IAEA
International Atomic Energy Agency

INDC(NDS)- 0671
Distr. LP,NE,SK

INDC International Nuclear Data Committee

Plasma-material Interaction with Steel Surfaces

Summary Report of a Consultancy Meeting

IAEA Headquarters, Vienna, Austria

20 August 2014

Report prepared by

Bastiaan J. Braams
Kyungmi Lim

IAEA Nuclear Data Section

September 2014

IAEA Nuclear Data Section
Vienna International Centre, P.O. Box 100, 1400 Vienna, Austria

Selected INDC documents may be downloaded in electronic form from
http://www-nds.iaea.org/publications
or sent as an e-mail attachment.
Requests for hardcopy or e-mail transmittal should be directed to
NDS.Contact-Point@iaea.org
or to:
Nuclear Data Section
International Atomic Energy Agency
Vienna International Centre
PO Box 100
A-1400 Vienna
Austria

Produced by the IAEA in Austria

August 2014

INDC(NDS)- 0671
Distr. LP,NE,SK

Plasma-material Interaction with Steel Surfaces

Summary Report of an IAEA Consultants Meeting

IAEA Headquarters, Vienna, Austria

20 August 2014

Report prepared by

Bastiaan J. Braams
Kyungmi Lim

IAEA Nuclear Data Section

Abstract

A Consultancy Meeting was held on 20 August 2014 at IAEA Headquarters in Vienna to review data needs for plasma-wall interaction with reduced-activation steel surfaces in fusion devices and delimit the scope of a possible coordinated research project on that topic. The proceedings and discussions during the meeting are summarized here.

September 2014

TABLE OF CONTENTS

1. Introduction

The development of fusion energy is challenging in many ways and among the most severe challenges is the control of plasma-wall interaction. The choice of wall material in a fusion experiment or in a reactor design involves a compromise between demands of low erosion, low radiation loss as a plasma impurity, high melting point and high thermal conductivity, low propensity to absorb tritium, low nuclear activation, tolerance for radiation damage and acceptable cost. For present experiments these requirements have generally led to the choice of carbon-based materials or tungsten for the regions of highest heat load. Beryllium is used for the main wall (away from the region of highest heat load) on the JET experiment and is likewise planned to be used in ITER. Steel is the main structural material in any fusion experiment or design, but in the wall it is at present used only in regions where there is very little exposure to plasma.

For several reasons steel is at present again being considered as a plasma-facing material for a fusion reactor. Carbon-based materials absorb tritium rather easily and it is generally believed that this rules out the use of carbon in any region that is exposed to fusion plasma. The erosion rate of beryllium is expected to be acceptably small for ITER, but a fusion demonstration device (DEMO) or a reactor will have a much higher duty cycle and beryllium is not considered viable. Tungsten remains the leading candidate material for a reactor in the regions of highest heat load, but its tritium retention behavior after radiation damage is a big concern.

Various kinds of reduced-activation steel have excellent properties with respect to tritium retention: low solubility of hydrogen in the material (similar to tungsten) and less sensitivity of the hydrogen solubility to radiation damage than is the case for tungsten. On the other hand, erosion is much more severe for steel than for tungsten. These considerations about plasma-material interaction properties of steel are, however, rather qualitative. At a quantitative level simply not enough is known about plasma interaction, erosion and tritium retention in reduced-activation steels to allow a confident assessment of the extent to which steel can be used as plasma-facing material in some regions of a fusion device.

The mission of the Nuclear Data Section (NDS) in the area of atomic and molecular data is to enhance the competencies of Member States in their research into nuclear fusion through the provision of internationally recommended atomic, molecular, plasma-material interaction and material properties databases. In the area of plasma-material interaction the atomic and molecular data unit manages at this time two Coordinated Research Projects (CRPs). CRP F43020 on "Data for erosion and tritium retention in beryllium plasma-facing materials" (2012-2017) is concerned with erosion due to physical and chemical sputtering of beryllium, trapping and reflection of hydrogen (H, D, T) on beryllium surfaces, the transport of hydrogen in beryllium and means to extract trapped tritium. CRP F43021 on "Plasma-wall interaction for irradiated tungsten and tungsten alloys in fusion devices" (2013-2018) is intended to enhance the knowledge base on the effects of fusion relevant irradiation on plasma-wall interaction and hydrogen retention in tungsten-based materials.

The Subcommittee on Atomic and Molecular Data of the International Fusion Research Council makes recommendations to the IAEA Nuclear Data Section as to its programme in support of this mission. In its biennial meeting in April 2014 the subcommittee assessed priorities for a possible Coordinated Research Project (CRP) in the area of plasma-material interaction in fusion devices. The subcommittee recommended a CRP on plasma interaction with reduced activation steel surfaces as its highest priority in that area. This reflects an assessment that (despite consideration given to liquid metals, certain ceramics and once again graphite) really tungsten and steel are the leading candidates for the plasma-facing surfaces in a reactor.

The present report is the output of a Consultancy Meeting on "Plasma-material interaction with steel surfaces" that was held at IAEA on 20 August to review the state of understanding of erosion and tritium retention properties of steels and to make recommendations about the scope of the planned CRP. The meeting followed immediately upon a two-day Research Coordination Meeting (RCM) of the CRP F43020 on beryllium surfaces and it shared several participants.

Section 2 summarizes the 6 presentations at the meeting. Section 3 summarizes the discussions and conclusions. Appendix 1 provides the list of participants and Appendix 2 provides the meeting agenda. In Appendix 3 a list is given of contributions on the topic of plasma interaction with steel surfaces given at several recent major meetings that attract researchers in the area of plasma-material interaction studies for fusion science and technology.

2. Presentations

B. J. Braams: Opening

The scientific secretary, Bas Braams, welcomed participants to the meeting. Five of the external participants (Drs Jacob, Doerner, Köppen, Irle, Nordlund) and IAEA staff were together already on Monday and Tuesday for the second meeting of the CRP on beryllium surfaces and they are joined by Dr Golubeva and Dr Unterberg for today's meeting on steel surfaces. The objective of the meeting is to review knowledge about plasma-material interaction properties of reduced-activation steels and to advise about the scope of a possible CRP on that topic. If the CRP is approved then the first meeting could be held early in 2015.

W. Jacob: Plasma surface interaction issues for steel as plasma-facing material

Dr Wolfgang Jacob opened the scientific part of the meeting with a survey of research on plasma-material interaction with steel. Primarily one considers steel as an alternative to tungsten for some regions of the wall. It is clear that tungsten is the material of choice for a high heat load divertor: advantages of tungsten are low hydrogen retention, strong resistance to sputtering and a high melting temperature. However it has disadvantages too: it is expensive, it is non-trivial to join tungsten tiles to structural steel, pure tungsten is brittle and the material properties of tungsten degrade due to neutron irradiation.

Many present-day tokamaks and stellerators have a steel vacuum vessel, but direct plasma contact is always with a limiter or divertor and there the material is graphite, tungsten or something else, but not steel. Besides, on present devices the steel is generally Inconel. The main kind of steel that is being considered for future fusion applications, both structural and plasma-facing, is Reduced Activation Ferritic Martensitic (RAFM) steel of which there are various standard kinds including EUROFER in Europe, RUSFER-EK-181 in Russia and China Low-activation Martensitic steel (CLAM steel) in China. They are all quite similar in composition and differing from other martensitic steel mainly in the replacement of Mo by W as a minor ingredient.

Many experiments have been done to compare the sputtering behavior of pure iron and that of steel containing some tungsten. Over a wide range of energy the sputtering yield of iron is higher than that of tungsten by a factor of about 30. When a steel surface is exposed to plasma there is preferential sputtering of the lighter ingredients, the concentration of tungsten is enhanced near the surface and the sputtering yield is reduced. This enrichment (of Mo in standard steel) was seen already in experiments by Roth, Bodansky and Hofer in 1976.

To assess the compatibility of RAFM steel as first wall material, impurity generation, impurity transport from the wall to the core and radiation properties in the core have to be considered for any experiment. In addition, reactor-relevant processes should also be taken into account. Main additional issues for a reactor are total (life time), hydrogen (tritium) inventory in walls and hydrogen migration, and many effects of radiation. Preferential sputtering has a large effect on plasma-material interaction properties and the detailed study of surface evolution under plasma exposure will be an important component of the planned CRP.

TRIDYN simulations are being carried out at IPP to study preferential sputtering in an Fe-W composite. For bombardment by D at 100 eV there is a large effect; at this energy Fe is sputtered and W is not sputtered and the surface concentration of W increases up to unity. This effect is expected to be pronounced at impact energies between about 40 eV and 210 eV; at higher energies also W gets sputtered. The TRIDYN simulations also show an effect of the crystal phase.

To sum up, steel may be an option for some regions of the first wall of DEMO. However, a scientific basis should be developed to assess the fusion plasma compatibility of different types of metals taking into account all reactor relevant properties. For the planned CRP it must be emphasized that steel is not the same as iron; the CRP should really focus on the special properties of relevant (RAFM) steel. Many of the relevant topics can be addressed in laboratory experiments. A sputtering data base should be compiled and further developed. Finally, although this presentation has concentrated on sputtering, permeation of hydrogen isotopes is another important issue that must be considered.

A. Golubeva: Retention and permeation of hydrogen isotopes through RAFM RUSFER-EK-181

The key facilities in the Russian 2013 strategy for development of the fusion-fission hybrid are DEMO-FNS (fusion neutron source) and PHP (pilot hybrid plant). Construction of DEMO-FNS is planned by 2023 and that of PHP is planned to start by 2030. For construction of FNS native materials are supposed to be used and steel is a wall material. In any case retention and permeation of hydrogen through steel are very important topics of investigation.

Rusfer EK-181 is the standard Russian low-activation steel, already available in almost industrial quantities. Its properties are being investigated in the frame of the Russian fission programme. Additional tests are necessary for fusion application: hydrogen retention, gas-driven and plasma-driven permeation of hydrogen, and the influence of the fusion neutron spectrum on all properties.

For the study of plasma interaction with steel the Kurchatov Institute cooperates with TRINITY in Troitsk, the A. A. Bochvar Institute of Inorganic Materials in Moscow, The National Research Nuclear University "MEPhI" in Moscow and with IPP Garching. Facilities of Kurchatov Institute and cooperating institutes include PIM for deuterium permeation, ATLAN for gas loading, the linear plasma simulator LENTA for high flux plasma irradiation, the quasistationary plasma accelerator QSPA at TRINITI, Nuclear Reaction Analysis at IPP Garching, a thermal desorption spectroscopy (TDS) stand at MEPhl. There is also cooperation with University of Toyama, Japan, for β-ray induced X-ray spectrometry.

Studies have started of deuterium retention in Rusfer steel using gas and plasma exposure, also deuterium retention in damaged material, and deuterium permeation. The surface structure is an important property. When RUSFER and EUROFER are annealed, surface roughness changes and many tiny grains appeared. Other experiments show that deuterium is mainly trapped near-surface layer and concentrations of deuterium trapped in damaged samples are close to those in undamaged samples. Furthermore, the maximum deuterium retention is observed at about 500K and this deuterium is trapped in a surface layer of about 0.2 µm.

The plans of the group are deuterium gas-driven permeation through RUSFER after high heat flux irradiation and influence of helium production in material on hydrogen isotopes retention. Also, some topics like hydrogen isotopes permeation and retention in RAFMs and influence of neutron effects on mechanical properties and thermal conductivity of RAFMs should be considered.

Dr Golubeva notes that there hasn't yet been much comparison between plasma-material interaction properties of different RAFM steels and the planned CRP should address that. In particular we want experimental projects in the CRP to have access to standard clean and damaged wall materials.

R. Doerner: Sputtering of EUROFER and Fe-W layers by D+ in PISCES A

The studies at UCSD on plasma interaction with steel are being carried out in cooperation with IPP Garching and the objective is to explore the possibility to use RAFM steel (here EUROFER) as plasma-facing material on the main wall of a DEMO device. As a plasma-facing material the limiting factor for steel is erosion life time. Therefore, the influence of tungsten on the erosion yield, low energy and high fluence erosion, preferential sputtering in the simple Fe-W system and modelling of tungsten enrichment in EUROFER have been the main issues for investigations on PISCES.

Earlier studies showed that sputtering yield of EUROFER is strongly reduced compared to pure iron and the reason for the reduction is thought to be tungsten enrichment at the surface. In order to investigate this 350 nm tungsten-iron layers were exposed to similar plasma conditions as EUROFER and ion beam analysis was done at IPP Garching to obtain depth resolved measurements of the tungsten concentration and distinguish iron erosion from tungsten erosion. All of the results are used for validation of TRIDYN code simulation.

Outstanding issues are determining temperature threshold for yield reduction, exposure of EUROFER (or similar steel) to mixed deuterium/helium plasma, influence of other trace materials in steels, and changing surface morphology and dealing with that in a database. Dr Doerner recalls that early investigations of W were hampered by the variety of materials and fabrication techniques and we must keep this in mind for the Steel CRP. The CRP needs to identify and share common material for study.

B. Unterberg with M. Köppen: Plasma surface interaction issues for steel as plasma-facing material – FZJ perspective

There are some important aspects to be discussed for steel as plasma facing materials. First, quantification of EUROFER erosion and investigation of tungsten surface enrichment via preferential sputtering. This includes study of the effect of impact energy, surface temperature, surface morphology, behavior of steel under transient heat loads, and radiation defects including comparison of neutron irradiation with high energy charged particle irradiation. Next to erosion the other main issue is fuel (tritium) retention in steel with possibly modified surface composition. For fuel retention the key subtopics are the effect of temperature, plasma impurities and surface morphology, characterization of trap sites (trap energy), isotope exchange in steel, tritium permeation, impact of irradiation defects on fuel retention in steel, and comparison to diffusion trapping codes.

At FZJ plasma-wall interaction with steel can be studied using the linear plasma device PSI-2 to expose plasma-facing materials to high flux and high fluency plasmas with well-defined conditions. In addition transient heat loads are simulated by laser irradiation. On PSI-2 there is an exchange chamber for in-vacuo analysis of the exposed surface. Other facilities for post-mortem analysis include a thermal desorption spectroscopy (TDS) set-up, ion beam analysis using a tandem accelerator, the ARTOSS surface science facility (moved with Ch. Linsmeier from IPP Garching), a focussed ion beam (FIB) and scanning electron microscope (SEM) and X-Ray Photoelectron Spectroscopy (XPS) and X-Ray Diffraction (XRD). At FZJ a new linear device, Jule-PSI, modelled on PSI-2, is being assembled in a hot cell to enable study of neutron-irradiated materials.

The group at IEK-4 in Jülich collaborates with the Magnum-PSI group through the triregio cluster; Magnum-PSI has special capability for high-fluence experiments. We should note also the Eurofusion project on plasma-facing components.

S. Irle: Brief review of quantum chemical calculations on H-Fe interactions

Dr S. Irle provided a brief literature review of relevant quantum chemical calculations. However, thus far the quantum chemical studies of steel for fusion are devoted to structural steel and there do not seem to be reports in the literature using density functional theory (DFT) specifically devoted to erosion or retention of hydrogen in steel as a plasma-facing material.

Some work existing work is relevant anyway, notably there are studies devoted to hydrogen embrittlement of steel (structural weakening followed by crack formation, important in nuclear fission reactors) and there are studies devoted to hydrogen storage in alloys (Mg, Li, Al, Ti and other hydride-forming metals).

DFT calculations of hydrogen diffusion in iron have mostly been carried out in the group of Emily A. Carter at Princeton University (e.g. Jiang and Carter, PRB70, 2004). Spin-polarized DFT was used to calculate properties of adsorption, absorption, dissolution and diffusion energetics of hydrogen in bulk bcc iron. The calculations revealed that dominant absorption site of hydrogen is tetrahedral site rather than octahedral site. Besides, hydrogen prefers to stay absorbed on the surfaces and dissolution of hydrogen atoms in iron is endothermic with the energy of 0.3eV. Finally, hydrogen easily migrates from one tetrahedral site to the next. Dissolution of hydrogen into bulk iron is found to be endothermic, which is associated with 0.4 eV – 1 eV barrier between tetrahedral sites.

For the planned CRP there is plenty of work that needs to be done in the area of fundamental computations. Potentials for steel need to be developed, either classical or tight-binding DFT, for use in MD simulations. At present there are potentials for Fe-H, but not for H in steel. Dr Irle emphasizes that steel is extremely challenging for first principles calculations, because small impurity concentrations have a big effect. For example, treatment of the significant effects of 0.1% carbon requires a unit cell that contains at least 1000 atoms.

K. Nordlund: Review of development of interatomic potentials and MD calculations for Fe-H and beyond

Dr Nordlund started his presentation with a general introduction of steel and stainless steel. (Steel is iron with a carbon impurity in a certain range, stainless steel is steel with chromium, ferritic steel means BCC crystal structure, austenitic means FCC, and generally steel involves many other alloying elements besides C and Cr such as Ni, Mo, W, …). Various Fe-C and Fe-Cr-C crystal phases exist and the phase diagram is important for hydrogen retention properties. Above 0.022% C (by weight) one expects cementite inclusions.

In nuclear reactors, radiation damage is important. The primary stage of damage is formed when a MeV neutron occasionally hits a lattice atom nucleus and gives it recoil energy; this is a PKA (primary knock-on atom) event and it is the key event at the start of an MD simulation. The typical PKA energy extends up to about 100 keV.

To enable modelling of stainless steels Dr Nordlund's group developed in 2009–2012 an interatomic potential for the iron-chromium-carbon system. Tests were done including study of melting of FeC cementite.

There are several alternative potentials based on the embedded atom method (EAM). In fact, tens of potentials for pure Fe (note esp. Ackland-Mendelev and Dudarev-Derlet) several for Fe-Cr (note Olsson, Caro, Marinica), recent potentials for Fe-W and Fe-Ni (Bonny-Malerba et al.), potentials for C in Fe (Hepburn), Fe-He, Cr-He (Juslin) and Fe-H (Carter group). However, one cannot just combine these potentials to get Fe-Cr-C-He-H; the EAM method does not allow that.

In 2006, Lorenzo Malerba reviewed the status of damage production simulations in iron and 1 year later, Nordlund's group restricted the comparison to modern potentials. It appeared that quantitative reliability was achieved, but a bit later it was recognized that depending on how the low-energy limit of electronic stopping is treated one can get a major (~factor of 2) variation in damage production and ion beam mixing. Therefore, even primary damage is not yet predicted with quantitative accuracy.

For the purpose of the planned CRP we should take note of a major EFDA (now Eurofusion) activity on multiscale modelling of radiation damage in steels; it is coordinated by S. Dudarev and by S. Gonzales. (However, S. Gonzales has just moved from Eurofusion to the Physics Section at IAEA.) Almost all EFDA partners are participating in this materials project. The Helsinki group is contributing the development of a new potential for Fe-H based on DFT with fitting to several crystal structures.

The big Eurofusion activity is devoted to structural steel and it leaves plenty of issues that need to be addressed for steel as a plasma-facing material. The planned CRP will need to address determination of sputtering yield, fuel (tritium) retention, hydrogen reflection, difference between sputtering and reflection from austenitic and ferritic steels, and surface enrichment or depletion of the various constituent elements.

3. Discussion and Conclusions

At the end of the meeting the main issues for the planned CRP on steel surfaces were recalled and reviewed. Erosion and tritium retention are both important and erosion is a much more complicated problem for steel than for elementary metals due to the expected differential sputtering. The participants in the Consultancy Meeting all affirmed the need for a coordinated research project devoted to plasma interaction with steel surfaces for fusion.

A CRP is for coordinated research and this must be emphasized strongly. The CRP has to arrange that different groups carry out experiments using the same target materials, including pre-damaged targets. (The damage will generally be produced by surrogate irradiation, not neutrons.) Besides coordination within the CRP we need to coordinate with the Eurofusion project on study of radiation damage of steels.

For potential participants in the CRP the list of contributions at recent meetings (Appendix 3) is a good guide. However, it is seen there (and participants in the Consultancy Meeting agree) that most of the work on plasma-material interaction with steel is experimental work. For theoretical work the development of potentials is done anyway for study of steel as a structural material, but dedicated modelling of plasma-material interaction with steel will need to be encouraged.

List of Participants

Mr Kai NORDLUND, Department of Physics, University of Helsinki, P.O. Box 43, Pietari Kalmink 2, Helsinki 00014, FINLAND.

Mr Bernhard UNTERBERG, Forschungszentrum Jülich, Leo Brandt Strasse, Jülich 52425, GERMANY.

Mr Martin KÖPPEN, Forschungszentrum Jülich, Leo Brandt Strasse, Jülich 52425, GERMANY.

Mr Wolfgang JACOB, Max-Planck Institut für Plasmaphysik, 85748 Garching bei München, GERMANY.

Mr Stephan IRLE, Nagoya University, Institute for Advanced Research, Furo-cho, Chikusa-ku, Nagoya 464-8602, JAPAN.

Ms Anna GOLUBEVA, State Research Center of the Russian Federation, Kurchatov Institute, Kurchatova Squ. 1, Moscow 123182, RUSSIAN FEDERATION.

Mr Russell DOERNER, University of California, UCSD Fusion Program Experimental Research Division, 9500 Gilman Dr., La Jolla CA 92093-0417, UNITED STATES OF AMERICA.

Mr Bastiaan J. BRAAMS, IAEA Nuclear Data Section, Division of Physical and Chemical Sciences, P.O. Box 100, A-1400 Vienna, AUSTRIA.

Ms Hyun-Kyung CHUNG, IAEA Nuclear Data Section, Division of Physical and Chemical Sciences, P.O. Box 100, A-1400 Vienna, AUSTRIA.

Ms Kyungmi LIM, IAEA Nuclear Data Section, Division of Physical and Chemical Sciences, P.O. Box 100, A-1400 Vienna, AUSTRIA.

Appendix 2

Consultancy Meeting on "Plasma-wall interaction with reduced-activation steel surfaces in fusion devices"

20 August 2014, IAEA Headquarters, Vienna, Austria

Scientific Secretary: Mr Bastiaan J. Braams

Agenda

Wednesday, 20 August **Room M0E67**

09:00:	**B. J. Braams**: Welcome, introduction to planned CRP.
09:15-10:15:	**W. Jacob**: Plasma surface interaction issues for steel as plasma-facing material. Survey and general discussion.
10:15-10:30:	Break
10:30-11:15:	**A. Golubeva**: Retention and permeation of hydrogen isotopes through RAFM RUSFER-EK-181.
11:15-12:00:	**R. Doerner**: Sputtering of EUROFER and Fe-W layers by D^+ in PISCES A.
12:00-13:15:	Lunch
13:15-14:00:	**M. Koeppen and B. Unterberg**: Plasma surface interaction issues for steel as plasma-facing material – FZJ perspective.
14:00-14:45:	**S. Irle**: Brief review of quantum chemical calculations on H-Fe interactions.
14:45-15:00:	Break
15:00-15:45:	**K. Nordlund**: Review of development of interatomic potentials and MD calculations for Fe-H and beyond.
15:45-16:30:	**All**: General discussion.
16:30:	Close of meeting.

Selected Recent Conference Contributions on PMI with Steel Surfaces

14th International Conference on Plasma Facing Materials and Components for Fusion Applications (PFMC 2013), Jülich, 13-17 May 2013

Papers are in Physica Scripta: http://iopscience.iop.org/1402-4896/2014/T159.

Invited and oral contributions

C9 A. V. Spitsyn, A. V. Golubeva, M. Mayer, D. I. Cherkez, N. P. Bobyr, N. S. Klimov, Yu. M. Gasparyan, O. V. Ogorodnikova, V. Kh. Alimov, V. S. Efimov, A. Putrik, V. M. Chernov: Retention and Permeation of Deuterium in Low-activation Steels by Gas and Plasma Exposure

Poster contributions

A042 S. Korica, A. Manhard, T. Schwarz-Selinger, M. Siljegovic, A. Kalijadis and W. Jacob: Fe and Cr as Model Systems for Deuterium Retention Studies in EUROFER

A048 O. V. Ogorodnikova, K. Sugiyama, Yu. Gasparyan, V. Efimov: Deuterium retention in displacement damage produced by fast heavy ions in tungsten and Eurofer

A062 S. Lindig, A. Houben and T. Schwarz-Selinger: The Native Hydrogen Content in EUROFER97

A068 V. Kh. Alimov, Y. Hatano, K. Sugiyama, T. Höschen, M. Oyaidzu, J. Dorner, M. Fußeder, T. Yamanishi: Surface Modification and Deuterium Retention in Reduced Activation Ferritic Martensitic Steels Exposed to Low-Energy, High Flux D plasmas and D2 Gas

A120 A. Houben, F. Koch, and Ch. Linsmeier: Ceramic Coatings as Tritium Permeation Barriers on Eurofer97

16th International Conference on Fusion Reactor Materials (ICFRM 2013), Beijing, 20-26 Oct 2013

Plenary, invited and other talks

Farhad Tavassoli, CEA, France: Current status and recent research achievements in ferritic/martensitic steels

Natalia Luzginova, NRG, Netherlands: An overview of 10 years of irradiation experiments on EUROFER 97 steel at high flux reactor in Petten

Takuya Yamamoto, UCSB, USA: In situ He injection and dual ion irradiation studies of reduced activation tempered martensitic steels and nanostructured ferritic alloys

Zhongwen Yao, QueensU, Canada: Radiation induced microstructures in austenitic ODS steels under dual-beam ions

Viacheslav Kuksenko, PSI, Switzerland: Nano-sized clusters formation in ferritic-martensitic steels under mixed proton-neutron irradiation

Jean-Louis Boutard, CEA, France: Oxide dispersion strengthened ferritic steels, a basic research joint program in France

Xu Wang, UM, USA: Microstructure analysis of ion beam irradiated CNSI and CNSII steels

Alexander V. Spitsyn, NRC KI, Russia: Retention of deuterium in damaged low-activation steel RUSFER (EK-181) after gas and plasma exposure

Poster contributions

16-110 Hui Zheng: The inhibition effect of low-temperature pre-irradiation of helium ions on the growth of helium bubble in 316L stainless steel: A Monte Carlo simulation

16-140 Dmitry Terentyev: Interaction of minor alloying elements with lattice defects in ferritic high-Cr steels: Ab initio study

16-162 Hongen Ge: Microstructure investigation on clam steel under H+/He+ dual-beam irradiation

16-234 Haishan Zhou: Plasma- and gas-driven hydrogen permeation through a reduced activation ferritic steel alloy F82H

16-248 Olga V. Ogorodnikova: Deuterium retention in reduced-activation ODS steels irradiated by 20 MeV W ions

16-281 Christiane Vieh: Pressure analysis of He-bubbles in He-implanted bcc and fcc steel

16-475 Naoko Ashikawa: Effects of helium bombardment on hydrogen retention in F82H steel

16-530 Chenyang Lu: Effects of helium ion implantation on the microstructure of two 9Cr ODS steels

16-537 Takuya Yamamoto: Modeling of helium effects on microstructural evolution in reduced activation tempered martensitic steels and nanostructured ferritic alloys: the effects of He/dpa, temperature, dose and dose rate

16-158 Chi Zhang: Microstructural evolution of nanocrystalline RAFM steel irradiated with helium ion

16-049 Djamel Kaoumi: Irradiation induced defect structures in two model F/M steels

16-116 Jihong Chen: Microstructure of reduced-activation martensitic steels irradiated by sequential He and Fe ions

16-211 Jinsung Jang: Irradiation induced microstructure evolution in ferritic and austenitic oxide dispersion strengthened steels

16-398 Qian Zhan: Effects of ion irradiation on microstructure of precipitates in China low activation martensitic steel

16-419 Weiwei Zhao: Research progress of tritium permeation barrier coatings on CLAM steel for CN DFLL-TBM

16-163 Yanhong Chang: Comparison between hydrogen and helium irradiation effects on both surface and bulk mechanical properties of 12Cr-ODS steel

16-255 Hui Zheng: The inhibition effect of low-temperature pre-irradiation of helium ions on the growth of helium bubble in 316L stainless steel: A Monte Carlo simulation

16-277 Inês Carvalho: Characterization of He implanted and neutron irradiated Eurofer97 steel

16-467 V.I. Zhurba: Step character of deuterium retention coefficient in austenitic stainless steel implanted at temperature~295K

21st International Conference on Plasma Surface Interactions in Controlled Fusion Devices (PSI 2014), Kanazawa, 26-30 May 2014

Invited and oral contributions

O9 K. Sugiyama, J. Roth, V. Kh. Alimov, K. Schmid, M. Balden, S. Elgeti, F. Koch, T. Höschen, M. J. Baldwin, R. P. Doerner, H. Maier, W. Jacob: Erosion study of Fe-W mixed layer towards assessment of RAFM steel as plasma-facing material

Poster contributions (first author only)

P1-023 A. Hakola: Erosion of tungsten and steel in the main chamber of ASDEX Upgrade

P1-057 I. Takagi: Hydrogen-Deuterium exchange on plasma-exposed W and SS surface

P1-096 N. Yoshida: Retention and Desorption of Hydrogen and Helium from Stainless Steel Exposed to Plasmas of LHD

P2-005 N. Ashikawa: Effects of helium bombardment on hydrogen retention properties in F82H steel

P2-016 R. A. Pitts: Final case for a stainless steel Diagnostic First Wall on ITER

P2-026 T. Takizuka: Combination of helical ferritic-steel inserts and flux-tube-expansion divertor for the heat control in tokamak DEMO reactor

P3-020 M. Balden: Surface modifications of RAFM steels by deuterium exposure: Variation from coral-like/fuzz-like to blister-like features

P3-048 H. Zhou: Effects of surface conditions on the plasma-driven permeation behavior through a ferritic steel alloy observed in VEHICLE-1 and QUEST

12th International Workshop on Hydrogen Isotopes in Fusion Reactor Materials, Toyama, 2-6 June 2014

1-PM-11 D. Zhu, T. Oda: Influence of Hydrogen-Vacancy Interaction on Mobility of Hydrogen and Vacancy in bcc-Metal

2-AM-5 Yu. M. Gasparyan, I. M. Timofeev, V. S. Efimov, M. S. Zibrov, A. A. Pisarev: Effect of Surface Conditions on Deuterium Retention and Desorption in Ferritic-Martensitic Steels

2-AM-6 Y. Hatano, V. Kh. Alimov, N. Yoshida, H. Watanabe, M. Oyaidzu, T. Hayashi: Surface Morphology of F82H Reduced Activation Ferritic/Martensitic Steel Exposed to High Flux Deuterium Plasma

2-AM-7 V. Kh. Alimov, Y. Hatano, J. Roth, K. Sugiyama, M. Oyaidzu, M. Baldwin, R. Doerner, M. H. J. ’t Hoen, H. T. Lee, Y. Ueda, M. Matsuyama, T. Hayashi: Deuterium Retention in Reduced Activation Ferritic Martensitic Steels Exposed to D Plasmas and Irradiated with D Ions

2-AM-8 N. P. Bobyr, A. V. Spitsyn, A.V. Golubeva, M. Mayer, Y. Hatano, N. S. Klimov, B. I. Khripunov, V. Kh. Alimov, D. I. Cherkez, O. V. Ogorodnikova, V. M. Chernov: Hydrogen Isotopes Retention in Low-Activated Structural Materials

Nuclear Data Section
International Atomic Energy Agency
Vienna International Centre, P.O. Box 100
A-1400 Vienna
Austria

E-mail: NDS.Contact-Point@iaea.org
Fax: (43-1) 26007
Telephone: (43-1) 2600-21710
Web: http://www-nds.iaea.org