IAEA TM on Liquid metal reactor concepts: Core design and structural materials

12-14 June 2013, Vienna (Austria)

## NA DEPARTMENTAL ACTIVITIES RELATED TO NUCLEAR MATERIALS FOR ADVANCED REACTOR SYSTEMS Andrej ZEMAN NAPC / Physics section



### **Coordinated Research Project (finished)**

(1) IAEA CRP on Accelerator Simulation and Theoretical Modelling of Radiation Effects, joint NA-NE (2008 – 2012).

Objectives: *Study of issues related to the proton and ion beam irradiation in order to mimick the high dpa neutron damage.* 

Following specific issues have been addressed:

- Better understanding of radiation effects and mechanisms of material damage and basic physics of accelerator irradiation under specific conditions,
- (2) Improvement of knowledge and data for the present and new generation of structural materials,
- (3) Contribution to developmental of theoretical models for radiation degradation mechanism,
- (4) Fostering of advanced and innovative technologies by support of Round Robin testing, collaboration and networking.



### **Coordinated Research Project (finished)**

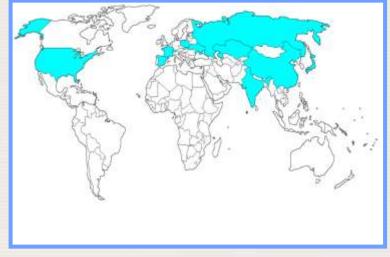
IAEA CRP on Accelerator Simulation and Theoretical Modelling of Radiation Effects (joint NA-NE)

**CRP members:** BEL, CHN, EC, FRA, IND, JAP, KOR, KAZ, POL, RUS, SPA, SVK, SWZ, UKR, and USA, (18 labs).

Theoretical and experimental studies have been focused on:

- Nature of radiation effects in materials (En > 1MeV) and ion beam simulation of high dpa damage in metallic structures.
- Multi-scale modeling and application of available tools in order to study processes an phenomena at atomiclevel, as well as nano-structural and micro-chemical evolution, and mechanical behavior.
- Correlation of theoretical models with experimental data (verification).





### **Coordinated Research Project (finished)**

CRP member	Austen.	ODS	Model alloys	FM	RPV
Belgium/SCK		1,2,3,4,5,6	2,3,6	2,3,4,5,6	
China/CIAE		3	3,6	3,6	
France/CEA		5	2,3,5		
France/EDF			2,3,6		
Holland/JRC		1,2,3,4,5,6	2,3,6	2,3,4,5,6	2,4,5,6
India/BARC			2,6		2,4,5,6
Poland/IAE	3,6				
Russia/IPPE	3,4,5	3,4,5	3,4	3,4,5	
Russia/KI		1,2,3,4,5,6			
Slovakia/STU		1,2,(3)	2,(3)	2,(3)	
Spain/IFN		1,2,3,4,5,6			
Switzerland/PSI		6	6	6	
Ukraine/KIPT	3,4,5, 6	2,3,4,5	2,3	2,3,4,5	
US/LANL	3, 5, 6	3, 5, 6		3, 5, 6	
US/LLNL		1,2,3,4,5,6	2,3,4		

J. PROBLEMS OF ATOMIC SCIENCE & TECHNOLOGY, 4 (62) 2009, Physics of Radiation Effect and Radiation Materials Science



IAEA Technical Meeting (TM-34567) photo

# IAEA publication in preparation (2013), it will summarise all experimental data and results of theoretical modelling of research work.

 Primary damage, cascade and sub-cascade formation; 2) Irradiation activated kinetic processes; 3) Void and gaseous swelling, including He+H synergisms; 4) Radiation induced segregation; 5) Phase stability (precipitation) under irradiation;
 Irradiation effects (incl. He) on mechanical properties (embrittlement, hardening, creep...)



(2) IAEA CRP on Benchmarking of advanced materials preselected for innovative nuclear reactors, Joint NA-NE (2011 – 2014) Critical review of recently developed ODS steels in terms of macroand microstructural properties and other important features.

- MS demand regarding R&D of str. Materials via coordinated mechanism.
- Performance testing of materials pre-selected for primary components of new innovative reactor systems.
- Round Robin testing of various ODS grade steels; application of techniques.
- Assessment and harmonisation of methods, (sub-size samples, in-situ experiments, computer modelling, etc.).
- > Application of computer modelling for understanding of specific issues.
- Project launched, 1<sup>st</sup> meeting took place <u>2-6 May 2011, Vienna!</u>





**Participating labs:** AUS, CHN, CZR, FRA, GER, IND, ITA, JAP, KOR, NET, ROM, RUS, SPA, SVK, UKR, USA; and EC.

Supply of ODS-grade steels for CRP Round Robin: ORNL (14YWT), Bochvar (EP450 ODS), KAERI (12Cr), IGCAR (9Cr), Kyoto Uni (9 and 16Cr), USTB (12, 14, 18Cr), KIT (EUROFER ODS).

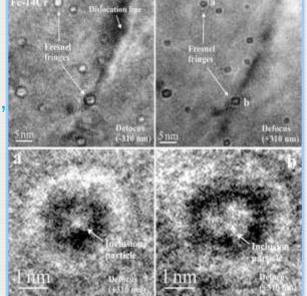
#### Main objectives:

- Development and harmonization of test procedures (pre-qualification phase).
- Test matrix developed during RCM, principle same test to be carried out, at least, by 2 different labs!
- Results collected evaluated/reviewed compared verified
- Data will be compiled in form of inputs for database



- Mechanical properties: instrumented CV, HT fracture toughness (morphology), small punch, tensile tests and (micro)hardness, etc.
- Microstructure: grain size, particle size and distribution, dislocation density, tools: APT, (HR)TEM, SANS, EDX, XRD, (FE)SEM, PAS, MS, FE-EPMA, FE-Auger, etc,
- Chemical stability and interaction with coolant: oxidation/corrosion of ODS steels in Pb, Pb-Bi eutectics at elevated temp, control of oxygen, study of oxidation kinetics (weight change, scale thickness), phasestructure and composition of oxide layers, similar tests proposed for SCWR environment (O and H).
- Specific ion-irradiation tests: simulation of fission fragments (different temp and dpa), radiation stability of nano-size oxides.
- Modelling: radiation stability of oxide particles and role of this interface in the microstructural stability (limited)

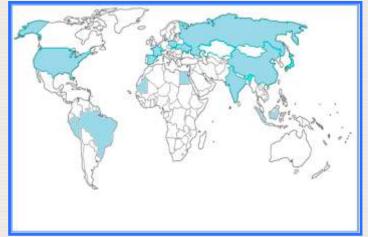




(3) IAEA CRP on Utilisation of accelerator-based real-time methods in investigation of materials with high technological importance (2012 – 2015), *AUS, ALG, ARG, CAN, CRO, FRA, GRE, IND, ITA, JAP, NET, RUS, SAF, SVK, SRB, SPA, THA, UKR, USA, VIE.* 

#### **Overall objective:**

- Increase the capacity of Member States to utilize frontline accelerator based methods in order to support their R&D needs.
- Stimulate exchange of information and best practice and to contribute to international consensus in the R&D effort related to the energy.



- Develop of a knowledgebase with recommendations for their specific real-time and in-situ characterisation of materials (methodology)
- Harmonisation of methodologies for benchmarking of experimental results in the area of materials for energy applications



IAEA CRP on Utilisation of accelerator-based real-time methods in investigation of materials with high technological importance (2012 – 2015)

### Specific objectives:

- Identification and selection of specific research issues related to energy in order to promote accelerator based techniques and their added value.
- Contribute to the solution of pending research and technological issues (incl. nuclear and structural materials)
- Combination of different experimental techniques in order to bring new data which otherwise will not be available (correlation on multiple scales) for evolution of structures of both bulk systems and thin films.
- Material containment and manipulation of sample environment;

Radiation damage/formation expected upon exposure to extreme



(4) IAEA CRP on Development, Characterization and Testing of Materials of Relevance to Nuclear Energy Sector Using Neutron Beams, joint NA-NE (2009 – 2013) 10 RCs + 9 RAs

### Specific objectives:

- Investigation and characterization of materials relevant to nuclear energy applications
- Optimization and validation of experimental and modelling methods creation of a database of reference data for nuclear materials research
- Enhancement of the capacity of research reactors for nuclear materials research

#### **Expected output:**

- Multilateral network in the field of advanced nuclear materials research
- Creation of an experimental reference database for models and calculations



IAEA CRP on Development, Characterization and Testing of Materials of Relevance to Nuclear Energy Sector Using Neutron Beams, joint NA-NE (2009 – 2013)





Examination of the radiation-induced structural changes in cladding materials, analysis of crystalline lattice structure of two cladding pin steels 16Cr-15Ni-2Mo-2Mn-Si-Ti-V-B and 16Cr-20Ni-2Mo-2Mn-Si-Ti-V-B-

- Perform neutron diffraction and SANS
  Si-Ti-V-B measurements on thermo-mechanical loaded ODS steel rods,
- Investigate residual stress in ODS friction welds,
- Perform texture analysis and investigate hydrogen uptake in zircalloy tubes,

Apply neutron radiography for nuclear fuel characterization.

## **Education & training activities**

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AEA

International Atomic Energy Agency

DIRECTORS

A. ZEMAN

(IAEA, Vienna, Austria)

V. INOZEMTSEV

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IAEA



The Abdus Salam International Centre for Theoretical Physics

Joint ICTP/IAEA Advanced Workshop on Development of Radiation Resistant Materials

20 - 24 April 2009



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Recent

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Joint ICTP/IAEA Advanced Workshop on Multi-Scale Modelling for Characterization and Basic Understanding of Radiation Damage Mechanisms in Materials

> 12 – 23 April 2010 Miramare – Trieste, Italy

The Abdus Salam International Centre for Theoretical Physics (ICTP, Trieste, Italy), in cooperation with the International Atomic Energy Agency (IAEA, Vienna, Austria), is organizing an Advanced Workshop on Multi-Scale Modelling for Characterization and Basic Understanding of Radiation Damage Mechanisms in Materials, to take place in Trieste from 12 to 23 April 2010.

The objective of this Workshop is to provide knowledge transfer and understanding of the theory and practical application of multi-scale modelling for structural materials being used, and planued to be used, in the nuclear industry. The Workshop's outcome is intended to increase the awareness of, and make more widely available, essential knowledge of basic physical processes in materials under irradiation, their characterisation, modelling and computer simulation techniques. This Workshop targets researchers with a demonstrated interest in advanced nuclear techniques and radiation materials science seeking further professional and career development.

### Further details: www.ictp.it

- Support of international and regional education and trainings.
- Cooperation with ICTP and other collaborating centres (ANL, ANSTO, RID, ELETTRA, etc.).



The Abdus Solom International Centre for Theoretical Physics

#### Joint ICTP-IAEA Workshop on PHYSICS OF RADIATION EFFECT AND ITS SIMULATION FOR NON-METALLIC CONDENSED MATTER

#### 13 - 24 August 2012

SCIP, Manager - Taison, Stale

The Abdus Salam International Contro for Theoretical Physics (ICTF) will organize the alone. Workshop to be hold at the ICTP in Triotle, from 15 to 24 August 2012.

The paragram of this reachings is to review the correct violan of ion induced enderine effects an error methodic method (a second-triver and involution), and special advanced toxicing and an indication contange pietimen for early single researchers as well as more experimented sciences in the important violent. As anglerain will be given to microstructure response and evolution, mersenant levels in these and space, encodeductions and generatives, etc. Thus usin includes the initive soft space, encodeductions and generatives, etc. Thus usin includes the segmentation exploration of computer texts. Ensuit theoretical priorityles will be granted, for alteration will be given to the application of these types of maintain specifically for directors, includes exploring remetions, electronic and muchan paratelials.

The Workshop will force on modeling and consultation approaches (Brang Collision Approximation and Mulanular Dynamics colocications with and emperational approaches into beam induced charge, this resolved, deep level insuisant sportmerspip photoistaneous or prostom manifoldation spectracogy do. The workshop will also nonnarrier reveals noted for resolve an addression damage by decisions, heavy ious and resolvers. A their overvoer on the RMD inductors will be grean including foture trends can perspectra sense for factors advections, process.

#### PARTICIPATION

Early steps researchers (primerity peet dates and PhD) students) in the field of mapping monithing and inde size physics related to the redutibles multitle based interactions are instituted to solvent; their applications. All participants should present the results of their measures tauk in the forms of a pactor. Appropriate time well be addressed for solventifidiscussions in relate to offensize further development and on operation among the participants.

Participants from all constricts that are members of the 10%, URESCO or MAEs one attend the fickets. The Workshop will be constrained in English therefore participants must have adequate hequage knowledge. Althrough the mans parapose of the Centra is to help measurements from derivinging consultance, graduate students and paral derivind attention from derekapet countries would equally benefit from the Workshop and are seconstrained to apply.

As a real, travel and aubicidence appears of the participants already in hereas by the house institution. Every effort checkle he made by sandatetts to to be any their laws in a fract half down. Canthof house will be available for some participant who are notionais of and motiong in, a devoluting gravity, and who are not more than 45 pages off. There is no engineering and motion of the source stars.

The online application from for this Workshop is available at http://telesamolial.ictp.it/bit\_staning.ata?weasi=50siars.11152

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30 April 2012



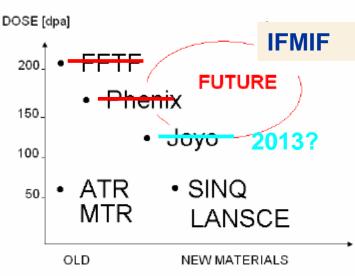
## **Recent IAEA publications**



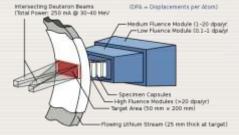


## **Material research – current issues**

- Current commercial materials not optimised (T91, MA956, HT9), new materials - only limited data available, limited information at elevated dose, temp, coolant compatibility (far from designed conditions).
- Most of candidate materials for innovative reactor concepts (ODS, SiC/SiC, etc.) are not (fully) qualified, long term process!
- Low and medium energy ion beam irradiations for study of high dpa response (only informative), due to difficult bulk analysis.
- Miniaturisation of specimens would be an option, however appropriate standards to be developed (e.g. ASTM)







## **Material research – current issues**

- Both fission reactor (GEN-IV) and fusion designs (DEMO) need advanced structural and functional materials, incl. fuel clads.
- New evolutionary materials (RAFM-ODS, Si- Al-enhanced, SiC-SiC etc.) to be tested (irradiated), however there is lack of testing facilities (MTR fast spectrum).
- Several candidate materials already available however they have to be fully tested, unfortunately access to irradiation facilities is very limited (BOR60 ~20 dpa/y, HFR ~6 dpa/y).
- Need for the International Fusion Materials Irradiation Facility (IFMIF), it is accelerator based neutron source that will use the Deuteron-Lithium stripping reaction to simulate the 14 MeV neutrons originated in the D-T nuclear fusion reactions.
- Currently, IFMIF is a proposal for joint project of EU, Japan, Russian and USA (see more: http://www.ifmif.org).





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