Tritium diagnostics for in situ inventory and waste management

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Poster No. 103

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Introduction:

Thermonuclear reactors will operate with a D-T fuel mixture leading to tritium (T) trapping in materials. During the lifetime of the device but also for the waste management or dismantling activities, the measurements of the T inventory in such materials is mandatory to comply with safety regulations. In that frame, it is of major importance to have an accurate measurement of the quantity of trapped T within tokamak relevant materials.

Link for a Zoom Q&A session during Poster session I (Monday, 21st Sept. 17:00 to 18 :30): (pass.: JSI-sabina)
https://fmf-uni-lj-si.zoom.us/j/2951480083?pwd=dW11NjU3ZjNOTHNzQ3JhZm9xMjBxQT09

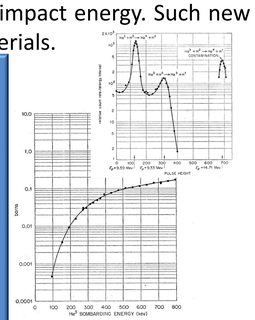
The development/upgrade of T diagnostics, that can be used during operating tokamak reactor and for tritiated waste management is one of the targets of fusion development and is considered in the H2020/TRANSAT project (http://transat-h2020.eu/). Nuclear reaction analysis (NRA), autoradiography and laser induced breakdown spectroscopy (LIBS) are the tritium detection techniques being developed within the TRANSAT project.

Nuclear Reaction Analysis

Goal is to measure T trapped in materials to depths of a few micrometers. It relies on the detection of products (d, p) from the nuclear reaction between ^{3}He and T. First measurements by ^{3}He beam with energies from 0.7 MeV to 5 MeV on T_2 gas loaded W sample pre-irradiated by 20 MeV W ions show a small but measurable signal around 7.5 MeV increasing with ^{3}He impact energy. Such new technique will enable simultaneous detection of D/T in materials.

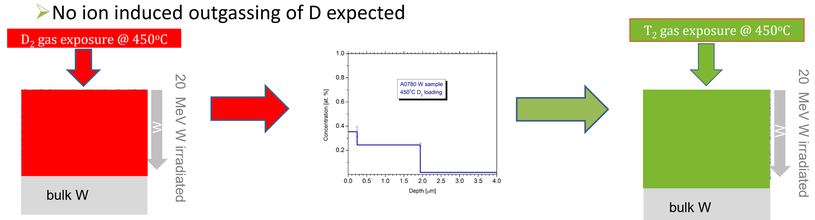
Use of ion accelerator – MeV energies
- ^{3}He ion beam
- Goal is to use same ion beam as for D detection in the bulk of materials – efficient analysing method for D
- Nuclear reaction for tritium:
- $^3He + T = {}^4He + d + 14.31$ MeV
  $= {}^4He + p + n + 12.08$ MeV

Challenge:
- Determination of cross section (only literature from 50's, 60's)
- Production of stable tritiated sample
- Lab activation limit < 1 GBq

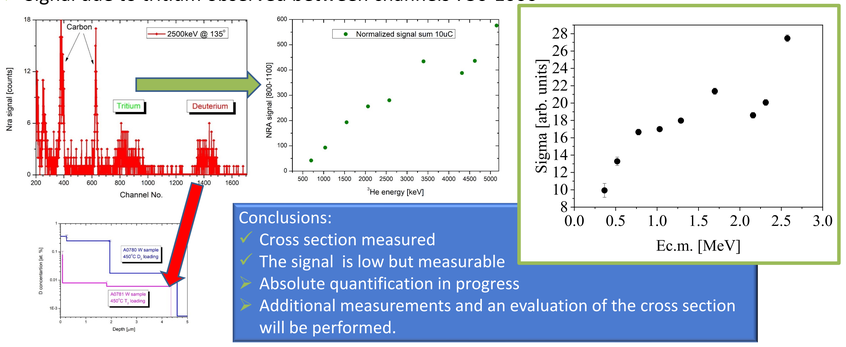


[C.D. Moak, Phys. Rev.: **92**, 383 (1953)]

Sample preparation
- 20 MeV W ion irradiated W samples - strong trapping of D
- Increased fuel retention in ion damaged W region 0.25 at. % for D_2 gas loading conditions
- No ion induced outgassing of D expected



Results:
- Tritium activity measured 220 MBq by liquid scintillation technique
- Little D contamination
- Signal due to tritium observed between channels 750-1000

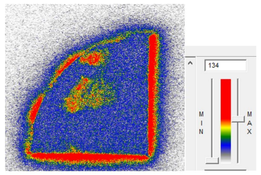


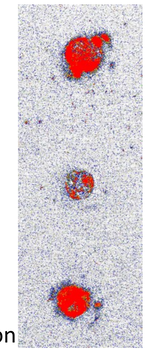
Conclusions:
- ✓ Cross section measured
- ✓ The signal is low but measurable
- ➢ Absolute quantification in progress
- ➢ Additional measurements and an evaluation of the cross section will be performed.

Autoradiography

With Autoradiography, we are currently testing a new type of autoradiographic camera based upon Silicon Photo Multipliers (SiPM) detectors closely connected with solid scintillators. It will allow rapid measurements of T contamination. An industrial device was built in 2019 and T sources were tested. We have successfully measured T on a solid surface with emerging activities as low as 100 Bq/mm^2 (with an exposure time of 5'). We will also show in the future how the autoradiography coupled with an accurate erosion technique (depth resolution < 100 nm) can be used to address the T depth profile in tritiated samples.

(1) First tries on W tritiated samples on phosphor screen technique:





First result:
Autoradiography is a very efficient technique for tritium measurement on solid surface

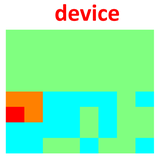
Main research goals:
- Evaluation of the tritium homogeneity on material surface
- and a semi quantitative value in Bq/cm^2.

T Maximum in red
Main drawback for phosphor Screen: potential T contamination
Spatial resolution of the phosphor screen = 150 µm

(2) The second tested system for autoradiography is based on solid scintillators which emit photons when exposed to radiations. The light is collected using 64 SiPM, a fairly new type of photosensors, with high gain, large photodetection efficiency and low voltage bias.
The industrial device called MAUD (Digital Autoradiography Measurement) has been tested on tritium source and an autoradiography image was obtained.

Image obtained with MAUD device

Tritium source



32 SiPM among the 64 in contact with tritium source

SiPM resolution = 6 mm

Conclusions:
- ✓ Autoradiography technique is effective for tritium non-destructive measurement
- ✓ Detection limit as low as 100 Bq/mm2 was reached
- ✓ A semi quantitative value on surface contamination can be provided.
- ➢ Additional measurements on W material spiked on surface with tritium are planed in the near future.
- ➢ Study of the contamination in depth

Laser Induced Breakdown Spectroscopy (LIBS)

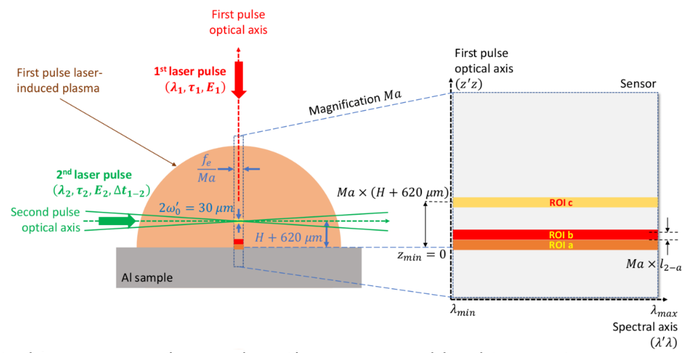
The LIBS development relies on picosecond laser interaction with the material producing a thermal plasma and allowing measuring the T mole fraction and its profile in the material. First attempts are performed on H and D at low level. T wastes are targeted. Preliminary results show that (1) only the alpha lines (Balmer series) are observed and (2) the temperature increase resulting from the absorption due to a second laser pulse in required.

Preparation of the samples

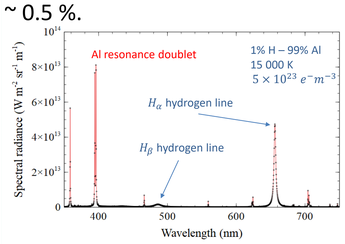
The samples are prepared by laser deposition of target (W or Al) on substrates in a H_2/D_2 low pressure atmosphere.

First attempts under ps/ns double pulse

The ps pulse (τ_1=30 ps, λ_1=1064 nm, E_1=20 mJ) is focused on the sample using a lens of 125 mm focal length. The nanosecond pulse (τ_2=6 ns, λ_2= 532 nm, E_2= 50 mJ) is delayed by $\Delta t_{1\text{-}2}$=350 ns and is tangentially focused (with a lens of 150 mm focal length) in the plasma produced by the ps pulse at a distance H (=0 or 1 mm) + 0.62 mm above the sample's surface.



Spectral images are observed on the sensor and lead to spectra compared with calculated ones assuming the Local Thermodynamic Equilibrium of the plasma. The composition is then determined. The lowest measurable H mole fraction is ~ 0.5 %.



For LIBS see also poster No. 332 (Bultel et al.)

Next step: LIBS in collinear ps/ps double pulse

The previous ns pulse will be replaced by another ps pulse (τ_2=30 ps, λ_2=1064 nm, various E_2, various $\Delta t_{1\text{-}2}$ ~ some 100 ps) on the same optical axis to maximize the absorption.