VISIONI: plasma simulator for tritium retention in (Be, T) contaminated and neutron irradiated materials

I. Uytdenhouwen on behalf of the SMP team

SMP (Plasma Wall Interaction Unit)
SMA- Structural Materials
NMS - Nuclear Materials Science
iuytdenh@sckcen.be
4 main strategic lines at SCK•CEN in fusion

- **Materials (NMS)**
  - Study effect of radiation (neutrons) (SMM, SMR, SMT)
  - Plasma Wall Interaction (SMP)

- **Diagnostics & Remote handling (ANS)**
  - Study effect of radiation (neutrons & gammas) on instruments for diagnostics and robotic components
  - Develop rad-hard components

- **Waste & socio-economics (EHS)**
  - Development and studies on waste minimization, detritiation and recycling
  - Public awareness

- **Participation to Broader approach (BSU)**
  (IFMIF/EVEDA and IFERC/Demo)
SMP team
(Plasma Wall Interaction Unit)

- I. Uytdenhouwen: Unit Head & Project leader
- J. Schuurmans: Engineer VISIONI
- H. Van Eyck: Operator T-lab and VISIONI
- O. Van Hoey: PhD student: ERO modelling
- Y. Zayachuk: PhD student: retention in W-Ta alloys
- H. Sheng: PhD student: TEM on W

Plans for the future (2012-…)

- N.N.: Engineer T-lab
- N.N.: Training scheme, engineer in Be handling (3 years)
- N.N.: Training scheme, engineer for set-up QA system (3 years)
- N.N.: Post-doc (2 years) and/or fixed position later on?
- N.N.: PhD (4 years)
- N.N.: Master thesis students
**ETHEL**: the JRC experimental program (Ispra, Italy, 1993)
- European Tritium Handling Experimental Laboratory

**Shut down ten years ago**

**Due to decommissioning of ETHEL buildings**
- Contract between SCK•CEN and JRC to transport plasmatron
- Several parts of equipment was missing or totally outdated (were used for other projects)

**New name**

**plasmatron VISION I**

*(Versatile Instrument for the Study of ION Interaction I)*
Refurbishment route

1993 ... 2006

ETHEL

Transfer from JRC to SCK

2007

Start refurbishment

Empty lab

2008

First vacuum

Dismantled plasmatron

2009

Initial gloveboxes

Plasmatron on new frame

Control cabinet
New PLC’s
Power supplies
Control and data logging software

...
Refurbishment route

1993 ... 2006

ETHEL

Transfer from JRC to SCK

2007

Start refurbishment

2008

First vacuum

2009

First Ar Plasma

In-situ plasma cleaning

Operational filaments

Argon plasma

Cleaned chamber

Pressure chamber: $10^{-8}$ mbar

With getter pumps: $10^{-10}$-$10^{-11}$ mbar
Plasmatron VISION I
(Versatile Instrument for the Study of ION Interaction)

Volume: 18 litres
Target diameter: ~ 24 cm
Ion energies: 20 - 500 eV
Magnetic field: 0.2T
Pulse duration: steady state
Flux density target: ~ $10^{20}$-$10^{21}$ ions/m$^2$.s

Deuterium and Tritium plasma
Neutron Irradiated samples
Beryllium samples
VISION I: Vacuum system
Refurbishment route

<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>1993</td>
<td>ETHEL</td>
</tr>
<tr>
<td>1993-2006</td>
<td>Transfer from JRC to SCK</td>
</tr>
<tr>
<td>2007</td>
<td>Start refurbishment</td>
</tr>
<tr>
<td>2008</td>
<td>First vacuum</td>
</tr>
<tr>
<td>2008</td>
<td>First Ar Plasma</td>
</tr>
<tr>
<td>2009</td>
<td>Basic diagnostics</td>
</tr>
</tbody>
</table>

Commissioning plasma monitor He, Ar plasmas

- EQP 1000
- Neutrons, ions, ion energy, appearance potential (discrimination D₂/He)

Planar probe

Mass and Energy scan (He)
Diagnostics

● **Basic plasma diagnostics**
  - Chamber & manifold pressures OK
  - Filament, Anode current & voltage OK
  - Temperature & current target OK
  - RGA (residual gas analysis) OK
  - Calorimetry target future
  - Plasma (ion (-, +), neutral) process monitor (EQP with QMS, discrimination between He & D₂) OK

● **In-situ surface diagnostics**
  - Probes (Langmuir: $T_e$, $n_e$, $V_p$; Discs; ...) OK
Plasma composition (EQP)

- $D_2^+$ and $D_3^+$ have same energy profile, concentration dependent on pressure
- Mainly $D_3^+$ at 0.3Pa
- Low level of contamination
- Shortcomings: No $T_e$, $n_e$, $V_p$, $V_f$, …
Plasma parameters (Langmuir probe)

- Specimen as Langmuir probe
- In-situ measurement of ion flux, $T_e$, $n_e$, $V_p$ and $V_f$ at the specimen

**Typical conditions:**
- few eV ($T_e$)
- $10^{16}$-$10^{17}$ m$^{-3}$ ($n_e$)
- 0.5 – 5 µbar ($p$)
- First experiments with Deuterium
- Additional safety software (remote control)
Industrial safety

- **“What-if” analysis**
  - Identification of critical failure modes
  - Set-up of appropriate actions and procedures

- **Visualisation, control and data acquisition**
  - EurothermSuite (SCADA) programming
  - Safety and protection strategies
  - **Future**: remote control operation and logging.
  - ALARA: Limit exposure time for operator (tritium and/or radiation)
Planning

- First experiments with Deuterium
- Additional safety software (remote control)

## The TEC PWI non-tokamak facilities

<table>
<thead>
<tr>
<th>Feature</th>
<th>MAGNUM-PSI PILOT-PSI</th>
<th>JULE-PSI – JUDITH (inside Hot Cell)</th>
<th>VISION I (inside T laboratory)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FOM (Netherlands)</td>
<td>FZJ (Germany)</td>
<td>SCK•CEN (Belgium)</td>
<td></td>
</tr>
<tr>
<td>Reactor like divertor conditions (steady state loads)</td>
<td>YES, divertor simulator</td>
<td>NO, but reactor like plasma fluence and ion energies</td>
<td>NO, but relevant first wall conditions</td>
</tr>
<tr>
<td>Reactor like transient heat loads</td>
<td>YES, pulsed plasma source under development</td>
<td>YES, with e⁻ beam</td>
<td>NO</td>
</tr>
<tr>
<td>Tritium</td>
<td>NO</td>
<td>NO T- plasma but moderate T handling capabilities</td>
<td>YES</td>
</tr>
<tr>
<td>Toxic materials (Be)</td>
<td>NO</td>
<td>YES</td>
<td>YES</td>
</tr>
<tr>
<td>Neutron irradiated materials</td>
<td>NO, but simulation of neutron damage by ion beam irradiation planned</td>
<td>YES</td>
<td>YES but limited to moderately neutron activated samples</td>
</tr>
</tbody>
</table>
Status Refurbishment

- First experiments with Deuterium
- Additional safety software (remote control)

- T-lab refurbishment
- Move to T-lab

CAD drawing gloveboxes

- Load lock system
- Plasmatron VISION I
- Diagnostic glove-box
- Preparation glove-box

CAD drawing plasmatron
Work-area Tritium-lab (>2010)

Installation VISION I in T-Lab beginning 2010

- 130 m² controlled area
- Extraction rate 15.350 m³/h
- 1 process cell 15 m²
- 2 glove-boxes
- 2 fume hoods
Refurbishment Tritium lab

- 130 m² controlled area
- Extraction rate 15.350 m³/h
- 1 process cell 15 m²
- 7 glove-boxes
- 3 fume hoods
- Plasmatron VISION I

To be licensed for 370 TBq $^3$H. (~1g tritium $^3$H)
Status Refurbishment

2010
- First experiments with Deuterium
- Additional safety software (remote control)

- T-lab refurbishment
- Move to T-lab

2011
Start of first scientific experiments

First scientific experiments:
- D retention in W-Ta alloys: PhD Y. Zayachuk
- TEM analysis of W after e- and ion loading: PhD H. Sheng
- Improved H tracing with ERO modelling: PhD O. van Hoey
Deuterium retention in W-Ta alloys

- Data consistent with literature
  - basic check of good operation of diagnostics system
  - plasmatron is very compact device but still retains ITER relevant data

Y. Zayachuk et al., Fusion engineering and design (SOFT)
Y. Zayachuk et al., to be published in Physica scripta
Tracing of H isotopes with the ERO code

- Dissociation of traced methane produces hydrogenic species

- TEXTOR: roof limiter and nozzle experiments
- VISIONI: lab experiment

- Modeling of hydrogen injection experiments
- Modeling of the background plasma

Chemical erosion traced hydrogen not taken into account !!!
Status Refurbishment

- First experiments with Deuterium
- Additional safety software (remote control)

- T-lab refurbishment
- Move to T-lab

Start of first scientific experiments

Start design:
- Gas injection system
- Advanced target/load lock systems

Advanced diagnostics:
- SIMS/TDS combined system
- Optical emission spectroscopy (2012)

Exploration advanced diagnostics
Diagnostics

- **Basic plasma diagnostics**
  - Chamber & manifold pressures: OK
  - Filament, Anode current & voltage: OK
  - Temperature & current target: OK
  - RGA (residual gas analysis): OK
  - Calorimetry target: future
  - Plasma (ion (-, +), neutral) process monitor: OK
    (EQP with QMS, discrimination between He & D₂)

- **In-situ surface diagnostics**
  - Probes (Langmuir: $T_e$, $n_e$, $V_p$; Discs; ...): OK
  - Optical spectroscopy: future

- **Ex-situ surface diagnostics**
  - TDS (thermal desorption spectroscopy): in progress
  - SIMS (Secondary ion mass spectroscopy): in progress
In-house characterization tools at LHMA (Laboratory for High and Medium Activity)

- PAS
- SEM / EDX
- EPMA
- XRD
- TEM
- BR2 Hot-cells
- BR1 XPS/AES
- ICP-MS

Advantageous to have
- Characterization tools (for T, neutron, Be)
- Neutron irradiation reactors (BR1, BR2)
- Plasmatron VISION I

At the same location for safety, transport, …

Others:
- density,
- Open porosity
- Profilometry
- …
Target possibilities

- **Special existing features**
  - Preheating up to ~700°C by plasma
  - Large size of specimens (up to diameter of ~25 mm)
  - Thermocouple in direct contact
  - Custom specific targets

- **Future modifications**
  - Several small specimens (10mmX5mm) on large target plate
  - Vacuum docking system for small irradiated specimens
  - Shadowed target above plasma for mirrors, dust, …
  - Small volume gives possibility for quantitative dust collection (baffles)
Programmatic lines of VISION I

- Retention / recycling / diffusion
  - Long term (steady state) studies
  - Effect of surface temperature & gradients, influence of hot surfaces
  - Mixed plasma (D, T, H, He, Ar seeding, …) fluxes
  - **Neutron** irradiated materials (low activation)
  - **Tritium** influence on chemical erosion, permeation, diffusion, …
  - In-situ dynamic & stationary retention studies
    (small volume, clean chamber due to possibility of in-situ cleaning)

- In-situ Tritium removal techniques, ex-situ detritiation
  - e.g. oxidising plasma, glow discharges, laser treatment, …

- Dust formation
  - dust characterization, co-deposition layers & alloy formation, removal techniques, influence on mirror performances, …

=> small volume of plasmatron: better quantitative analysis
Conclusions: Exposure conditions & operational regimes

- **Deuterium plasma**
  - Ion flux, fluence & energy was determined
  - ITER first wall can be simulated
  - Specimen heated up to 250°C
  - Additional heating by ion influx up to 600°C
  - Attracting electron current (bias sweeping) up to 750°C possible
  - Plasma pressures 3-5 µbar: most of D is in D$_3^+$ state

<table>
<thead>
<tr>
<th></th>
<th>VISIONI</th>
<th>ITER first wall</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ion energy [eV]</strong></td>
<td>&gt;60</td>
<td>100 – 500</td>
</tr>
<tr>
<td><strong>Ion flux density [m$^{-2}$s$^{-1}$]</strong></td>
<td>$10^{20}$ – $10^{21}$</td>
<td>$10^{20}$ – $10^{21}$</td>
</tr>
<tr>
<td><strong>Surface temperature [°C]</strong></td>
<td>&gt;350</td>
<td>400</td>
</tr>
<tr>
<td><strong>Tritium</strong></td>
<td>+ (future)</td>
<td>+</td>
</tr>
<tr>
<td><strong>Neutron activation</strong></td>
<td>+ (future)</td>
<td>+</td>
</tr>
</tbody>
</table>
Conclusions

- **TEC**: complete and unique focus on “Nuclear PWI”
  - Based on complementarity of devices (Magnum, Pilot, PSI-2, Jule-PSI and VISIONI)
  - Irradiation devices (BR1, BR2)
  - Post-mortem tools (both cold and hot)

- New PWI group formed at SCK•CEN

- **VISIONI**
  - Tritium capability (plasma and contamination)
  - Beryllium handling
  - Low neutron activation materials
Thank you for your attention

Any Questions?
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