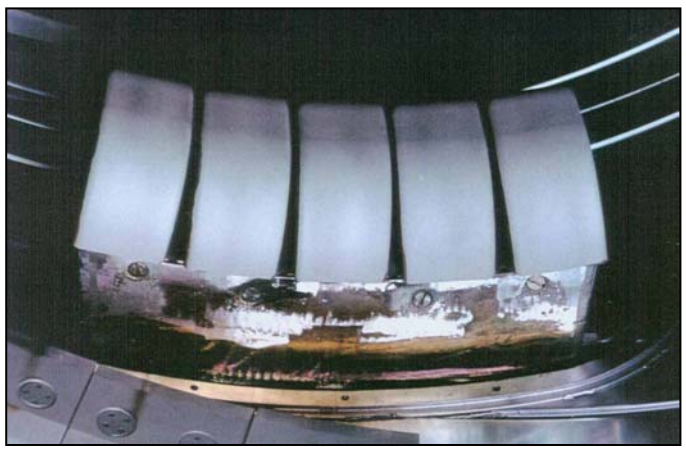
- *There is no single method (technique) to answer all questions.*
- *A combination of in-vessel diagnostic tools and ex-situ analysis methods required.*

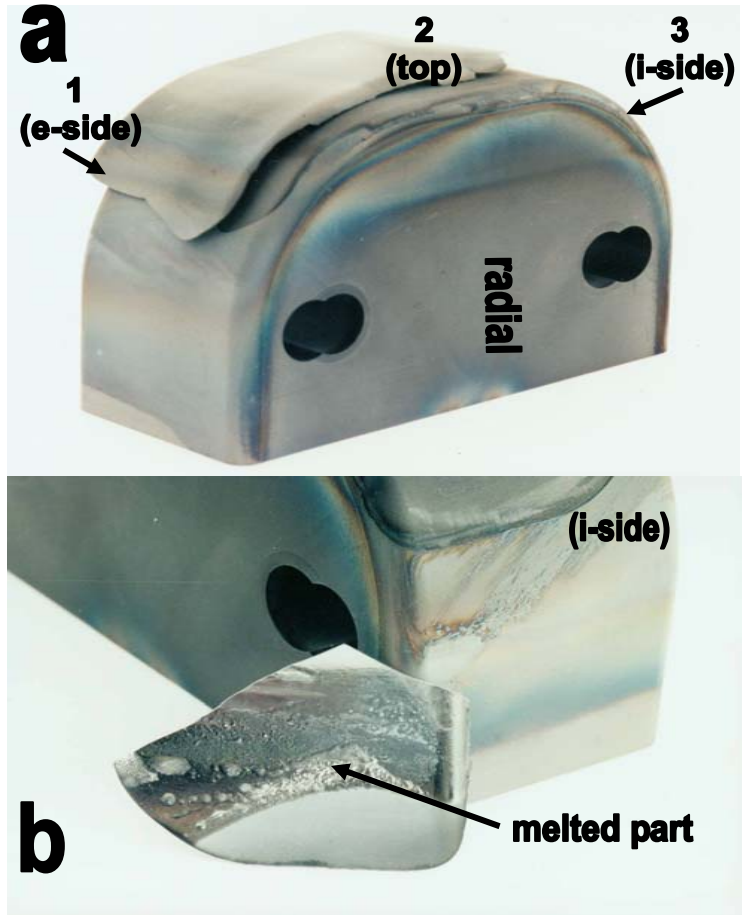
Test PFC Tiles in Studies of Material Mixing

VPS Tungsten-coated Limiter at TEXTOR

MAIN POLOIDAL LIMITER

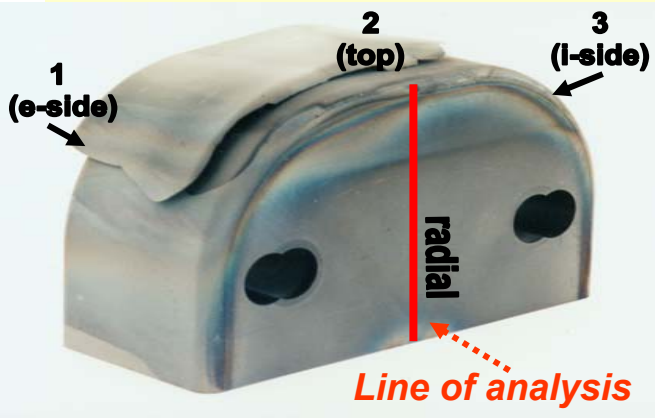
VPS - tungsten coating on graphite (500 μm W)



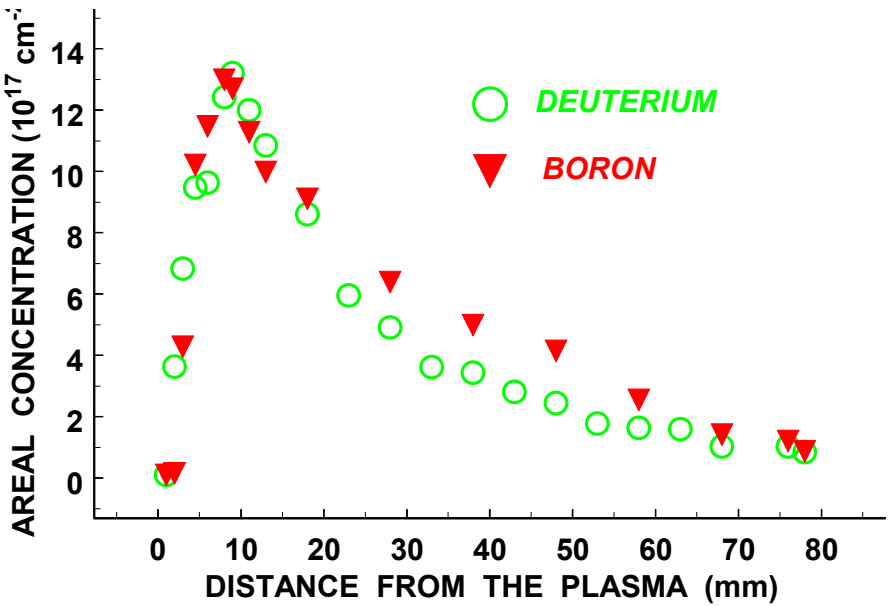


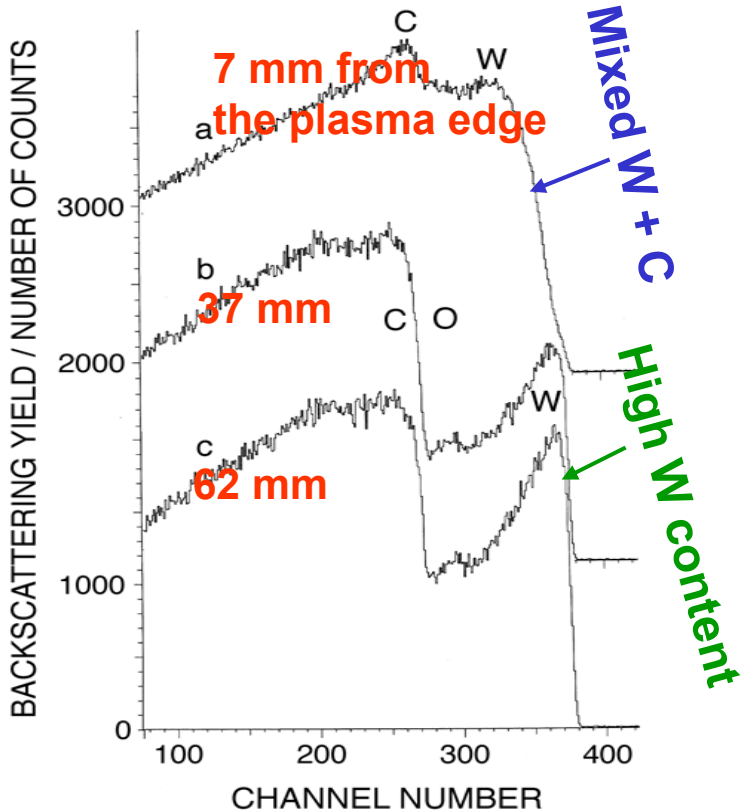
A damaged tile: detachment and melting of W layer

VPS Tungsten-coated Limiters at TEXTOR: Material Mixing on Side Surfaces of the Limiter



Radial distribution of deuterium, boron, carbon and tungsten.





Messages:

- Eroded tungsten is transported to the gaps between the tiles.
- Significant C, D, B and W mixing on the side surface.

Carbon Transport and Fuel Inventory

Carbon Transport and Re-deposition

Carbon is used in most of present-day devices and is foreseen for the ITER divertor.

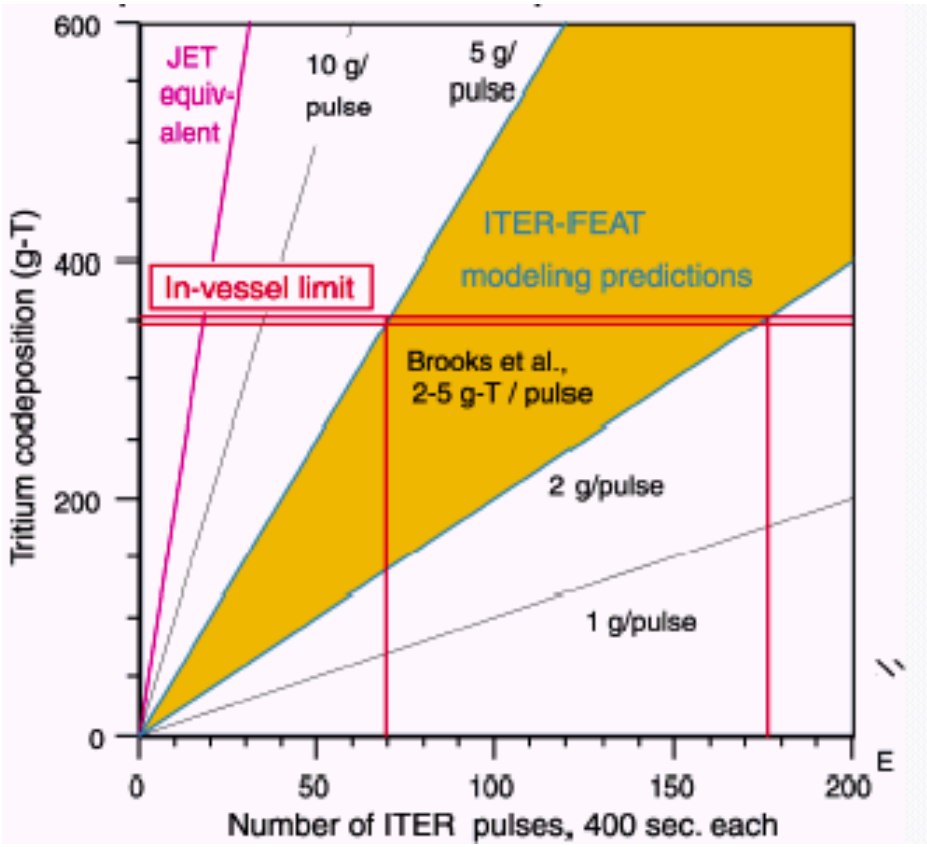
Co-deposition of carbon with fuel atoms.

Fuel (tritium) inventory by co-deposition is a driving force in studies of carbon transport.

Motivation for studies:

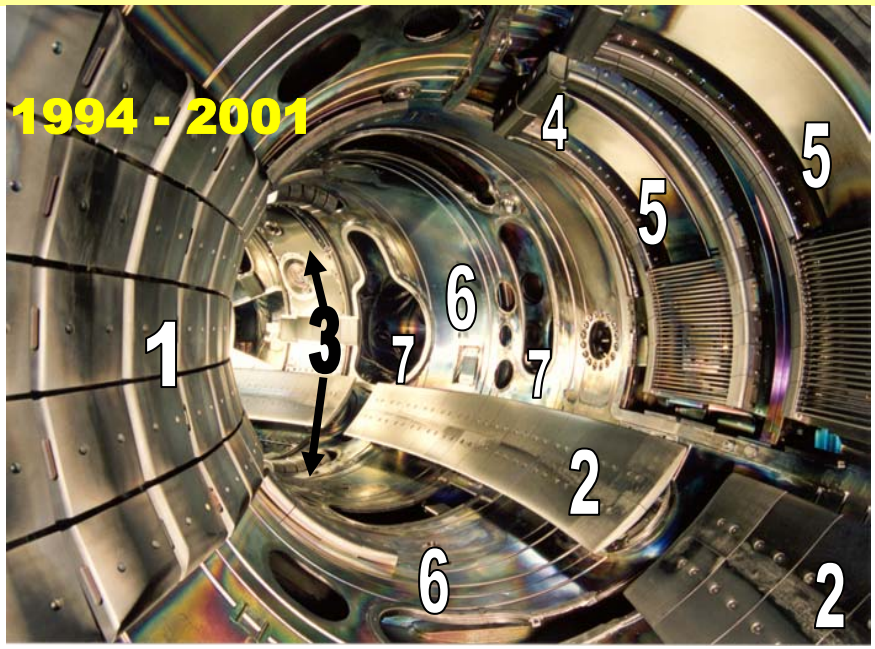
Reactor safety & licensing

1 g Tritium = 9652 Ci



Clean-up of the vessel after reaching the limit of 350 grams T !

Inside the Vacuum Vessel of TEXTOR



Graphite Limiters :

Inner bumper	(1)
Toroidal pump	(2)
Poloidal	(3)
RF antennas protection	(4)
RF antennas	(5)
Liner (Inconel®	(6)
Diagnostic ports	(7)

Rare Isotopes as Transport Markers

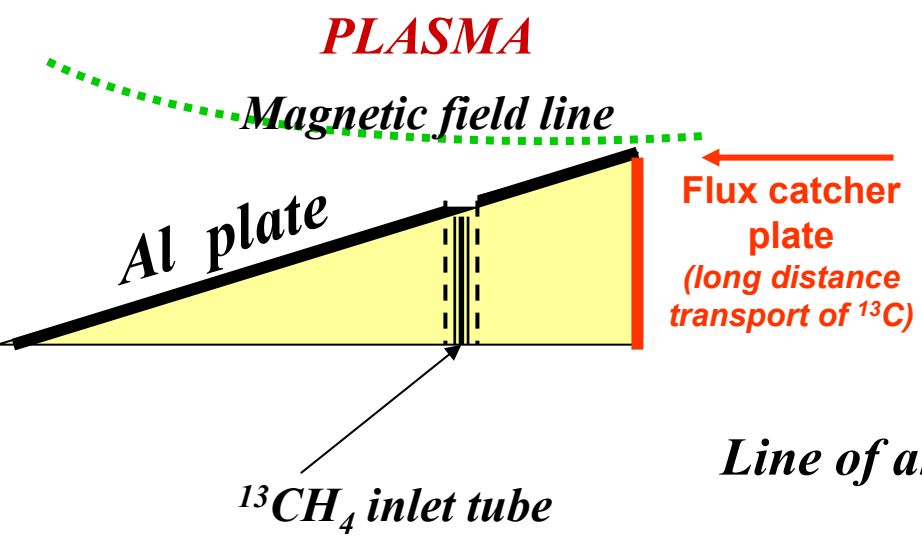
Carbon Transport in TEXTOR: C-13 tracer in the C-12 surrounding

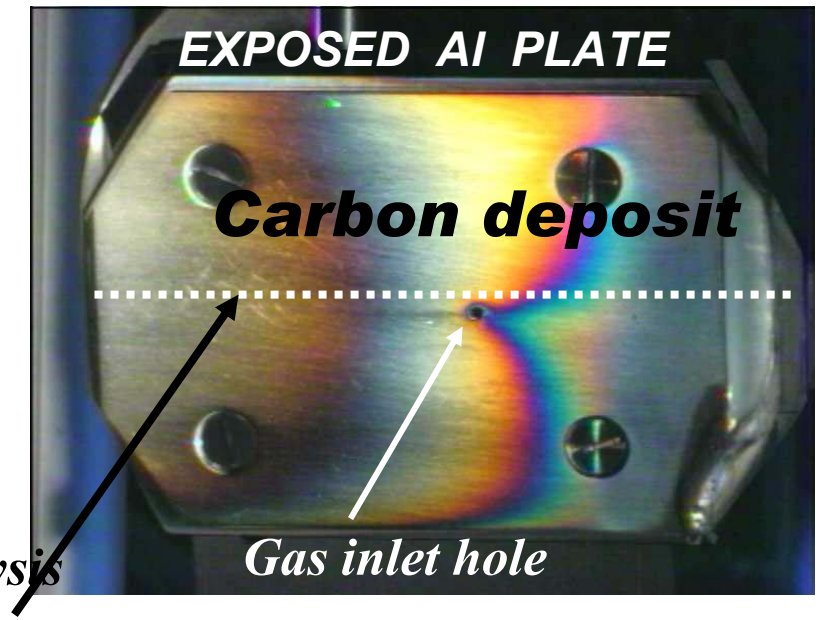
Experiment: Injection of $^{13}CH_4$ to the plasma edge.

The aim: To determine where does the carbon go:

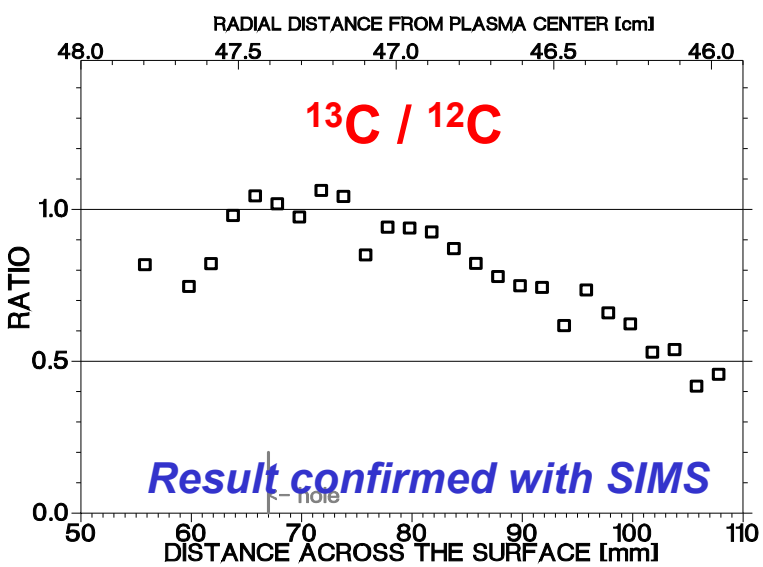
the amount and distribution of locally and globally transported C,

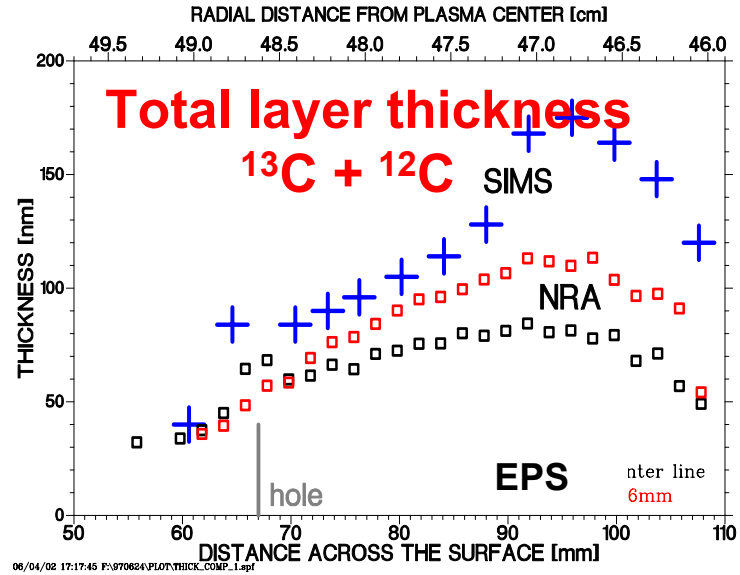
the ratio of ^{13}C / ^{12}C in the deposit.





Messages from Ion Beam Analysis of C-13 and C-12





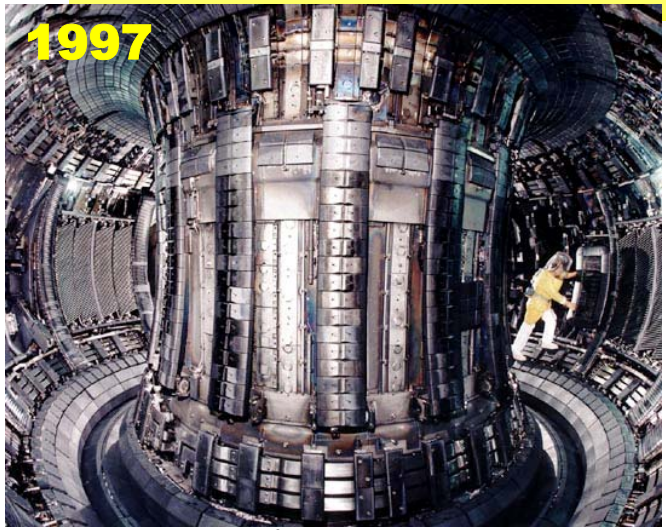
Film composition is dominated by ^{12}C eroded from the tokamak wall.

Only 1 % of injected ^{13}C was deposited locally (on the plate).

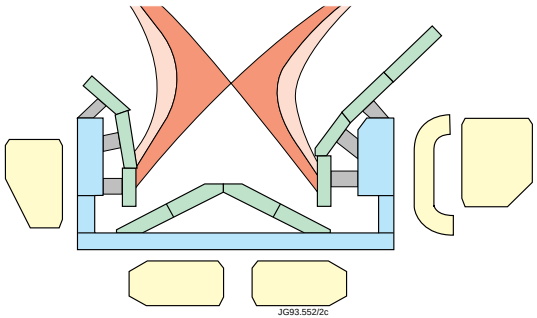
99 % of injected ^{13}C was transported over long distances
(significant amount of C-13 found on the catcher plate $^{13}C/^{12}C$ = 0.23).

JET

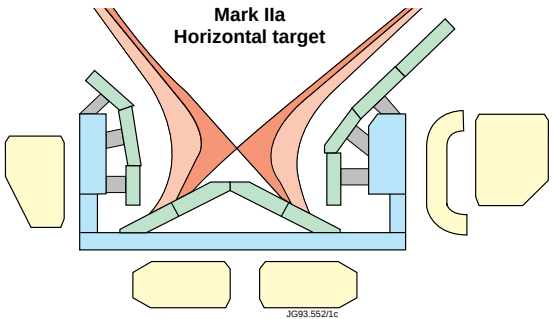
JET Vacuum Vessel and Divertors

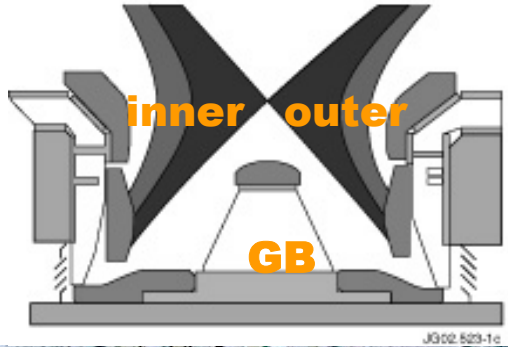


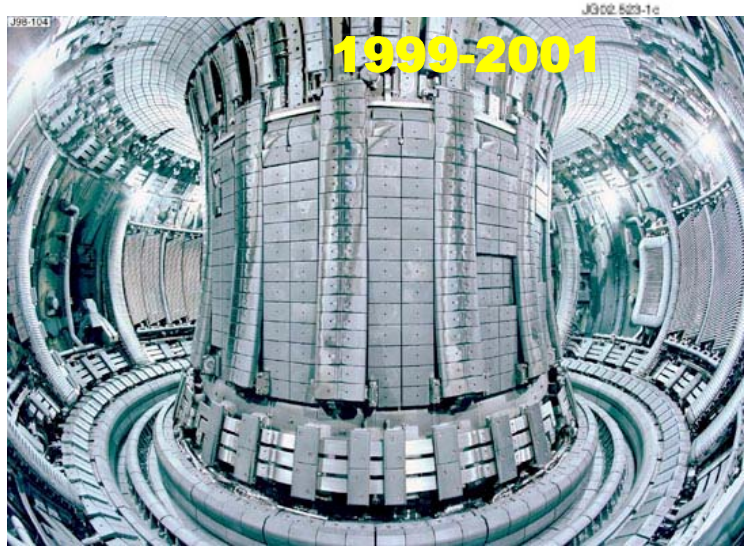
Mark IIA
Vertical Target



Mark IIa
Horizontal target





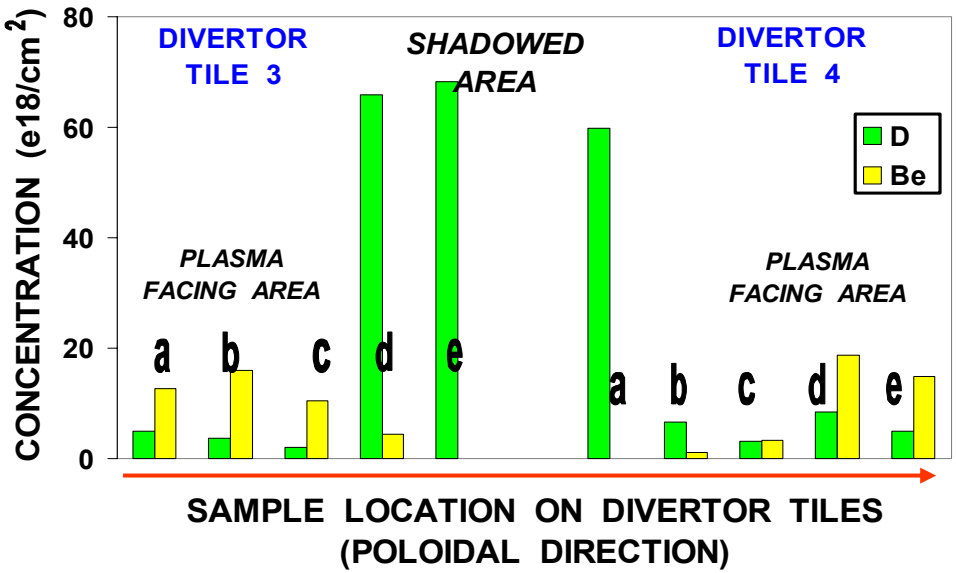


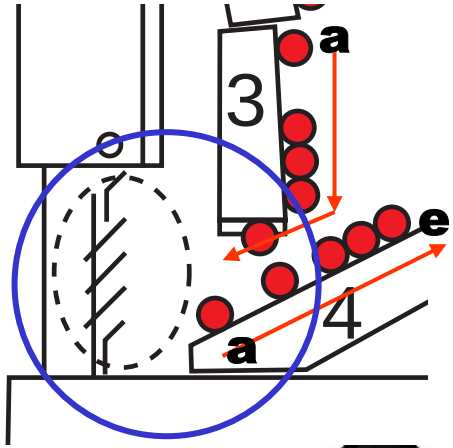
Beryllium and Tritium environment:

- *Be evaporation on the wall*
- *D - T experiments*

Situation at JET after the D - T Experiment

High fuel inventory localised mainly in the inner divertor.





Carbon flakes under divertor

Messages:

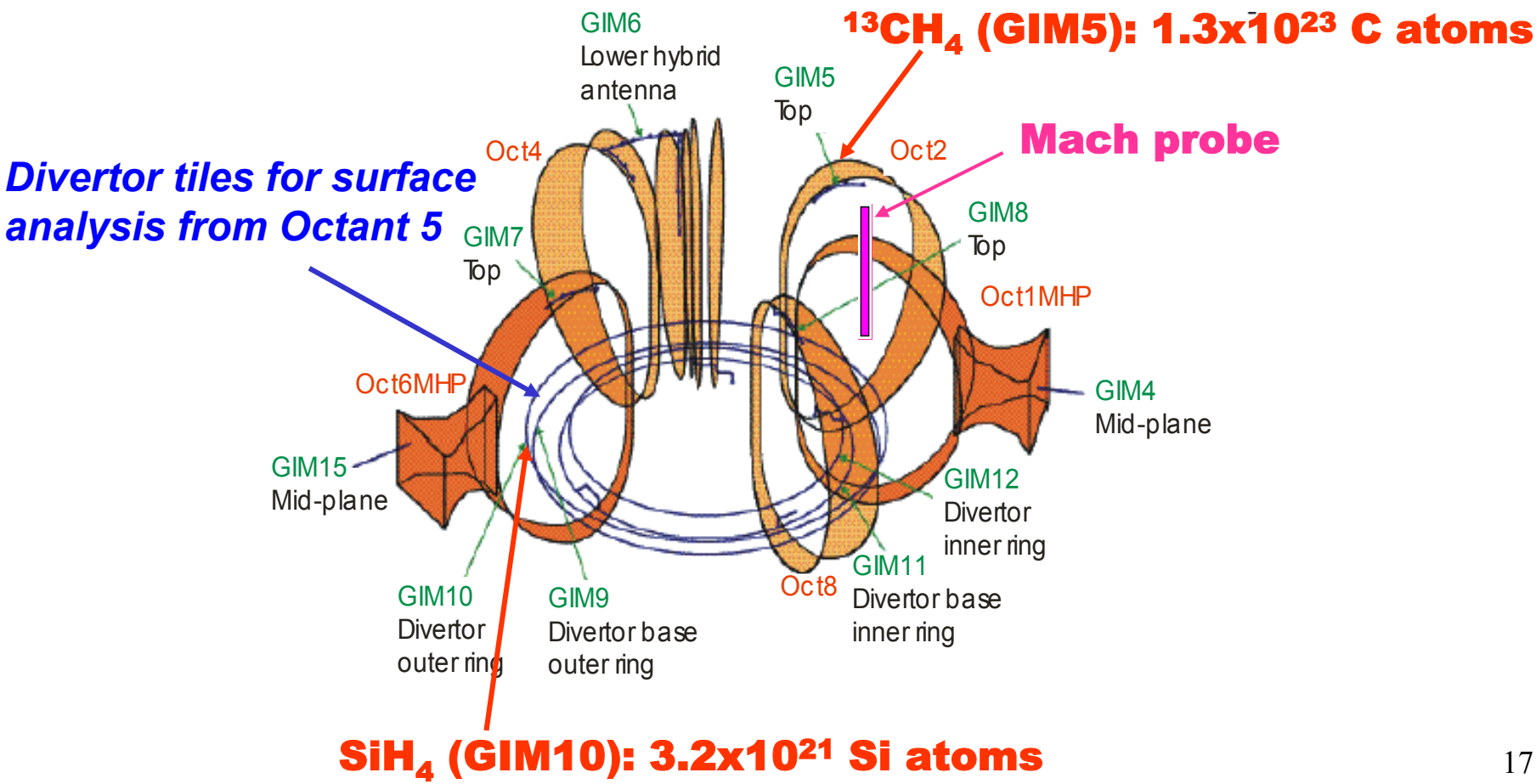
Be content decreases towards the inner corner.

High fuel content but <u>no</u> beryllium in shadowed areas

Fuel in the shadowed area is co-deposited with carbon.

$^{13}CH_4$ Injection into the JET Plasma

The aim:
To assess the carbon transport and flow direction.



Material Migration in JET: Results, Conclusions and Implications

RESULTS:

^{13}C found only in the inner divertor.

^{13}C distribution corresponds to the strike point location.

^{13}C in the layer of up to ~ 1 μm.

^{13}C content increases towards the inner corner of the divertor.

~ 45 % of injected ^{13}C found in that region.

No ^{13}C found in the shadowed region.
Possibly, C transport to that region is a multi-step process, i.e. longer time scale.

No beryllium in the shadowed region.

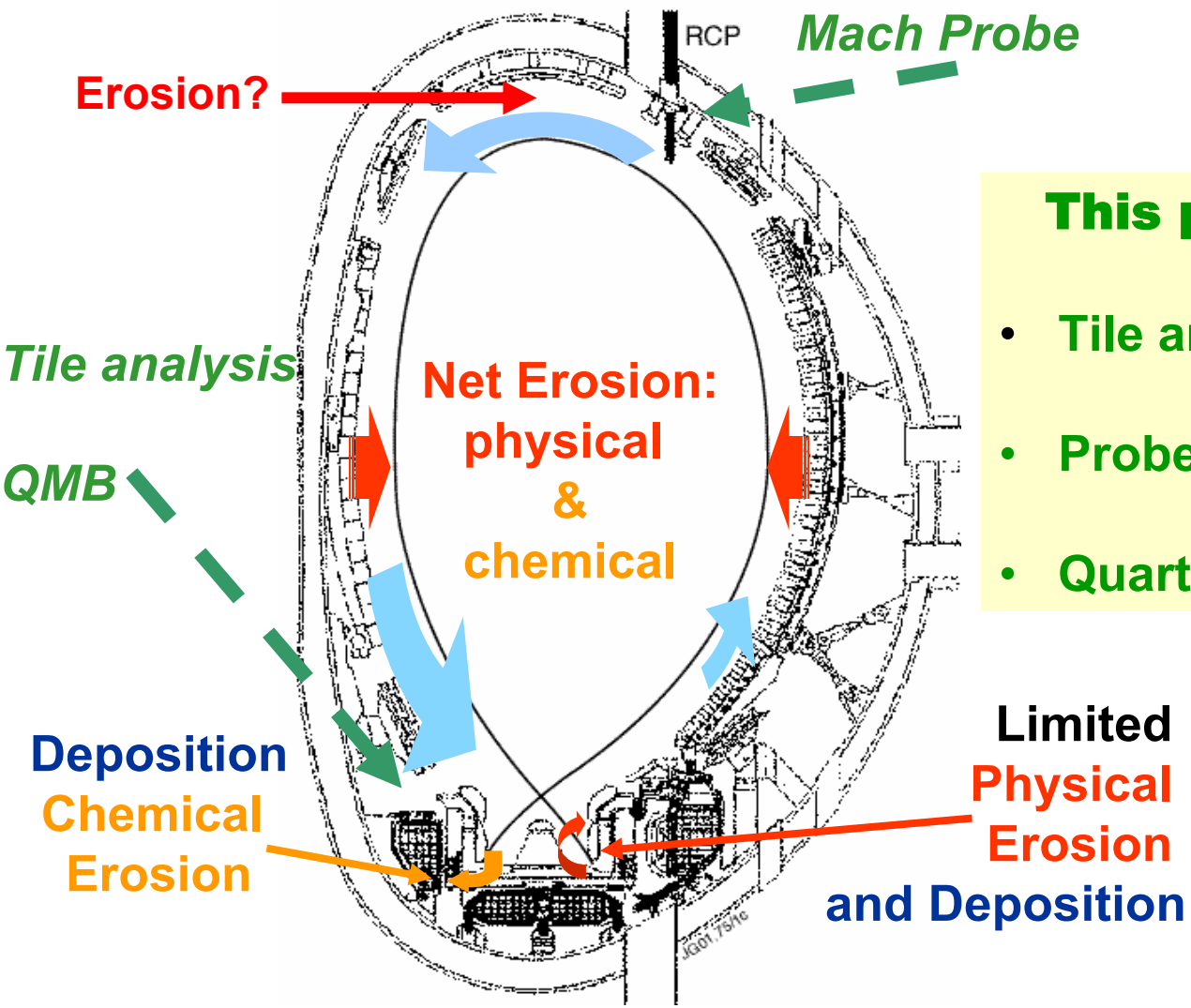
CONCLUSIONS:

Chemically eroded carbon is transported to shadowed areas where it becomes co-deposited with vast amounts of fuel.

Beryllium, physically sputtered from the main chamber wall, does not migrate to the shadowed zone.

The results suggest that in a machine with an all beryllium wall in the main chamber, fuel retention may be significantly reduced due to removal of the carbon source.

Overview of Material Migration in JET



This picture is based on:

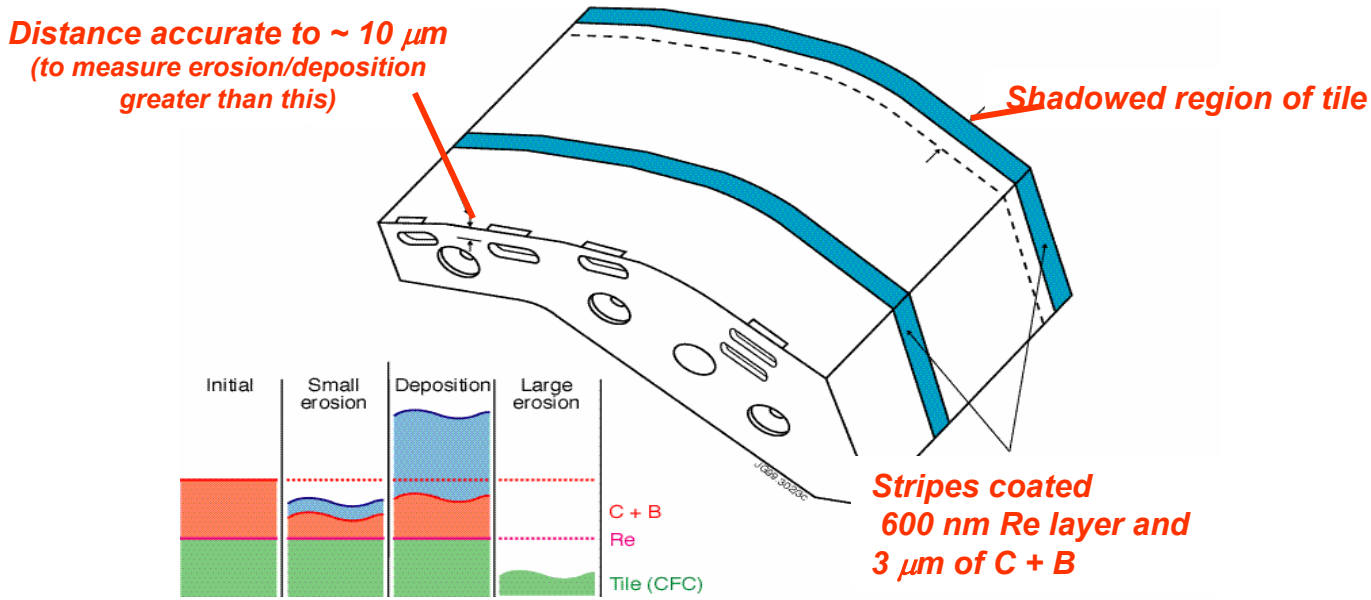
- Tile analysis
- Probe measurements
- Quartz micro-balance data

Next Step in Assessment of Erosion / Deposition: New Diagnostics for Installation in JET

- **Quartz micro-balances:**
  - » open quartz crystal,
  - » with shutter
  - » water-cooled
  - » heatable
- **Rotatable (indexable) collector**
- **Passive deposition monitors with shutters (trap type)**
- **Cassettes with mirrors (First Mirror Test for ITER)**
- **Divertor and limiter tiles coated with a high-Z marker layer (Re)**
- **Louver clips**
- **Fast reciprocating probes (Collector, Mach, Retarding Field Anal.)**

- ***Devices are placed in several locations.***
- ***Installation of all devices compatible with remote handling.***

Marker Tiles: CFC Coated with Films



CONCLUDING REMARKS

- Inter-machine comparison is an important step in obtaining a detailed picture of erosion and fuel inventory.

- The application of marker techniques provides conclusive information.

- The issue of using carbon in a next step machine must be re-assessed.

Workshop Agenda