FEMAS-CA Report Summary

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Final Report Summary - FEMAS-CA (Fusion energy materials science coordination action)

Executive summary:

On the way to realise fusion as an energy source, a demo reactor is the crucial step in order to demonstrate the feasibility of fusion. The materials for demo are on the critical path. These materials have to sustain extreme power, particle, and neutron loads, while keeping mechanical integrity, sufficient heat conductivity, and stability against erosion by energetic particles from the plasma. In order to deliver qualified materials in time for the realisation of demo, fusion material development needs strengthening and acceleration, a highly challenging task. It can only be achieved by broadening the scope of fusion materials science, the availability of advanced preparation and characterisation techniques, as well as materials knowledge from research areas outside the fusion materials community.

The European FEMAS-CA activity aimed at integrating large-scale facilities and university groups not yet active in the fusion materials field by stimulating, organising and financing collaborative activities, training courses, workshops and conferences. Within the European Seventh Framework Programme (FP7), these goals have been reached through the FEMAS-CA initiatives. During the execution of the project, around 120 cooperative activities have been carried out, each of them on average involving several scientists and mutual visits. In particular the European large-scale facilities providing synchrotron, ion or neutron beams, are now deeply integrated into fusion materials science activities, which has not been the case before FEMAS-CA. Moreover, the scientific communities paired with these facilities recognised the need of their capabilities in developing materials for fusion. In addition, many university research groups could be attracted to and integrated into the fusion community.

The cooperative activities started within FEMAS-CA received strong recognition also within the fusion community, which was in particular visible through contributions at the 'International conference on fusion energy materials science', jointly organised by FEMAS-CA and the 'International workshop on Plasma-facing materials and components (PFMC)', a well-established meeting within the fusion materials community. The combination with the FEMAS-CA project lead to a doubling of the number of tutorial talks, introducing in particular the advanced materials characterisation techniques available at large-scale facilities, an overall extension of the meeting duration by 25 %, and a new record of 280 participants.

By integrating the FEMAS-CA activities and partners into the European European fusion development agreement (EFDA) structures, it is guaranteed that the FEMAS-CA-specific activities will be continued on a long-term scale. This was achieved by participation of FEMAS-CA partners in the EFDA meetings of the topical group materials science and the plasma-wall interaction task force. Many of the FEMAS-CA-initiated activities will such be continued within the work programs of these EFDA organisations.

Project context and objectives:
The overarching objective of this coordination action is:

The FEMAS-CA will create a European research environment in which fusion materials science for the realisation of fusion power can be carried out with optimum effect.

To enforce this objective, the goals of the coordination action are:

1. it will strengthen the application of advanced materials characterisation methods which is an essential ingredient for the successful development of fusion reactor materials in Europe;
2. it will form a strong European network involving institutions and large-scale facilities which are presently not yet part of the fusion program, as well as institutions which are already integrated in the European Atomic Energy Community (Euratom) frame;
3. within this network bi and multilateral collaborative activities shall be carried out;
4. together with EFDA activities it will contribute to the formation of a lasting and efficient European structure for fusion materials science and development.

Background

The development of fusion energy is quickly approaching a stage where the capabilities of materials will be dictating the further progress and the time scale for the attainment of fusion power. The main requirements to materials for fusion reactors are:

1. structural materials: resistance to neutron irradiation, mechanical stability up to high temperatures, low activation property;
2. plasma-facing materials: plasma compatibility, ability to remove high heat fluxes, resistance to neutron irradiation, stability up to very high temperatures;
3. coatings: depending on the specific application: electric insulation and corrosion resistance under irradiation and in contact with liquid metals; tritium permeation barrier function and stability under irradiation.

The development of such materials is a long-term activity which has to include aspects of basic materials sciences, materials development, characterisation, irradiation and mechanical testing, and qualification procedures.

In Europe the long-term Research and technology development (RTD) work on these materials is being carried out in the Euratom fusion associations and in institutions collaborating with these associations. It is coordinated by EFDA (European Fusion Development Agreement). The following groups of fusion reactor materials are regarded as most relevant by EFDA and will be in the focus of this CA:

1. oxide dispersion strengthened ferritic steels (‘ODS steels’) with low activation properties;
2. tungsten-based materials for plasma-facing high heat flux applications;
3. coatings with barrier function, for corrosion protection and electrical insulation.

In addition, EFDA is coordinating a significant European activity aiming at understanding the materials processes taking place under neutron irradiations and the evolution of irradiation damage.

Roadblocks to fusion power deployment

The materials used in present fusion devices do not have the capability to perform under the operational conditions in future fusion power reactors.
Most critical performance deficiencies are:

1. the insufficient irradiation resistance of existing materials: consequences are embrittlement under irradiation, strong shift of the brittle-to-ductile transition temperature, irradiation induced creep at high temperature, degradation of barrier properties of coatings, loss of adhesion of coatings;
2. the insufficient heat removal capability at high temperature as needed in a power reactor;
3. the insufficient plasma compatibility of most high temperature materials.

For use in a fusion reactor these materials issues need to be fully resolved. This will require a strong effort in basic materials sciences to understand the damage mechanisms which are acting on the materials in a fusion environment. This, in turn, requires the application of most sophisticated and advanced materials characterisation methods to quantitatively elucidate the structure of materials (from nano to composite level) and the damage which occurs on these scales. On the basis of this understanding target-oriented materials development activities can take place to arrive at materials solutions which meet these challenges.

The European fusion community is aware of these problems and a consistent technology activity on fusion materials development is being carried out in the European fusion associations coordinated by EFDA.

It has, however, been recognised by EFDA, the European Commission and the research partners of this programme that the present effort is not sufficient to advance the development of fusion materials as fast as needed for the timely attainment of fusion power. On this background the Commission, Directorate Euratom, launched a call for proposals for a coordination or support action in the field of 'Materials research', Topic Euratom-Fusion-2007-7.2.

The project focuses on this topic and addresses its objectives and scope.

Existing deficiencies of the present RTD activities which will be addressed by the FEMAS-CA. Regarding the present long-term materials program, three major deficiencies can be identified which form the definition basis for the FEMAS-CA:

1. The European fusion materials community does not fully employ the most advanced characterisation methods to a width and depth that is required to establish the fundamental understanding of the materials behaviour under operational conditions in a fusion reactor.
2. A neutron irradiation facility (IFMIF) which allows to irradiate materials under fusion specific conditions will not be available for the coming years. Thus in the meantime, an integrated program which consists of neutron irradiation damage studies employing fission-based or accelerator-based irradiations in combination with a consistent scientific modelling effort has to be installed and carried out.
3. The European fusion materials community is too small to properly address the problems associated with fusion materials development on the time scale required for the fast deployment of fusion energy. By enlarging the fusion materials community through cooperation and integration of further specialised materials R&D institutions, the required knowledge can be generated at a faster time scale and with higher quality.

Objectives of this coordination action

1. The project addresses the deficiencies listed above by having adopted the following main objectives:

a. to increase the involvement of experts from the non-fusion materials field especially with respect to the application of advanced materials characterisation methods;
b. to strongly enhance the application of those advanced materials characterisation methods throughout the fusion materials community which are essential for fusion material science and development and which are presently not applied in full
breadth and depth;
c. to enhance the fundamental understanding of radiation damage by strengthening the experimental basis for benchmark experiments to validate numerical simulation results and by the enhanced application of materials characterisation methods for the quantification of irradiation damage at the nanoscopic and microscopic level.

The CA activities are carried out in close coordination with EFDA to make it an integrated part of the European fusion development effort. This integration will also give the CA activities a lasting effect which is of immense importance with respect to the long-term character of the overall challenge.

Project results:

As the FEMAS-Ca is a coordination action no RTD activities took place and no foreground was generated.

Potential impact:

FEMAS-CA was primarily aiming at the integration of new research groups and large-scale research facilities like synchrotron, ion and neutron sources into the fusion materials community, thus accelerating materials development for fusion as an energy source. To achieve this, within the FEMAS-CA project cooperative activities were defined and carried out, aiming either at the introduction of new preparation and characterisation techniques for materials into the fusion community, or at bringing the specific fusion materials related materials requirements to the attention of groups outside the traditional fusion community.

During the project, about 120 cooperative activities were defined and carried out. Each of these activities involved typically two or more FEMAS-CA partners, several scientists from each partner's side, and several exchange visits. During these cooperative activities, both new materials concepts and materials characterisation and preparation techniques were subject of the respective activity.

A first FEMAS-CA workshop was held in January 2009 in Lisbon. During this workshop, a number of cooperative activities were defined and planned by the partners. In particular, the activities at large-scale facilities, which require a successfully peer-reviewed proposal for admittance, were discussed in detail. As a consequence, the majority of FEMAS-CA-initiated beamtime applications, both for the synchrotron sources HZB-BESSY II and ESRF, the multi-beam ion accelerator facility JANNuS, and the neutron source FRM II at TUM, were successful.

The second FEMAS-CA workshop was held in January 2012 in Athens and served again as a discussion forum for cooperative activities, as well as a forum to report on the ongoing activities. Again, a number of new cooperative projects were identified and started after the workshop.

In the field of micromechanical testing, which is a fast growing discipline in materials science, two summer schools were organised by FEMAS-CA partners. Both summer schools addressed modern micromechanical techniques, becoming increasingly wider available with the growing number of specialised microscopic devices (e.g. focused ion beams, combined with electron microscopy and in situ mechanical testing equipment). These techniques are particularly important for testing of fusion materials before and after neutron irradiation. Generally, the sample size in irradiation rigs is strongly limited by the available volume within the reactor core. Therefore, the development and benchmarking of micromechanical tests is a crucial step in the development of radiation-resistant materials for fusion applications.

An important part of the FEMAS-CA knowledge dissemination activities were the presentations of FEMAS-CA activities at international scientific workshops and conference. As a representative example the invited talk at the '15th international conference on fusion reactor materials', held in October 2011 in Charleston, USA, is to be mentioned. This talk specifically focused on the FEMAS-CA consortium, its ideas, realisation and, in a few examples, scientific collaborative activities.
The main knowledge dissemination activity of FEMAS-CA was the organisation of an international conference, open to the international scientific community. In order to integrate the FEMAS-CA activities into the fusion materials science community, the FEMAS-CA conference was jointly organised with the well-established ‘International workshop on plasma-facing materials and components’, which has a tradition of 26 years. The conference was held in Rosenheim from 9-13 May 2011. The first day of the conference was dedicated to eight tutorial talks, aiming at an overview on plasma-material interaction, both for newcomers to the field, but traditionally also appreciated by old-stagers. The subjects ranged from basic processes of plasma-wall interaction through radiation effects in fusion materials and component test procedures, to the construction of components for the first wall of ITER. For the first time - and stimulated by the FEMAS-CA consortium - topics of materials characterisation were also a key aspect: modern methods of materials characterisation with synchrotron and neutron sources, latest techniques of transmission electron microscopy as well as micro-mechanical test methods and analysing techniques specially adjusted to first wall material.

With more than 280 participants the conference reached its best turnout ever. In 35 plenary talks current developments in the focal topics of wall materials and components were presented. The subjects ranged from ‘Diagnostics and dust’, ‘First wall research at JET’, ‘Hydrogen retention’ and ‘Impurity transport’ through ‘Beryllium as first wall material’ and ‘Tungsten under high heat loads’ to ‘New materials concepts’ and ‘Advanced characterisation techniques’. In addition to that about 200 posters were presented in Rosenheim. The proceedings of the conference will be published as a special issue of Physica Scripta with more than 80 peer-reviewed papers. They will be released still in 2011. The FEMAS-CA integration into this community not only led to a doubling of the number of tutorial talks, but also to a new record of 280 participants and also in an extension of the meeting duration by 25 %. Also as a consequence of FEMAS-CA, the PFMC workshop was renamed. The next ‘International conference on plasma-facing materials and components' will be held at the Forschungszentrum Jülich, Germany, in spring 2013, now with the FEMAS-CA-specific topics as an integral part.

Finally, the continuous integration of the activities into the EFDA framework assured that the FEMAS-CA activities carried out by partners new to the field of fusion materials science will be transferred to a lasting structure. This integration was achieved by participation of FEMAS-CA partners in the EFDA meetings, both of the topical group materials science and the plasma-wall interaction task force. Furthermore, FEMAS-CA partners started to participate in the EFDA-supported research activities. Together with the international conference, these EFDA-related activities guarantee a continuation of activities stimulated by the FEMaS-CA.

Project website: http://www.femas-ca.eu

Related information

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Subjects

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