



ICFRM-18

Closing Session

1. Conference Overview

- *Akira Hasegawa, Executive Committee Chairman*

2. Brief Technical Summary

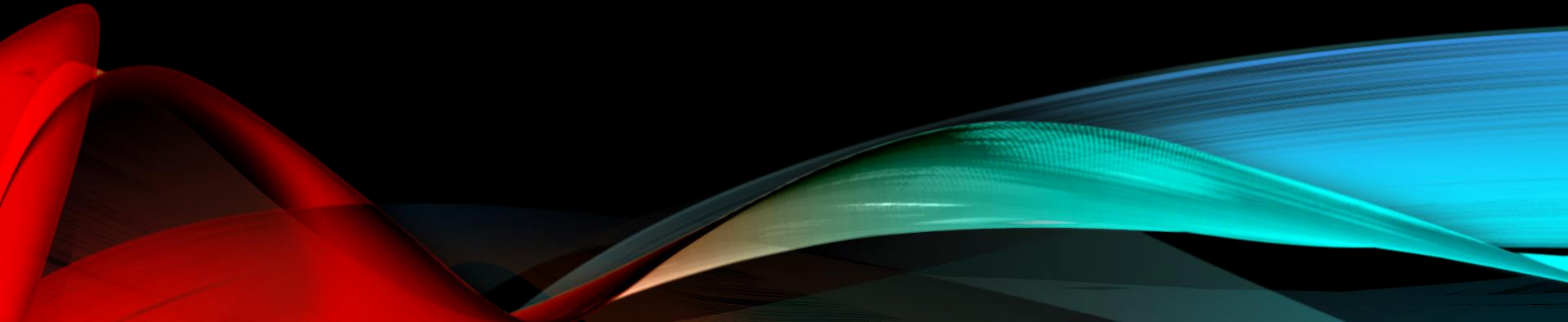
- *Ryuta Kasada, Executive Committee Vice-Chairman*

3. Closing Address

- *Takeo Muroga, Organizing Committee Chairman*

Conference Overview

Akira Hasegawa, Chairman of Executive Committee



Satellite meeting

- 7 satellite meetings

- IEA RAFM
- IEA SiC/SiC
- IEA W
- IEA V
- Discussion on a R&D plan on modeling/simulation in BA Phase II
- IEA executive committee for the implementing agreement on a program of R&D on fusion materials
- Japan-US post-PHENIX review meeting

Exhibitions (industries etc.), Luncheon seminar, Homepage Sponsorship

- **23 Exhibitions**

- Rokkasho Village & Shin-Mutsu-Ogawara Inc., Hitachi Appliances, Inc., NIPPON STEEL & SUMIKIN TECHNOLOGY Co., Ltd., Aomori Prefecture, Aomori City (City Information), YONEKURA MFG Co., Ltd., TOYAMA Co., Ltd., Metal Technology Co., Ltd., SPANISH SCIENCE INDUSTRY, Hitachi High-Technologies Co., Ltd., JEOL Ltd., Tsukishima Kikai Co., Ltd., Yamatogokin Co., Ltd., Lasertec Corporation, Kobe Material Testing Laboratory Co., Ltd., MITSUBISHI HEAVY INDUSTRIES, LTD., SHIMADZU CORPORATION, A.L.M.T. Corp., MORISE PRECISION CO., LTD., Visit the Tohoku Pacific Coast, National Institute for Fusion Science (NIFS), National Institute for Quantum and Radiological Science and Technology (QST, ITER Project), National Institute for Quantum and Radiological Science and Technology (QST, BA Project)

- **2 Luncheon seminars**

- JEOL Ltd., SHIMADZU Corporation

- **9 Homepage banner sponsorship**

- KOBELCO, Journal of Nuclear Science and Technology, Keyence, TOCALO, TOSHIBA, Fritsch Japan, NGK, Miyakojima Seisakusyo Co.Ltd., Visit the Tohoku Pacific Coast

Special introductory session

- On Nov 5th, three distinguished lecturers gave the overview and history of fusion materials research from both scientific and engineering viewpoints in front of ~160 participants.
 - Dr. Anton Möeslang: Overview of current reactor design and structural materials
 - Dr. Steven J. Zinkle: Fundamentals of radiation effects in materials
 - Dr. Takeshi Hirai: ITER plasma-facing components, materials, design and manufacturing technologies

LEGO Workshop on Energy & Fusion Reactor for Aomori citizens

- Also on Nov. 5th, Prof. Kasada, Dr. Mukai and their students as Kyoto University LEGO club had a LEGO workshop on energy and fusion reactor for Aomori citizen in order to thank for giving sponsorship and accommodation for ICFRM-18.
- LEGO-ITER which is the 3rd one made by students of Prof. Akira Hasegawa, Tohoku Univ. (1st one in Kyoto Univ. and 2nd one in ITER organization, France made by Prof. Kasada student team) was exhibited.
- **123 people including 64 children** enjoyed the workshop and fusion reactor!

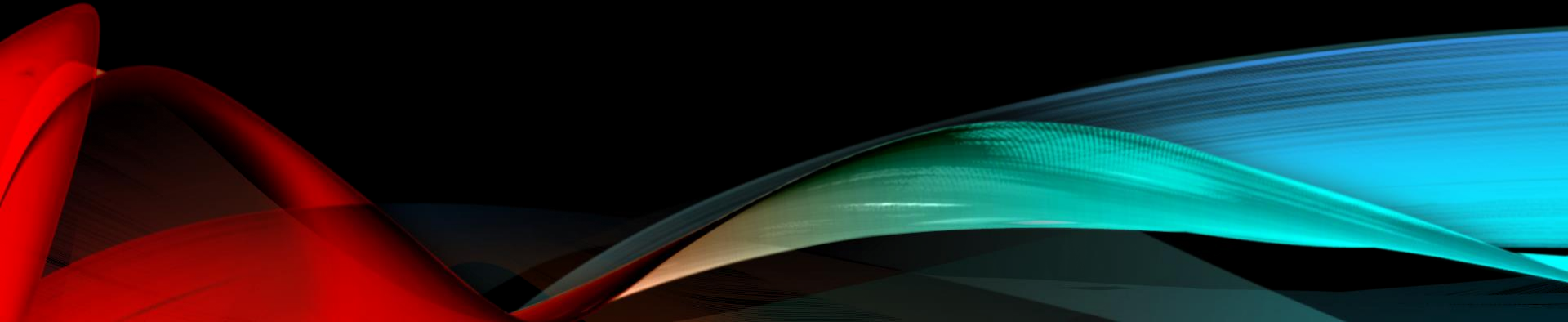


Student Award Winner

- 7 students won Poster Award.
 - 6PT5: [Ryotaro Kiyoku](#) (Osaka University), "EVALUATION OF HOT CRACK SUSCEPTIBILITY IN MULTI-PASS WELDS OF REDUCED ACTIVATION FERRITIC/MARTENSITIC STEEL F82H USING LONGITUDINAL VARESTRAINT TEST"
 - 6PT58: [Alexandra Cackett](#) (UK Atomic Energy Authority), "Spherical Indentation and the Size Effect in Copper-Chromium-Zirconium"
 - 7PT23: [Kohei Tsuchida](#) (Tohoku University), "Recrystallization Behavior of Hot Rolled Pure Tungsten and Its Alloy Plates during High Temperature Annealing"
 - 7PT104: [Moeki Matsunaga](#) (Shizuoka University), "Lithium-lead corrosion behavior of erbium oxide and zirconium oxide coatings fabricated by metal-organic decomposition"
 - 8PT31: [Janina Schmitz](#) (Forschungszentrum Jülich, IEK-4, Germany/Ghent University), "SMART ALLOYS AS ADVANCED PLASMA-FACING MATERIALS FOR FUSION REACTORS"
 - 8PT96: [Dan Sun](#) (School of Physics, Dalian University of Technology), "Ab initio investigation of Helium at Y2O3 cluster in the ODS steel"
 - 8PT111: [Zhang Xuesong](#) (Beihang University), "Atomistic simulations of nanoscale tungsten cluster: from structure, energetics to melting properties"

Technical Summary Talk

Ryuta KASADA, Vice Chairman of Executive Committee



Contributed by...

- T. MUROGA, A. KIMURA, T. HINOKI
 - Plenary Lectures
- Y. YAMAMOTO, D. HAMAGUCHI, T. NAGASAKA
 - Ferritic/martensitic steels
 - Advanced steels & ODS steels
- M. NAKAMICHI
 - Environmental Effects
- H. TANIGAWA
 - Advanced Materials & Fusion-Specific Application of Materials
- Y. MATSUKAWA, HATANO, H. KISHIMOTO, S. KONDO
 - Fundamentals of radiation effects and advanced characterization
- S. NOGAMI, Y. OYA, S. O'hira
 - Plasma facing materials and High heat flux materials
 - Tungsten, refractory alloys and other high-Z materials
- T. MUROGA
 - Materials technologies and testing in IFMIF, ITER and beyond, and Materials design interface issues
- N. HASHIMOTO
 - Ceramics, ceramic composites, SiC/SiC composites and other low-Z materials
- M. SATO, Y. WATANABE
 - Multi-scale modelling

Special lectures

- Ikeda from QST, Japan presented a comprehensive overview for **BA** and **Japanese TBM**. Plan and prospect for **A-FNS** program was discussed.
- Matsuura from MEXT, Japan reported general **Japanese fusion program overview**, such as ITER, BA, LHD, Laser and DEMO oriented program including Japanese roadmap. **Future plan of BA and possible participation from the countries other than Japan and EU** were discussed.

Ferritic/martensitic steels

- (PL) Achievement of F82H in BA activity by Dr. Hiroyasu Tanigawa
 - Fabrication technologies, including ESR method for removing inclusions,
 - Irradiation database and modeling/simulation prediction methods of materials behavior under fusion neutron irradiation
 - Basic engineering for material property and the structural designing interface focusing on the reduction of ductility as the design limit of the highly damaged structure. The prediction of the critical condition to distinguish the effect of fusion and fission neutron irradiation effects is inevitable.
- Material database
 - Efforts to create EUROFER97 databook in Europe
- Neutron irradiation
 - Atomistic modeling results of defects properties under neutron irradiation on ferritic/martensitic alloys were discussed with experimental results obtained by MEGAPIE and TWIN-ASTIR irradiation programs.
- Ion irradiation
 - The effects of He on defects production as well as on mechanical properties was discussed from the results obtained by dual ion-beam irradiations.
 - Synergetic effect of H with He and displacement damage on swelling as well as on irradiation hardening by means of triple ion-beam irradiations was discussed.
- New F/M steel
 - Recent progress on the development of new PWHT-free bainitic steel for lifetime structural component applications in next generation fusion devices was reported.

ODS steels

- (PL) Overview of international R&D of ODS-F/M steels by Dr. Jean Henry
 - Fabrication (with a focus on **recrystallization** processes)
 - Mechanical properties (in-situ studies of **deformation mechanisms**)
 - High dose irradiation behavior and **He management**.
 - The status of alternative ODS fabrication routes, which do not involve mechanical alloying, or based on **additive manufacturing** techniques.
 - Remarkable progress has been achieved for these decades. The next issues of concern are **fracture toughness** and **joining technologies**.
- Fabrication
 - Castable Nanostructured Alloys
 - **Large scale production** of 14%Cr ferritic ODS alloys for First Wall mock-up fabrication
 - Nitrogen and carbon as process control agent (PCA) for mechanical alloying (MA) of austenitic ODS steel.
- Controlling nano-oxide particles
 - **Zr/Ti synergy mechanisms** important to keep fine particles in ODS steels. (Zr suppresses Al-induced particle coarsening and enhance defect fluorite formation with the synergy.)
 - Nitrogen effect on the ferrite phase formation and strength of 9Cr-ODS steel. (Nitrogen should be less than the current specification concentration, 0.07 mass%, to avoid loss of ferrite phase with high-density nano-particles.)
- Creep mechanism
 - **Grain boundary sliding** for Y-Al, Y-Ti and Y-Zr ODS steels.
 - Creep properties of FeCrAl (Zr) ODS steels and their **compatibility with Pb-Li**. 10-12Cr-5Al-Zr ODS steel exhibited good creep property and compatibility at 700C and above.
 - Creep deformation mechanism and irradiation damage of MA957
- Irradiation effects
 - HFIR irradiation on RAFM, classic ODS MA957 and Nanostructured Ferritic Alloys (NFA) up to 39-87 dpa at 300-500C. **NFA exhibited the lowest neutron irradiation embrittlement** at 300-330C.

Plasma facing materials and High heat flux materials (1/2)

- (PL) Progress of the European research programme by Dr. Michael Rieth
 - The changes in divertor conceptual design strategy
 - Recent developments in the area of DEMO divertor materials, including 1) heat sink materials, Cu alloys, 2) W materials for structural and armor applications, 3) composites, 4) interlayer materials, 5) joining technology, 6) high heat flux testing, and 7) mockup production to demonstrate performance and scalability to industrial manufacturing.
 - Launch of nine neutron irradiation campaigns of which seven are dedicated to DEMO divertor materials.
- (PL) Status of world programs & research directions by Dr. Henager
 - Mechanical properties improved by composite and alloying including yttria interface composites,
 - W-Ni-Fe, W-Cu laminates and W-ZrC.
 - Models to study ductile material was developed.
 - Oxidation behavior of various W was evaluated.
 - 3D printed tungsten shapes are being.
- (PL) Recent progress of PFM and PFC in China by Dr. Luo
 - W/Cu PFCs were fabricated and evaluated to apply for EAST
- (PL) Irradiation Effect of W by Dr. Akira Hasegawa
 - Summary of irradiation data of W and W materials, stressing roles of transmutation elements, prediction of irradiation response for future fusion devices, remaining issues and on-going or future neutron irradiation program.

Plasma facing materials and High heat flux materials (2/2)

- Alloy development & characterization
 - Tungsten fiber-reinforced tungsten, W-ZrC alloy, cold-rolled, ultrafine-grained tungsten sheets and W-Re alloy with various results, such as those of post-irradiation examination, characterization (e.g. DBTT) by manufacturing process, impurity effects on embrittlement and stability, stability of He clusters, etc.
- Thermo-mechanical properties of W
 - Thermo-mechanical properties of commercially-available W-based heavy alloy (W-Ni-Fe) was studied. Similar or better properties than the pure W were clarified.
 - Thermal-mechanical response tests of tungsten plasma facing material/component with experiment and simulation are undergoing, including transient heat flux condition.
- Plasma and material interaction
 - Helium-induced nano-structure of W and other period 6 transition metals and helium retention of W in simultaneous He/H implantation were systematically investigated.
 - Evaluation of PFCs in JET is performed, which are highly contaminated. Need for the hot materials research facilities on-site at ITER is pointed out.
- Tritium retention in W
 - W plasma spray coating with fabrication control reduces tritium retention.
 - The neutron-irradiated W at high temp. reduces D retention compared to room temp., but D migration toward bulk was enhanced.
 - Neon seeding plasma exposure induces the surface modification and reduces D retention in W.
- Copper alloys for heat sink
 - Advanced copper alloys (Cu-Cr-Nb-Zr, Cu-Cr-Ta-Zr and so on) were proposed and evaluated from the viewpoint of material development and DEMO design.

Ceramics, ceramic composites, SiC/SiC composites and other low-Z materials

- (PL) Recent progress in SiC composites for Fusion by Dr. Koyanagi
 - High-dose irradiation effects on material property changes and microstructural evolution
 - Joining technology
 - Fusion-fission cross-cutting research assessment of SiC components.
- Progress and R&D on SiC and SiC matrix composites for fusion, fission and others were presented and discussed on, especially corrosion mechanism, joining method, microstructure evolution in irradiated SiC.

Advanced Materials & Fusion-Specific Application of Materials

- **Advanced materials**
 - High irradiation resistance of High-Entropy Alloys (HEA), such as TiVZrHfTa, was reported.
- **Neutron Multiplier**
 - High potential of new advanced neutron multiplier, Be₁₃Zr, was reported.
- **V-alloy**
 - Void formation suppression by formation of TiX (X:C,O,N) by high Ti addition on V-4Cr alloy was reported.
- **Irradiation effects on optical materials**
 - Best neutron irradiation resistance was reported on Sapphire samples after irradiation.
- **Irradiation effects on high temperature superconductors (HTS)**
 - Loss of O due to irradiation is reported as the significant phenomena in Zr-based HTS which causes the loss of superconductivity.
- **Tritium Breeder**
 - Good chemical stability, Tritium release properties, and grain stability were reported on newly developed LTZO(Li₂ZrO₃ added Li₂+xTiO₃+y).

Environmental Effects

- **Compatibility with LiPb**
 - Compatibility of **Al-forming steel** in flowing PbLi at 450-650 °C with temperature gradients was presented including the effect of pre-oxidation on the surface of steel.
 - The corrosion mechanism in LiPb and D permeation behavior of the **multi-layered coating of Er₂O₃-Fe** had been investigated.
- **Compatibility between solid breeders and RAFM**
 - The **effect of purge gas contents** on compatibility between breeders such as Li₄SiO₄ and Li₂TiO₃ and EUROFER steel was evaluated.
- **Effect of ion irradiation on D retention of RAFM**
 - The effect of irradiation damage in the surface and the bulk region of steel by high-energy ion irradiation on **D retention of CLF-1** steel was evaluated.

Materials technologies and testing in IFMIF, ITER and beyond, and Materials design interface issues

- **Materials Technologies in ITER**

- (PL) Melola explained current status and details of ITER in-vessel components.
- Barabash reported polymer related issues for ITER components. Difficulties in estimating radiation dose, including gamma, was pointed out.

- **Fusion neutron sources**

- Ochiai presented **A-FNS** neutron source program. Framework of the project (Japan only or by Japan-EU collaboration) and budget prospects were discussed.
- Mao, replacement of Wu, presented 14MeV neutron source program in China, **HINEG-I, II, III**. Tritium control issue and lifetime of the targets were discussed.
- Ibarra reported **IFMIF-DONES** program, d-Li neutron source program in EU. Use of the middle flux area and safety with respect to Li-water reaction were discussed.
- Kessell, replacement of Rowcliffe, reported materials issue for **FNSF**. Scheduling of DEMO and FNSF was discussed.

- **Materials design interface issues**

- Mahler reported **Creep-Fatigue assessment of EUROFER97**. The number of cycles applied to the material under operation is discussed.

Fundamentals of radiation effects and advanced characterization (1/2)

- (PL) Dynamic properties of radiation-produced defects in metals by Dr. Arakawa
 - Radiation defect behaviors were researched on W, Fe, Ni by **in-Situ TEM in ion and electron irradiation** environments.
- **Microstructural evolution under irradiation**
 - TEM analysis on the fundamental process of defect cluster formation, specifically, the formation of dislocation loops in bcc-Fe by using advanced characterization techniques such as **convergence weak beam diffraction**.
 - **Sink effects of various GBs** in F82H and microstructure evolution under irradiation.
 - Simulation and mechanism of radiation damage reduction in **equiatomic multicomponent single phase alloys**
 - Irradiation-induced defects on W were researched by the self-ion irradiation experiments.
 - Neutron irradiation effects for defect clustering and dispersed oxides on ODS Eurofer precisely researched by advanced microstructural methods.
 - Phase stability of nanoscale precipitates in binary alloy was studied by TEM and MD.
 - Computational results on the formation process of athermal solute defect clusters was reported.
 - Data analytics applied to experimental results of X-ray method and Transmission Kikuchi diffraction on SEM to extract more microstructural data.

Fundamentals of radiation effects and advanced characterization (2/2)

- He/H(D, T) effect

- First principle modeling of hydrogen behavior in Be and experimental validation.
- Interactions of He and displacement defects in neutron-irradiated Fe, W and SiC, investigated by TEM, TDS, LIBS, positron etc.
- Simulation of hydrogen trapping and transport at dislocations in alpha-Fe.
- Effects of SIA and He on stress-driven GB migration via atomistic simulations.
- The effect of Fe-ion irradiation on the permeation behavior of deuterium in yttrium oxide coating.
- Dislocation loop and bubble formation behaviors on Eurofer were researched using dual ion irradiation experiments, microstructural method and rate theory calculation.
- Strong correlation between D binding energy & various types of defects were reported.
- Irradiation and helium effects of RAFMs steels were investigated using Ni-58 doped steels irradiated at HFIR.
- Re-irradiation and bootstrap approaches, and “Lab-on-a Chip” irradiation opportunity are introduced for the evaluation of DPA and helium accumulation effects.

- Micro-mechanics

- Advanced characterization on the mechanical properties of ion-irradiated F82H steels by means of **nanoindentation and micro-pillar compression**.
- **Barrier strength of defect clusters and helium bubbles** produced in F/M steels by irradiation was experimentally determined and compared with computer simulations using molecular dynamics codes.
- **In-situ mechanical behavior of the ion irradiated micro-pillar W** was reported.

Multi-scale modelling

- (PL) Overview of modeling PSI in W by Dr. B. Wirth
 - Modeling the performance of divertor PFCs to investigate the surface evolution of tungsten such as fuzz and He bubble dynamics inside exposed to low-energy He and H.
 - Comparison of these modeling results with experimental results are discussed
- Advanced multi-scale modelling approaches for microstructural evolution under irradiation
 - SAAMD (self-adaptive accelerated molecular dynamics), BigDFT (linear scaling DFT), object kinetic MC+FP+MF (mean-field model), continuum mechanics+FP+MD, object kinetic MC+ALTE(anisotropic linear theory of elasticity)+MS (molecular statics method).
 - Mechanism to release the localized stress thorough emission of small loops from a larger loop in iron.
 - Diffusion mechanisms and the kinetic coupling between solutes and defects in tungsten.
 - Free energy of W-Re-Os alloys.
 - Correlation diagram of the microstructural evolution in RAFM-He.
 - Sink strength values of BCC Fe and V.
 - Understanding elastic dipole nature of crowdion defects and dislocation loops based on atomistic simulations and experiments.
- Multi-scale modeling irradiation effects on the deformation and fracture behavior
 - Dislocation dynamics simulation
 - Finite element method and crystal plasticity analysis.

Closing Address

Takeo Muroga, Chairman of Organizing Committee

