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| **IDM Reference** | ***EFDA\_D\_2PESFB*** *[IDM ID]* | **Version/Dates:** *see IDM* |

**SP X**

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| **Work Package:**  | WPPWIE | **Link to IMS:** | [*SP X.1*](https://ims.euro-fusion.org/fp9/Workpackage#?aWpId=3909&aTaskId=7112) |
| **Subproject:** | SP X / Plasma characterization, laser-based diagnostic development |  |  |
| **Task title:** | SP X.1 Atomic and molecular processes in attached/detached plasma | **Task Ref. Nr.:**  | PWIE-SP X.1.T-T004 |
| **WP Leader:****SP Coordinator:** | S. Brezinsek (FZJ)H. J. van der Meiden (DIFFER) | **Issue:** | 4 |
| **PSO:** | M. Reinhart (FZJ) |  |  |
| **Start Event:** | Start of the WPPWIE | **Planned Start Date:** | 01-Jan-2024 |
| **End Event:** | Final Report accepted | **Planned End Date:** | 31-Dec-2024 |
| **Task Reviewer:** | David Douai (CO) | **Date:** | 24-Jan-2024 |
| **Description:**This subproject involves in particular the determination of the distribution of the ro-vibrationally excited states of H2 and its isotopologues as well as the corresponding atom, born out of dissociation or from surface reflection. The study on molecules involves the H2 electronic ground state as well as the electronic excited state population in the plasma volume in front of different, first wall relevant, material surfaces. Moreover, the interplay of atomic and molecular species – including seeding species, thus during the detachment and recombination process will be investigated and compared with corresponding collision-radiative models (CRM). CRMs for hydrogenic species to be benchmarked are from established sources likes EIRENE and YACORA, but also from CRMS developed under TSVV-5. Active (e.g. LIF, CARS) and passive spectroscopy (OES and VUV) combined potentially with TS or Langmuir probes will be deployed to investigate the involved processes and underlying mechanisms with high accuracy and spatial resolution. Linear plasma devices that produce hydrogen and deuterium plasma within WPPWIE, are used as first testbed, each device covering complementary ranges in electron density, but a common overlap in the electron temperature range. Application in toroidal devices will take place in WPTE and WPW7X in coordination with the corresponding WPs. Additionally, JULE-PSI is brought into operation and initial plasma characterization in hydrogen will be done as input for plasma background modelling under SP D: visible spectroscopy and LP are used as day-1 diagnostics. This is required as the access in the hot cell itself will be very limited. |
| **Inputs required:** * Linear devices: MAGNUM-PSI, UPP, PSI-2, JULE-PSI
* VUV LIF diagnostics (dye laser etc. ) and VUV compatible passive spectroscopy systems
* VIS diagnostics (2D) as well as LP
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| **Tasks to be performed:*** Active spectroscopy in Magnum-PSI and/or UPP: Measurement of the atomic density of H(1s) and isotopes by improved TALIF setup and installation of CARS system and first attempts to measure of ro-vibrational ground state distribution H2 (DIFFER)
* VUV passive spectroscopy on H/H2 and isotopes in MAGNUM-PSI/UPP/PSI-2 (FZJ, DIFFER, CU)
* VIS molecule and atomic hydrogen spectroscopy in ionizing and recombining plasma conditions (FZJ, DIFFER, MPG)
* Measure electron properties (TS) in Magnum-PSI and UPP for power load estimations (DIFFER)
* Plasma characterization of JULE-PSI with LP, UV-VIS spectroscopy, and hyperspectral cameras (FZJ)
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| **Deliverables:**

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| **Deliverable ID** | **Deliverable Title** |
| D001 | Atomic density (TALIF) measured in MAGNUM-PSI and CARS installed in MAGNUM-PSI or UPP. VUV OES results H/H2 and ne/Te measurements in UPP and/or Magnum-PSI (DIFFER) |
| D002 | OES results H/H2, ne, Te and 2D distribution in JULE-PSI . VIS molecular and atomic spectroscopy in PSI-2 under ionising and recombining plamas (FZJ) |
| D003 | VUV OES hydrogen atom and molecule analysis of MAGNUM-PSI/UPP s H/H2 (CU) |
| D004 | Interpretation spectroscopy results using spectra simulation and (CR) modelling with YACORA (MPG) |

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| **Management Information****Human Resources (2024)**:

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| **Deliverable Owner** | **Beneficiary** | **PM** | **Deliverable (Team)** |
| H. van der Meiden | DIFFER |  8 | D001 (H. van der Meiden, I. Classen, …) |
| M. Reinhart | FZJ | 4 | D002 (M. Reinhart, r, G. Sergienko, O. Marchuk, M. Sackers ..) |
| P. Veis | CU | 2 | D003 (J. Kristof, …) |
| U. Fantz | MPG | 2 | D004 (U. Fantz, ...) |
| **Total** |  | 16 |  |

**Hardware/ Machine Resources: e.g. Materials / Linear devices type / days / HHF**

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| --- | --- | --- | --- |
| **Device** | **Beneficiary** | **Days** |  **Related Deliverable** |
| MAGNUM-PSI | DIFFER | 8 | D001 |
| UPP | DIFFER | 4 | D001 |
| PSI-2 | FZJ | 10 | D002 |
| JULE-PSI | FZJ | 5 | D002 |
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**Other resources:** **Collaborations:*** WPTE, WPW7X, EPFL

**Other information:*** Connected to TSVVs associated with WPPWIE
* This work is linked to ENR project ‘EPFL-01: Measurement of atomic hydrogen and deuterium densities in fusion relevant plasmas using two-photon absorption laser induced fluorescence with femtosecond pulses (fs-TALIF) (Marcelo Baquero Ruiz)’.
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| **Work Package:**  | WPPWIE | **Link to IMS:** | [*SP X.2*](https://ims.euro-fusion.org/fp9/Workpackage#?aWpId=3910&aTaskId=7114) |
| **Subproject:** | SP X / Plasma characterization, laser-based diagnostic development |  |  |
| **Task title:** | SP X.2 Optimization of laser-based surface analysis diagnostics | **Task Ref. Nr.:**  | PWIE-SP X.2.T-T004 |
| **WP Leader:****SP Coordinator:** | S. Brezinsek (FZJ)H. J. van der Meiden (DIFFER) | **Issue:** | 4 |
| **PSO:** | M. Reinhart (FZJ) |  |  |
| **Start Event:** | Start of the WPPWIE | **Planned Start Date:** | 01-Jan-2024 |
| **End Event:** | Final Report accepted | **Planned End Date:** | 31-Dec-2024 |
| **Task Reviewer:** | David Douai (CO) | **Date:** | 24-Jan-2024 |
| **Description:**The scope of this task is the optimization of laser-based techniques for the quantification of fuel content and material composition of PFCs (tungsten, boron, graphite) and deposits of those materials (oxygen, seeding and fuel species) in laboratory devices in view of in-operando operation in larger devices. This includes in particular the optimization of ps- and ns Laser-based techniques in single or double pulse mode regarding sensitivity for tungsten-based PFCs in vacuum and at elevated gas pressures, mimicking the potential conditions for LIBS and LIA-QMS in ITER, WEST and elsewhere. The work includes principle studies with pre-damaged tungsten material and with enhanced reservoir for hydrogen isotopes. Thus, providing vital input on corresponding systems under consideration for ITER, DTT and a reactor. The later task is in connection to SP C studies.Absolute sensitivity, depth resolution, temporal evolution, and identification of the resulting spectra are key parameters of interest that will be validated under different ambient conditions and for different material composition. Note, C is only included for the purpose of W7-X samples analysis. Overall, the ability to measure the absolute hydrogen isotope content, the He content, and its composition in W- and B-deposits or artificial layers (C in case of W7-X) with additional impurities present usually in toroidal devices will be assessed. Automatization of analysis with novel methods like AI will be supported in order to cope with a large number of measurements.Exploration of in-situ or in-operando systems in e.g. linear plasma devices are included covering in-addition hydrogen recycling, short-term retention and long-term aspects in one hand. The demonstration of in-situ and in-operando techniques under steady-state conditions serves the qualification of systems for steady-state toroidal devices as well as provide a testbed for global modelling under SP D regarding fuel retention and material migration.Moreover, the diagnostic results will be compared with a set of reference techniques (NRA, LIBS, LIA-QMS, LID-QMS, TDS, SIMS etc.) available in WPPWIE. Unique is here the in-situ ion beam analysis in MAGNUM-PSI which will be explored in connection to SP C. Oher novel techniques like LAMIS, based on molecular LIBS combined with spectral detection of isotopes of wall materials, or a combination of LIBS with TALIF for tungsten isotope analysis in PSI-2 will be explored.Due to the recent change in the ITER baseline, dedicated studies will be performed to cope with ultrathin B layers from deposition in the tens on nm range. Note, in-situ LIBS in JET on the remote handling arm developed in SP X2 is transferred to SP E. Within SP X2 LIBS measurements on Be will be carried out at VTT to support this LIBS@JET project. |
| **Inputs required:** * Machines: MAGNUM-PSI, PSI-2
* Accelerators
* Samples: layers or coatings from SP B
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| **Tasks to be performed:*** Comparison ps vs. ns LIBS regarding absolute composition and D content in reference and ITER-relevant (B containing) coatings which can include impurities (FZJ, CU, UT, ISSPUL, CEA)
* Comparison SP vs. DP LIBS (or alternative LIBS signal enhancement methods) regarding absolute material composition and D content in ITER- and DEMO-relevant W including self-damaged W and reference coatings. (FZJ, ENEA, CEA)
* Improve LIBS analysis by application of machine learning algorithm (IPPLM)
* (CF-)LIBS on Be containing coatings with different type of fuel content (in support of LIBS@JET project) (VTT, UT, CU)
* CF-LIBS on produced reference samples before and after *He* loading (FZJ, CU, UT, ENEA)
* Investigate erosion/deposition/fuel retention by *in situ* LIBS and NRA/RBS in MAGNUM. LIBS and LIA-QMS/EDX in PSI-2 with subjects of interest: outgassing, recycling, and role of impurities (O, N), Tsurface, and implantation energy on retention (DIFFER, FZJ, UT)
* Exploration of LAMIS and LIBS&TALIF combination for isotope resolved measurements (FZJ)
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| **Deliverables:**

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| **Deliverable ID** | **Deliverable Title** |
| D001 | Comparison of ps vs. ns LIBS: absolute content and composition / Comparison SP vs. DP LIBS, or alternative LIBS signal enhancement methods: absolute fuel content in W samples and composition (CEA) |
| D002 | Reference measurements of outgassing, recycling, and retention after D plasma loading: absolute content and composition in W and reference samples (DIFFER) |
| D003 | Comparison SP vs. DP LIBS, or alternative LIBS signal enhancement methods: absolute fuel content in W samples and composition / (CF)-LIBS results He loaded samples and surface modifications (ENEA) |
| D004 | Comparison of ps vs. ns LIBS: absolute content and composition / Comparison SP vs. DP LIBS, or alternative LIBS signal enhancement methods: absolute fuel content in W samples and composition / Reference measurements of outgassing, recycling, and retention after D plasma loading: absolute content and composition in damaged and undamaged Wsamples / LAMIS measurements and identfication of C and N containing molecules /Explore TALIF and LIBS for H isotope identification (FZJ) |
| D005 | Report on LIBS analysis by application of machine learning algorithm (IPPLM)  |
| D006 | Comparison of ps vs. ns LIBS: absolute content and composition / (CF)-LIBS results He loaded samples and surface modifications. (CF-)LIBS on Be containing coatings with different type of fuel content (CU) |
| D007 | Analysis of B containing coatings and/or W coatings with (CF)-LIBS: absolute content and composition / (CF)-LIBS results He loaded samples and surface modifications / Reference measurements of outgassing, recycling, and retention after D plasma loading: absolute content and composition in W and reference samples. (CF-)LIBS on Be containing coatings with different type of fuel content (UT) |
| D008 | Comparison of ps vs. ns LIBS: absolute content and composition (ISSP-UL) |
| D009 | (CF-)LIBS on Be containing coatings with different type of fuel content (VTT) |

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| **Management Information****Human Resources (2024)**:

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| **Deliverable Owner** | **Beneficiary** | **PM** | **Deliverable (Team)** |
| E. Bernard | CEA | 4 | D001 (A. Bultel...) |
| H. van der Meiden | DIFFER | 4 | D002 (H. van der Meiden, J. Vernimmen,…) |
| S. Almaviva | ENEA | 4 | D003 (S. Almaviva,, ...) |
| G. Sergienko | FZJ | 11 | D004 (G. Sergienko, R. Yi, E. Wüst, ...) |
| P. Gasior | IPPLM | 6 | D005 (P. Gasior, M. Kubkowska,...) |
| P. Veis | CU | 7 | D006 (J. Kristof,…) |
| I. Jögi | UT | 6 | D007 (I. Jögi, P. Paris, ...) |
| J. Butikova | ISSP UL | 3 | D008 (J. Butikova,…) |
| A. Hakola | VTT | 2 | D009 (A. Hakola, J. Karhunen and J. Likonen) |
| **Total** |  | 47 |  |

**Hardware/ Machine Resources: e.g. Materials / Linear devices type / days / HHF**

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| --- | --- | --- | --- |
| **Device** | **Beneficiary** | **Days** |  **Related Deliverable** |
| MAGNUM-PSI | DIFFER | 4 | D002 |
| PSI-2 | FZJ | 15 | D004 |
| Accelerator | DIFFER | 7 | D002 |
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**Other resources:****Collaborations:*** WPTE and WPW7X
* ITER and ITPA DIAG

**Other information:** |