# EFDA WORKPROGRAMME 2011

## Call for Participation

## Emerging Technologies

## Fusion Materials Topical Group

## Research Project:
## MAT-WWALLOYS: Tungsten and Tungsten Alloys Development

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## 1. Introduction

At its meeting in Dublin on the 23rd June 2010 the EFDA Steering Committee approved the EFDA 2011 Workprogramme, including the tasks identified below. This Call for Participation covers the activities of the 2011-WP of the MAT-WWALLOYS Research Project of the Fusion Materials Topical Group, Tungsten and Tungsten Alloys Development, and will be implemented on the basis of the provisions given in Art.5 of the EFDA Agreement.

## 2. Objectives

Tungsten and tungsten-based alloys are presently considered for helium-cooled divertor and for the protection of the helium-cooled first wall in DEMO designs, largely because these materials have high temperature strength, good thermal conductivity, and low sputtering rates. There are two types of applications for these materials, one as plasma-facing armour or shielding material, and the other as a structural material. These applications impose different sets of requirements on properties. An armour material needs to exhibit high crack propagation resistance under extreme thermal shock loading and thermal fatigue operation conditions, while a structural material has to be ductile within the operating temperature range. Properties of both materials types should remain within bounds, defined by the design criteria, under fusion neutron irradiation.

The objective of the present programme is to develop structural as well as armour materials in combination with the necessary production and fabrication technologies for DEMO divertor components.

Presently there is a number of unresolved issues associated with the use of tungsten-based materials. Therefore the roadmap for the development of tungsten-based materials follows the four lines of materials engineering R&D:

- Fabrication of Parts, and Joining Process Development
  The priority issue: joining of tungsten to tungsten, and tungsten to steel.
- Structural Material Development
  The priority issue: the development of material with significantly improved ductility, compatible with the optimum range of other relevant properties.
- Armour Materials Optimisation
  The priority issue: cooperation with plasma-wall interaction TG
- Irradiation Performance Testing
  The priority issue: identification of the low limit for the range of operating temperatures under neutron irradiation.

and a basic research line:

- Materials Science and Modelling (including analysis of activation and transmutation properties of tungsten, tungsten alloys, brazing alloys, and protection layer materials). Priority issues: discovering ways of improving the ductility of tungsten based materials, and identification of the origin of low temperature radiation embrittlement.

The main objective of these activities is the identification of operating conditions compatible with the use of tungsten and tungsten-based materials in helium-cooled divertor parts.

## 3. Work Description and Breakdown

### *3.1 Work Breakdown*

Within the structure and the objectives defined above the Work Breakdown will be as follows.

***(i) Fabrication of Parts and Joining Process Development***. This activity includes fabrication of parts, the development of joining process, screening of suitable brazing alloys, functional gradient joints including tungsten-vanadium-steel, and other ternary alloy based joining combinations, and investigation of activation and transmutation properties of these brazing alloys, and heat loading testing of parts fabricated according to the specification of a He cooled-divertor DEMO reference design. Within this activity, the fabrication of parts is going to be performed using the machining techniques and parameters already developed.

***The deliverables are summarised in the table below:***

| **Fabrication of Parts and Joining Process Development** | | |
|---|---|---|
| **Objectives** | **Milestones** | **Deliverables** |
| Development of W-Eurofer and W-W joints (brazing & functional gradient) | **Dec. 2011**: First set of RA braze alloys as alternative to commercially available products. Fabrication routes for ternary alloys-based gradient joints. W-EUROFER explosive bonding tests in plane geometry. | • **Dec. 2011:** Report on screening results of RA brazes. Development of electrolytic & galvanic layer deposition processes.<br>• **Dec 2011**: Report on ternary alloy-based gradient joint and explosive welding between W & EUROFER<br>• **Dec. 2011**: Report on activation and transmutation analysis of brazing and joining materials |
| Investigating, characterising and developing deep drawing and powder injection moulding processes | **Dec 2011:** Prototype production and the definition of production parameters | • **Dec. 2011:** Report on progress in deep drawing and powder injection moulding |

***(ii) Structural Materials Development***. This activity includes the development of a range of tungsten based alloys and screening of properties of these alloys. Several EFDA "standard" batches of nominally pure tungsten have been produced, and this activity will include carrying out full characterization of properties of these reference materials. A database of properties describing the reference materials, suitable for the use as input for DEMO design studies, will be compiled.

***The deliverables are summarised in the table below:***

| **Structural Materials Development** | | |
|---|---|---|
| **Objectives** | **Milestones** | **Deliverables** |
| Development and characterisation of basic mechanical properties of tungsten alloys for structural applications. | **Dec 2011:** Fabrication of W-V and W-Ti alloys.<br>**Dec 2011**: Characterization of reference W-V and W-Ti alloys. | • **Dec. 2011:** Report: Characterisation of warm or hot processed and severely plastically deformed W-V and W-Ti alloys.<br>• **Dec. 2011:** Report on W-V and W-Ti ODS materials: fabrication route & characterisation of basic mechanical properties. |

(iii) ***Armour Materials Optimization***. Armour materials have two different applications: as the plasma-facing layer of blanket components, and as plasma-facing layer of the divertor. For the armour materials for the blanket the focus of activity is on self-passivating alloys, improvement of their resistance to oxidation at high temperature, and their fabrication. For the divertor materials the focus is on assessment of their properties under high heat flux testing, thermal shock loading, thermal fatigues and H/He beam loading. Evaluation of lifetime of DEMO components is expected to be conducted in cooperation with the Plasma-Wall Interaction TF.

***The deliverables are summarised in the table below:***

| **Armour Materials Optimization** | | |
|---|---|---|
| **Objectives** | **Milestones** | **Deliverables** |
| Development , optimization and production of self-passivating coatings and bulk self-passivating materials. | **Dec 2011:** Characterization of the oxidation behaviour, up to high temperature<br>**Dec 2011:** | **Dec 2011:** Report on characterization of the oxidation behaviour, up to high temperature<br>**Dec 2011:** Report on |

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|---|---|---|
| | Identification and formulation of the production route. | identification and formulation of the production route. |
| Screening, optimisation, and thermal fatigue/shock, H/He beam testing of tungsten based armour materials | **Dec 2011:** characterization of new tungsten-based alloys<br>**Dec 2011:** transfer of test results to plasma-wall interaction Task Force | • **Dec. 2011:** Report on mechanical and high temperature/heat flux characterisation (electron, He, H) of batches of tungsten-based alloys. |

***(iv) Irradiation Performance Testing.*** This activity is focused on assessing how the properties of tungsten based alloys change under irradiation for DEMO-relevant operating conditions. Experimental tests will be performed using ion-beam irradiation facilities. The activity will also benefit from access to information from other materials testing programs.

***The deliverables are summarised in the table below:***

| **Irradiation Performance Testing** | | |
|---|---|---|
| **Objectives** | **Milestones** | **Deliverables** |
| Ion beam irradiation of tungsten and tungsten based alloys, testing of ion irradiated specimens, analysis of dose rate effects. Screening of information from other materials irradiation testing programs | **Dec. 2011**: Characterization of irradiation induced microstructures<br>**Dec. 2011**: Characterization of microstructures of high-temperature recovered ion-irradiated materials | • **Dec. 2011**: Report on characterization by micro/nano-indentation, TEM analysis of defect densities and dislocation structures<br>• **Dec. 2011**: Report on micro-structural characterization of ion-irradiated materials recovered by high-temperature treatment |

***(v) Material Science and Modelling.*** This activity will include the analysis of activation and transmutation properties of tungsten, tungsten alloys, brazing alloys, and protection layer materials. Fundamental experiments and simulations will also be performed to rationalize the observed low temperature brittleness of tungsten. The known ductilisation methods will be

assessed to determine the underlying mechanisms. Simulation tools adapted to tungsten materials will be applied to predict changes in properties occurring under irradiation.

The main objective for this activity is to identify the reason for the extreme brittleness of tungsten, explore the possible ductilisation treatments, transfer the new knowledge to the materials development area, and identify the range of possible operating conditions compatible with the use of tungsten-based materials in DEMO.

***The deliverables are summarised in the table below:***

| **Material Science and Modelling** | | |
|---|---|---|
| **Objectives** | **Milestones** | **Deliverables** |
| Plasticity studies and fracture mechanics with focus on texture and Re effect. | **Dec 2011:** Characterization of properties versus texture for W-X (X=Ta, V, Ti) alloys. | • **Dec. 2011:** Report on the effect of texture on mechanical properties of W-Ta, W-V, W-Ti. |
| Defect calculations with *ab initio*, molecular dynamics, and dislocation dynamics. | **Dec. 2011:** *Ab initio* evaluation of vacancy formation and migration energies for W-V and W-Ta alloys.<br>**Dec. 2011:** *Ab initio* evaluation of double kink formation energies for screw dislocations in W-X alloys.<br>**Dec. 2011**: Evaluation of surface defect dynamics including He trapping, including experimental validation. | • **Dec 2011:** Report on *ab initio* calculation of formation and migration energies of vacancies in W-Ta and W-V alloys.<br>• **Dec 2011:** Report on *ab initio* calculation of core structure, Peierls potential for screw dislocations in W and interaction with Re, Ta, V and Ti.<br>• **Dec 2011:** Report on assessment of trapping energies for helium desorption from W-X alloys, including experimental validation by thermal desorption and positron annihilation spectroscopy. |
| Analysis of activation and transmutation products under fusion neutron irradiation | **Dec. 2011:** Evaluation of activation and transmutation effects for W-based alloys for DEMO applications | • **Dec. 2010:** Report: Activation and transmutation effects in W-based alloys developed for DEMO applications |
| Analysis of applications and properties | **Dec. 2011:** Definition of a | • **Dec. 2010:** Report on the definition of a |

| | | |
|---|---|---|
| of composite tungsten foil based materials | fabrication route, evaluation of basic mechanical properties, microstructural characterization of tungsten foil based materials | fabrication route, evaluation of basic mechanical properties, microstructural characterization of tungsten foil based materials. |

**(vi) Priority Support:**

All the activities described above are foreseen under Base Line Support except the following ones for which Priority Support are proposed. They are given in the table hereafter and concern:

- Project Coordination: 0.5PPY per year.
- Transmutation and activation neutron calculations including the shielding effects, performed for a range of materials relevant to the tungsten programme: 0.5 PPY
- Development of composite tungsten foil materials: 0.5PPY, 15k€
- Microplasticity studies and experimental validation of He kinetics and dislocation interction via dual beam irradiation and TEM: 0.75PPY, 90k€
- H/He beam loading of tungsten and tungsten based alloys: 0.5PPY, 45k€
- Thermal fatigue/shock of tungsten based armour materials: 0.5PPY, 45k€
- Development and fabrication of self; passivating bulk materials: 0.25PPY, 15k€
- Transfer of industrial knowledge of PIM: 30k€
- Plasticity studies and fracture mechanics with focus Re effects and microstructure: 0.5PPY

| **Activities** | **Human Resources** | **Other Expenditures** |
|---|---|---|
| | **2010** | **2010** |
| Fusion Materials TG coordination | 0.5 | |
| Transmutation and activation neutron calculations including the shielding effects, performed for a range of materials relevant to the programme | 0.5 | |
| Development of composite tungsten foil materials | 0.5 | 15 |
| Micro-plasticity studies and experimental validation of He kinetics and dislocation interaction by dual beam and in situ TEM (joint coordinated activity involving several associations) | 0.75 | 90 |
| H/He beam loading of tungsten and tungsten based alloys | 0.5 | 45 |
| Thermal fatigue/shock of tungsten based armour materials | 0.5 | 45 |

| | | |
|---|---|---|
| Development and fabrication of self; passivating bulk materials | 0.25 | 15 |
| Transfer of industrial knowledge of PIM | | 30 |
| Plasticity studies and fracture mechanics with focus Re effects and microstructure | 0.5 | |
| Study of vacancy defects in tungsten: interaction with He and H isotopes | 0.2 | |
| TOTAL | **4.2** | **240** |

### *3.2 JET related activities*

Non applicable.

### *3.3 Publications*

A list of publications produced on the basis of results of the 2011-WP, will be compiled after the completion of these tasks.

## 4. Scientific and Technical Reports

### *4.1 Progress reports*

At the end of each calendar year and at intermediate times where appropriate, the Task Coordinator shall submit a report on activities under the Task Agreement to the EFDA Leader for his approval. These reports shall describe the progress made by each Association on each activity, and they shall indicate the level of achievement of the objectives, the status of the activities, the allocation of resources and recommendations for the next year where applicable. The EURATOM financial contribution will be made through the usual procedures for baseline support through the Contract of Association.

### *4.2 Report of achievements under Priority Support (final report and, when appropriate, intermediate reports):*

The progress of tasks undertaken under Priority Support and the status of deliverables will be reported separately to the EFDA Leader. A final report (and intermediate reports indicating any substantial progress in the achievement of deliverables, if requested by the EFDA Leader) shall be prepared by the Task Coordinator and submitted to the EFDA Leader. These reports shall include specific sub-sections for each of the Associations involved. They shall document the degree to which the deliverables outlined have been achieved, and shall include a breakdown of expenditure for each Association. The EURATOM financial contribution will be made after approval by the EFDA Leader of these reports.

### *4.3 Milestones.*

The results obtained within the Research Project Tungsten and Tungsten Alloys Development will be presented by the principal investigators and reviewed during joint monitoring

meetings held twice a year. On this basis the progress accomplished by the contributing Associations will be reported by the Coordinator to the EFDA Leader.

The report on the Association activities under Priority Support will be prepared by the Coordinator to be presented to the EFDA Leader at the end of every calendar year.

The final and technical report will be submitted to the Responsible Officer of the Topical Group for approval and uploading the IDM database.

## 5. Association Proposal

The Associations are requested to complete the Association Response via the ECoM system.