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**Fuel Retention Diagnostic Setup
(FREDIS) for desorption of gases from
beryllium and tritium containing
samples**

Preprint of Paper to be submitted for publication in Proceeding of
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Abstract: In fusion devices, the retention of the fusion fuel deuterium (D) and tritium (T) in plasma-facing components (PFCs) is a major concern. Measurement of their hydrogen isotope content gives insight into the retention physics.

In FREDIS, two methods of thermal desorption are used for retention measurements: In Thermal Desorption Spectrometry (TDS) the samples are heated by 6 infrared lamps up to 1433 K with linear temperature ramps of up to 1.67 K/s. The desorbed gases are detected up to 100 amu/e with a double-QMS (Quadrupole Mass Spectrometer) that can distinguish between helium and D₂ and uses an innovative differential pumping system. In a connected vacuum chamber, a \varnothing 3 mm spot can be heated on the sample surface by a high energy Nd:YAG laser pulse ($E_0 < 100$ J) within milliseconds (0.1-20 ms) to several thousand degrees. This method of Laser-Induced Desorption (LID) can also be applied inside the fusion chamber and is planned as in situ retention diagnostic for ITER. In FREDIS, LID is thus tested and used as ex situ analysis method utilising the same double-QMS for absolute quantification. FREDIS is capable of handling beryllium (Be) by means of glove boxes and in the future also tritium using a tritium trap to analyse also samples from JET and ITER. In this contribution we present the specifications of FREDIS and compare TDS and LID.

Research Data Related to this Submission

Title: Data for: Fuel Retention Diagnostic Setup (FREDIS) for desorption of gases from beryllium and tritium containing samples

Repository: Mendeley Data

<https://data.mendeley.com/datasets/73hvfzfmw/draft?a=ad1db22b-e850-40c1-9be6-3f923ffc7642>



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August 16, 2018

Subject: Paper entitled "*Fuel Retention Diagnostic Setup (FREDIS) for desorption of beryllium and tritium containing samples*" by M. Zlobinski

Dear Editor of FED - Special Issue SOFT 2018,

Please find enclosed the manuscript: *Fuel Retention Diagnostic Setup (FREDIS) for desorption of beryllium and tritium containing samples* by M. Zlobinski for consideration of publication in Fusion Engineering and Design - Special Issue SOFT 2018.

Please note that this article has received EURATOM funding, which prevents transfer of copyright.

I would appreciate if you would send correspondence regarding the refereeing process to the lead author: m.zlobinski@fz-juelich.de, but correspondence regarding copyright to Publications.Officer@euro-fusion.org.

The invoice for this paper should be raised in Euros and addressed to:

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With best regards,

A handwritten signature in black ink, appearing to read "Gál-Kinga" followed by a flourish.

Dr. Kinga GÁL
EUROfusion Scientific Secretary



Responses to Reviewer #1:

Thank you for reviewing our manuscript and for the positive assessment. Most of the changes you requested are included in the new version. Here the answers to your comments:

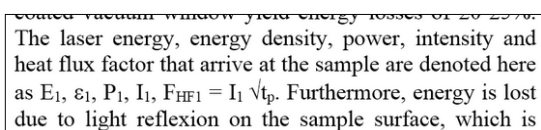
* The general layout was changed as requested to finishing left column at the end of each page before continuing in the right column at the top.

* page 3, par 2.2, Fig. 2a: I increased the writing on the axis for better readability, but inside the figure it is not possible because the lines and labels are so close to each other. You suggested to remove the graph to save space, but we would like to keep it because it shows the full laser parameter space, which is important to show the capability of our device.

* page 3, par 2.2, Fig. 2b: laser beam path and detection path added in drawing (as requested).

* page 4, par 2.4, line 9 left now line 13 left: The sentence "Opposite ... was applied there" was too long and complicated. I divided it in 2 sentences and rephrased to make it clearer.

* page 4, par 3.1, line 5 left: The sentence "The laser energy, energy density, ...". You wrote "the letter denoting the energy density is missing". But it is existing. It is a greek letter ϵ_1 . Maybe it is a display problem with greek letters on your computer. Here a screenshot how it looks in my Word programme. But it is missing in the pdf-Version. Probably this is a PDF conversion problem. I hope it will be correct in the final layout.



coated vacuum window yield energy losses of 20-25%.

The laser energy, energy density, power, intensity and heat flux factor that arrive at the sample are denoted here as E_1 , ϵ_1 , P_1 , I_1 , $F_{HF1} = I_1 \sqrt{t_p}$. Furthermore, energy is lost due to light reflexion on the sample surface, which is

* Thank you for the hint that the unit of the heat flux factor is often $\text{MJ/m}^2/\sqrt{s}$, but this is the same as $\text{MW}\sqrt{s}/\text{m}^2$ as I used it and in fact our notation is also often used in literature, e.g. in <http://dx.doi.org/10.1016/j.jnucmat.2014.11.002> (in Table 1) or in <http://dx.doi.org/10.1016/j.vacuum.2016.12.005> or <https://doi.org/10.1088/1741-4326/aaa5d5> (e.g. images on page 6 and 9). It is a matter of taste, but actually our notation has the advantage that it is a bit shorter. Therefore I did not change it.

Additional changes:

* page 3, fig. 2a: In the caption the reference was wrong: [1], now corrected:[7]

* page 4, par 3.2, last sentence: Small change: old "However, their accuracy is lower with $\pm 10\%$ for He and higher for other gases." >> new: "However, their accuracy is lower with $\pm 10\%$ for He and even lower for other gases.". Other cases have uncertainties of $\pm 15\%$ - 30% . This value is higher, but that means accuracy is lower. I corrected this.

* page 4, par 3.3, line 6 and 8: "thermoelements" changed to "thermocouples"

* page 5, par 5 line 13: I removed the model type of the tritium detector as we need to exchange it for a more sensitive one. To keep the paper as a reference paper to the machine, I want to keep this more general.

* Some changes were made on request by the other reviewer:

** I made several changes in Figure 1 requested by the other Reviewer (Legend). I made one additional small change in Fig. 1. For the tritium trap part, which is under construction, we recently found out, that the exhaust of the glove boxes is too high in air flow rate to go through the gas washing bottles. So their exhaust and the one from the air lock will not go to these bottles but will always by-pass to the main exhaust system (grey box). This is not a safety problem as the samples will not be heated in the glove boxes or air lock.

** page 4, Fig. 4 has added gas flow direction now (red arrows)

** page 5 in the last 5th line of section 5: "cached" -> "caught"

** The term t_p for the laser pulse duration was not defined. I introduced it at first appearance on page 2, section 2.2, line 8 left column.

Kind Regards,
Zlobinski

#####

Responses to Reviewer #2:

Thank you for reviewing our manuscript and for the helpful comments. Most of the changes you requested are included in the new version. Here the answers to your comments:

* 1. page 2, Fig. 1 I added the legend as requested.

Pre-Pumps:

I want to keep the identical, general symbols for the pre-pumps, although they are of different type. I did this on purpose already in the first version, because we exchanged the pre-pumps already several times due to failures. Therefore, I think it might change in the future again and the type of pre-pump is not really decisive. This paper shall be used as reference paper to the FREDIS devices for future measurements. In this general way, the figure will not be wrong, even when a pre-pump is exchanged again.

The different types of pre-pumps are mentioned in the text.

For your information: The pump combination in the red rectangle is explained in the text (TP+membrane pre-pump) in section 2.1. The three other pre-pumps on the left-hand side were scroll pumps first. But then the two at the bottom part of the figure were exchange by roots pumps. The pre-pump in the tritium trap part on the right-hand side will be a membrane pump, most probably.

* 2. The general layout was changed as requested to finishing left column at the end of each page before continuing in the right column at the top.

* 3. page 4, Fig. 4: You requested a clearer explanation of the direction of gas stream to QMS and TP. The TP is drawn in Fig 4. as red-framed device behind the plane of the cross-section (The arrow from the legend is hinting at the TP). It is flanged at the circular flange that you

can see as a circle in the figure. Thus, the gas stream direction is towards this flange and this pump, i.e. into the drawing plane. You can see this arrangement also in Fig. 1 from outside. It is more difficult to describe it in word, so I added red arrow to indicate the gas stream direction in the Fig. 4.

* 4. The term t_p for the laser pulse duration was not defined. Thanks for finding that. I introduced it at first appearance on page 2, section 2.2, line 8 left column.

* 5. on page 2, section 2.2: The sentence with "... numerical aperture of 0.2 that leads ...". You suggested to write "0.2 mm" but the numerical aperture has no unit. It is the sinus of the half-angle of the optical aperture of a fibre: $\sin(\alpha/2)$. Therefore its unit is 1.

* 5. on page 5 in the last 5th line of section 5: "cached" -> "caught". I changed this. Thanks for finding the error.

Additional changes:

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Fuel Retention Diagnostic Setup (FREDIS) for desorption of gases from beryllium and tritium containing samples

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Highlights

- In FREDIS samples can be heated in an IR oven or by laser to desorb retained gases.
- It combines TDS and LID using the same QMS for quantification of the desorbed gases.
- beryllium compatible device due to use of glove boxes and dust particle filters
- tritium compatible device due to tritium trapping system and tritium detection
- designed to analyse JET samples due to beryllium and tritium compatibility and its dimensions

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Keywords: fuel retention; desorption; laser; beryllium; tritium; FREDIS

1. Introduction

Retention of gases from the fusion plasma (mainly hydrogen isotopes, but also helium or seeding gases) in PFCs is an important issue for the tritium inventory limit in ITER and DEMO, hydrogen embrittlement of PFCs, fuzz formation, fuel retention assisted by other gases, the fuel cycle in general and other plasma-wall interactions. LID is capable of measuring the wall fuel inventory in situ even during plasma operation as demonstrated in TEXTOR[1-3] and is thus planned as T monitor system in ITER[4] to quantify the T inventory spatially resolved between plasma operation by mass spectrometry. Before in situ operation the method has been elaborated ex situ on the laboratory scale using QMS for quantification of all desorbed gases. Development started on carbon materials like graphite and amorphous hydrocarbon layers[2] and was extended to carbon fibre composites (CFCs), C/W mixed layers, W and W fuzz[3]. As JET and ITER have Be wall elements, LID has to be qualified for this new material especially for Be/^xH co-deposited layers as they contribute most to the long-term retention in JET-ILW[5]. The formation of such layers is also predicted for ITER[6]. Therefore, FREDIS was build to extend LID to Be application and quantification of H, D, T in JET wall elements and to qualify the LID method further by combining it with the more mature TDS method using the same QMS detectors. Its chamber dimensions and loading ports are capable of analysing an uncut W lamella of the JET divertor. The LID chamber

is even designed for a complete JET wall and divertor tile. Due to the T content of JET samples, FREDIS is located in a radiation controlled area – the High temperature Materials Laboratory (HML) – in the Forschungszentrum Jülich, where activated samples can be analysed.

2. FREDIS Setup

FREDIS consists of 3 main parts (cf. figure 1): the LID part, the TDS part and the QMS part in between. These parts are separated by pneumatic gate valves (GVs) that can be operated remotely by a PLC (Siemens S7-300) as most devices of FREDIS. The idea of this threefold structure is that the gas species released either by laser heating in the LID part or by heating in the TDS oven are analysed in the common QMS part with the same detectors. To our knowledge it is the first time that these two desorption methods are combined in one vacuum system in such a way. It allows to compare the two methods excluding differences in the detection setup and differences in detectors that otherwise arise for separated analysis chambers. Usually, for LID operation the GV to the QMS part is open and the GV to the TDS part is closed and vice versa for TDS operation. This allows measurements while the other part is in preparation for experiments (sample loading, evacuating, chamber conditioning etc.), but both GV's can be open during measurements to provide the same chamber volume during TDS and LID.

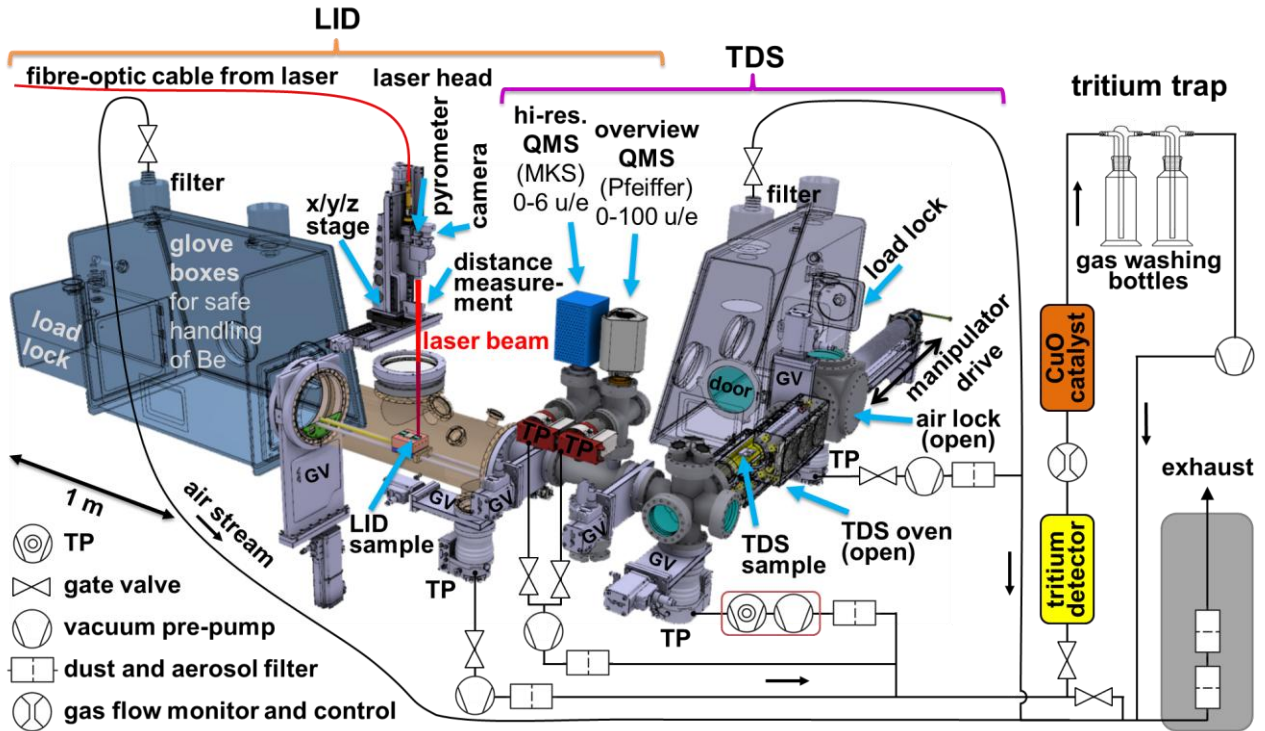


Fig. 1. Overview of the main components of FREDIS, TP = turbo molecular pump, GV = gate valve

2.1 Vacuum system

The LID part, TDS part and the TDS air lock are pumped by turbo molecular pumps (TP, Pfeiffer HiPace 300 C) separable by a GV from their chambers. In the LID part and the TDS air lock a valve follows on the way to the pre-pumps, that closes automatically in case of power failure to secure the TP. A scroll pump is used for the air lock TP and a roots pump for the LID TP. Due to the lower desorption flux in TDS owed to the slower heating the requirements for the partial pressures of the background especially of light elements like the hydrogen isotopes are higher than in LID. To lower these background pressures the primary TP of the TDS chamber is pumped by a second TP, which is combined with a membrane pre-pump in a standalone pumping stage (Pfeiffer HiCube 40, red box in figure 1). Typical base pressures below 5×10^{-9} hPa are reached as measured by the extractor hot cathode gauge located in the bottom of the QMS part. For general pressure measurements all separable vacuum parts are equipped with FullRange® gauges (Pfeiffer PKR 251) that combine a Pirani gauge and a cold cathode gauge in the inverted magnetron design.

2.2 LID setup

The LID vacuum chamber (cf. brown part in figure 1) is mainly a stainless steel cylinder of $\varnothing 250 \text{ mm} \times 900 \text{ mm}$ such that any JET wall and divertor tile fits inside. The laser is coupled from the top into the vacuum by an anti-reflexion (AR) coated vacuum window $\varnothing 200 \text{ mm}$. The laser pulse is generated by a flash lamp pumped Nd:YAG laser (LASAG FLS 652N) with 1064 nm wavelength. The pulse duration t_p can be chosen between 0.1 and 20 ms at a frequency up to 1000 Hz. However, the combination of the laser parameters is limited to an

average power of 500 W and a maximal laser pulse power of 40 kW. The possible parameter combinations can be retrieved from the working range diagram (figure 2a) valid for new flash lamps and optimal optical alignment of the laser resonator. Thus, typical energies are 10-15% lower. In order to deliver a reproducible pulse, the laser fires internally constantly with the chosen frequency in order to stabilise, while a negligible fraction of the laser power is coupled out by a beam splitter into an integrating sphere to measure the temporal pulse shape and energy. Afterwards a fast shutter follows that only opens for the laser pulses that are used for LID. These pulses are coupled by a lens into a 50 m long fibre-optic cable with a core diameter of 0.6 mm and numerical aperture of 0.2 that leads to the laser head (figure 2b). There, the end of the fibre is imaged by 2 lenses ($f_1=100 \text{ mm}$, $f_2=500 \text{ mm}$) and two mirrors in between them onto the sample. The last mirror and the mirror above are partly transparent in the wavelength range of the two-color pyrometer (1.66 and 1.8 μm). One of 4 available fibres with different diameters (50-400 μm) guides the light to the pyrometer. Hence, the pyrometer views the centre of the laser spot coaxially on differently large circles and different temperature ranges (cf. table 1).

Table 1. Pyrometer observation inside the LID laser spot

\varnothing fibre μm	\varnothing observation mm	temperature range
50	0.33	805-5721 K
105	0.7	677-2911 K
200	1.3	596-1946 K
400	2.7	546-1574 K

A 4th mirror is used to observe the laser spot with an infrared camera.

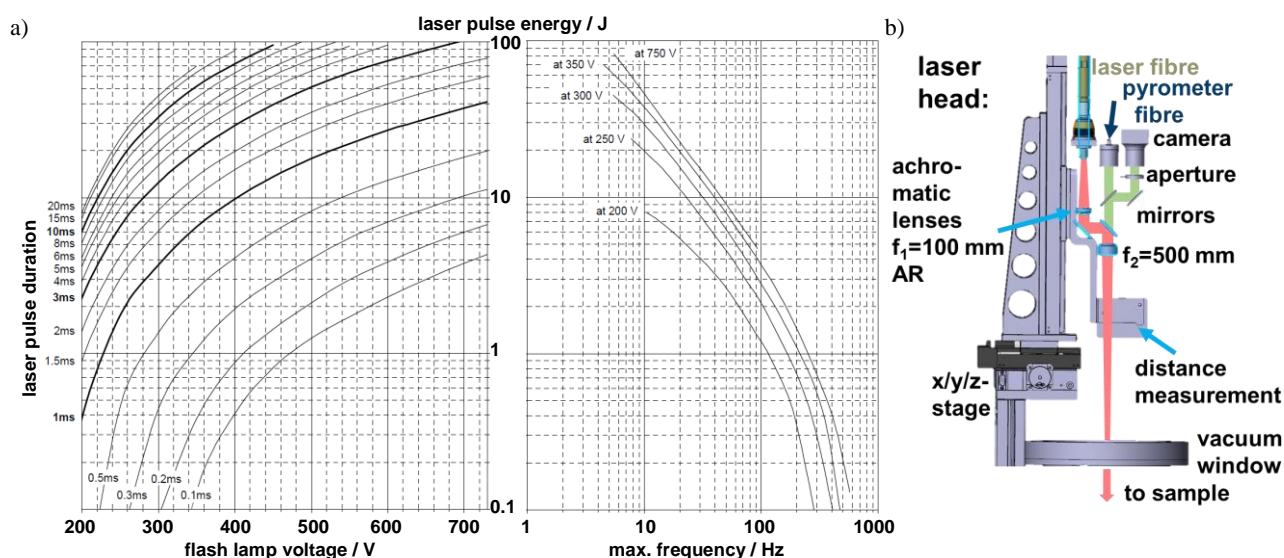


Fig. 2. a) Parameter space of the LID laser pulses[7]: pulse energy dependence on pulse duration (in ms), capacitor voltage and maximal repetition frequency; b) optical components inside the laser head; laser beam (red) and observation path (green)

The laser head is mounted on an x/y/z-stage which can move in any spatial direction via 3 step motors (5 $\mu\text{m}/\text{step}$ accuracy) controlled by the PLC. The laser beam was carefully aligned to the normal of the sample holder such that its position on the sample does not move, when the stage is moved up or down. The same alignment was performed for the distance measurement device which is also laser based (Keyence IL-300) and determines the distance to the sample based on a runtime measurement of the laser light. The vertical position of the laser head is always adjusted to the same distance to the sample surface independent of the target shape to assure that the LID spot is in focus on the sample. The laser head, x/y/z-stage and the AR coated window are enclosed in a light tight laser box with an access door that has an electric interlock contact in the laser safety loop. It switches off the laser pulsing in case the door and the laser shutter should be opened at the same time.

2.3 TDS setup

TDS is performed in a quartz glass tube (inner diameter $\varnothing 52 \text{ mm} \times 650 \text{ mm}$, Heraeus HSQ 300, max. working temperature in continuous operation 1433 K). The inner part of the oven is cooled by an air stream and water-cooled from behind. The oven is monitored by 8 thermocouples in the oven itself and 2 thermocouples in the vacuum in the centre of the oven between sample table and the top of the tube. Additionally, the part of the tube outside the oven (ca. 10 cm) connecting to the next stainless steel chamber part are cooled and monitored by a thermocouple on each side, which typically show temperatures of 350 K for short heating ramps. 6 IR halogen lamps (max. 3 kW each) are arranged symmetrically around the quartz tube and heat the sample with a maximum total power of 15 kW. The sample is introduced by an air lock (loading door $\varnothing 150 \text{ mm}$) in order not to break the good vacuum of the TDS chamber. The sample is laid on a quartz sample table (optional table material: mica) on a double-scissors manipulator. After evacuation (12-24 h) the GV to the

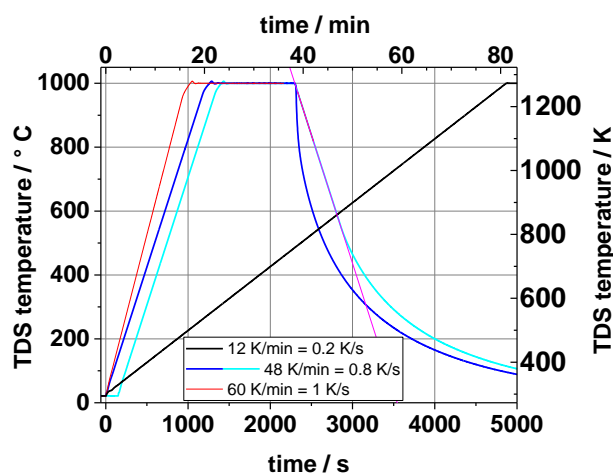


Fig. 3. Examples of TDS heating and cooling ramps

TDS chamber is opened and the sample table is driven by the manipulator drive into the TDS oven. In the centre of the oven the scissors are opened, thus lowering the table by few millimetres onto the inner tube walls. Examples of heating ramps and controlled cooling as well as fast cooling are shown in figure 3. The pink line is a linear reference to the light blue PLC-controlled cooling ramp.

2.4 QMS setup

An overview QMS (Pfeiffer PrismaPlus with an open ion source) for the mass scan 0-100 amu/e and a high-resolution QMS (MKS Microvision-IP, 0-6 amu/e) which can resolve helium and D_2 are mounted on the top of the QMS section. In the bottom several total pressure measurement devices are located. Beside the FullRange[®] gauge, a hot cathode gauge of the extractor type (Oerlikon Leybold Ionivac IM 540) is used for more accurate measurements and a spinning rotor gauge (MKS SRG-3) is installed as direct pressure

measurement to provide a reference for the other gauges. Additionally, Penning gauge spectroscopy for the atomic lines (e.g. $H_{\alpha}/D_{\alpha}/T_{\alpha}$) and molecular lines will be installed for partial pressure measurements of the hydrogen isotopes[8]. An innovative QMS differential pumping system was mounted (cf. figure 4) to keep the Channel-Secondary Electron Multiplier (C-SEM) always under low pressure, which shall increase its stability[9]. After the additional sealing piston which was attached to the QMS and tightly fits into the sealing cylinder an oil-free TP (Leybold Turbovac 90i) is mounted on a standard DN63 vacuum cross part for each QMS. Opposite of the TP a hot cathode ionisation gauge is monitoring the pressure at the C-SEM detector, which is at least one order of magnitude smaller than the main chamber pressure. This pressure reduction can be achieved because the only connection to the main FREDIS chamber is the small QMS entrance and remaining gaps between sealing piston, sealing cylinder and the DN63 flange. With this differential pumping system the ionisation volume of the QMS remains in the FREDIS chamber thus giving a high ionisation yield, which is typically not the case for classical differential pumping, where the QMS as a whole is located in a separate vacuum chamber.

3.1 LID Method

The energy E_0 and power P_0 of the laser light are partly lost on the laser path. Measurements with an energy detector at the laser exit and the AR coated vacuum window yield energy losses of 20-25%. The laser energy, energy density, power, intensity and heat flux factor that arrive at the sample are denoted here as $E_1, \epsilon_1, P_1, I_1, F_{HF1} = I_1 \sqrt{t_p}$. Furthermore, energy is lost due to light reflexion on the sample surface, which is usually estimated by measuring in advance the total reflectivity of the sample with a spectrophotometer using the value at 1064 nm. As this can only be done at room temperature, there is often quite high uncertainty in the reflectivity at higher temperatures, thus an upgrade of FREDIS with a reflectivity measurement during laser heating is intended. The absorbed energy E_{abs} and other laser pulse quantities are denoted with the index "abs". The most energetic pulse so far measured in the laser has an energy of $E_0 = 96$ J with $t_p = 3$ ms pulse duration. Although not the most powerful pulse (with $P_0 = 32$ kW) it is the so far strongest pulse with respect to heating, i.e. it has the highest heat flux factor $F_{HF1} = 182$ MW \sqrt{s}/m^2 and thus the highest temperature increase. Calculations show that melting of tungsten should easily be possible as $F_{HFabs} = 73$ MW \sqrt{s}/m^2 . The standard LID procedure is performed in the following order: Before the laser pulse is applied, the shutter to the TP of the LID part is closed at about 10^{-5} Pa base pressure. Hence, the QMS measure the continuous partial pressure increases originating from metal outgassing and leaks. Then the laser pulse heats the surface rapidly and the retained gases are released thermally giving a sharp jump in the corresponding partial pressures. Afterwards, the shutter to the pumping system is opened again. The evaluation of the QMS signals is based on the maximum peak values, that are fitted by an exponential function

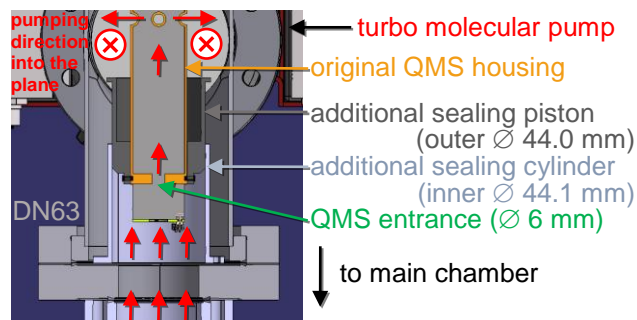


Fig. 4. Differential pumping of the QMS detector region behind an additional vacuum sealing

before and after the laser pulse. Both functions are extrapolated to the time of the laser pulse, where the jump in each mass channel is evaluated as difference between the two functions. This difference is converted to the amount of released D, H or other atoms based on QMS calibration during constant inlet of the calibration gases via calibration leaks described in the following section.

3.2 QMS Calibration

For calibration, leak standards with fixed gas reservoir (LACO Calmaster, for H_2, D_2, He, Ne) are used that are equipped with a zero volume valve to retain their individual leak rate in the range of 10^{-7} Pa m^3/s which is specified with an uncertainty of $\pm 4.5\%$. Other gases can be calibrated with test leaks (Leybold TL4, TL6) which can be used with any gas by an exchangeable balloon gas reservoir. However, their accuracy is lower with $\pm 10\%$ for He and even lower for other gases.

3.3 TDS Method

TDS or Temperature-Programmed Desorption (TPD) as it is called when performed with well defined heating ramps especially linear ramps like in FREDIS relies on slow heating of the entire content of an oven. The heating rate is small compared to the thermal diffusivity in the sample, sample table, thermocouples and quartz tube. Thus, all these components are in thermal equilibrium and the temperature of the thermocouples represents the temperature of everything in the centre of the oven. In TDS the measurements and calibration are typically performed with active vacuum pumping. The evaluation of the desorption flux relies on the maximum peak values of each mass peak like in LID. They are integrated over time and the background is subtracted that is measured with the same procedure just without sample. This second heating should be performed as fast as possible, typically 1-2 days before or after the TDS measurement to have comparable vacuum conditions.

4. Beryllium safety

To prevent the FREDIS staff from Be dust, glove boxes are attached firmly to the GVs of the LID chamber and TDS air lock. Their inner pressure is constantly kept 8-10 hPa below the outside pressure by self-adjusting flow controllers. Hence, Be cannot escape even in case of a small leak. The air flow out of the glove box passes through a filter that catches dust and aerosols. Both glove boxes contain a load lock where the sealed Be

samples can be introduced. Inside the glove box they are unpacked and mounted on the respective sample holder. During the LID and TDS experiment Be could also be mobilised in the vacuum chamber. Therefore, after each pre-pump filters are installed to constrain any Be contamination to the pumps and not contaminate the further exhaust tubes. Nevertheless, there is a crucial moment when unmounting samples. After packing in a sealed plastic bag and put into the load lock, the outside of the sealed bag might be contaminated due to Be dust in the glove box. To minimise this, the glove boxes are cleaned with water after each sample loading to keep their Be content low. When taking the potentially contaminated bag out of the load lock, dust protection masks and double gloves have to be worn while sealing the sample bag in a not contaminated second external bag. Therefore, especially the surfaces in front of the load locks, but also floors and desks are periodically analysed for total Be amount and areal Be density by smear tests.

5. Tritium safety

A tritium trap is under construction for FREDIS in analogy to the tritium trap of the JUDITH 1 electron beam heating facility in Jülich[10]. When no sample are heated the exhausts of all pumps and glove boxes can be directly connected to the main exhaust line as only negligible amounts of T can be released at room temperature. During heating of JET samples gas molecules that contain T can be released for example as HT, DT, T₂, HTO etc. As gases are not blocked by the dust filters they will stream along the exhaust pipes. Hence, before heating the valve to the T trap is opened and the valve to the direct exhaust closed. The gases pass then a tritium detector that measures the T amount in situ. The gas flow in this line is monitored as it has to stay within certain limits and can be varied by an electrically controlled valve that steers the intake of additional air into the pipes while a pre-pump runs the air flow in the tritium trap section. Then the T containing gases pass through a catalyst, which is a steel tube filled with CuO grains at a temperature above 573 K. The tritiated gases are reformed to tritiated water vapour in the catalyst by reactions like $\text{CuO} + \text{HT} \rightarrow \text{Cu} + \text{HTO}$. Finally, this tritiated water is caught in a chain of subsequent gas washing bottles, where the gas is forced through distilled water. It was measured in [10] by liquid scintillation counting analysis of the water that each gas washing bottle catches more than 95% of the tritium.

6. Discussion and Conclusion

Both methods have advantages and disadvantages that complement each other: TDS cannot do space resolved measurements unless samples are cut, while LID is locally applied on the sample surface and thus can provide two dimensional scans of the fuel and gas content. TDS assures complete desorption up to the applied temperature due to the long hot phase, while for some cases in LID incomplete desorption can occur due to the rapid and local heating, e.g. for hydrogen in tungsten, when it is deeply retained[3]. The maximum temperatures in LID are several factors above the

maximum temperature in TDS. A further disadvantage of TDS is that it consumes a lot of time due to the relatively slow heating, cooling, sample installation, background measurement and pumping procedures. Moreover, only one sample at a time can be introduced into the vacuum chamber. In contrary, in LID many samples can be placed in the vacuum chamber at once, which reduces loading procedures and due to the rapid heating reduces the measurement frequency to minutes compared to days in TDS.

Concludingly, in FREDIS comprehensive thermal desorption analyses can be performed, which feature space resolved measurements up to several thousand degrees by LID and binding energy determination by TDS with different linear heating ramps. With its Be and T compatibility and large size full JET tiles can be analysed as well as wall tiles of most fusion devices - in the future potentially also ITER samples. Moreover, FREDIS is suited to qualify the LID method on new materials as a direct comparison with the more mature TDS method is possible for the first time.

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