

*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**

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NAPC / Physics section



IAEA

International Atomic Energy Agency

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:

- (1) 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.

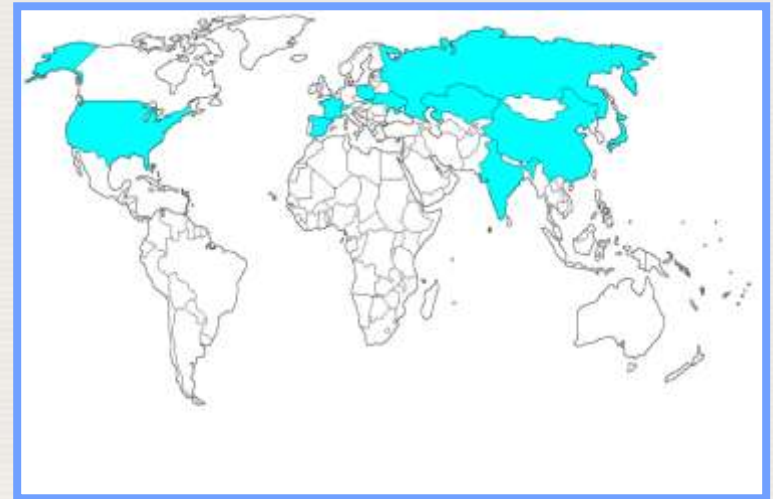
Coordinated Research Project (finished)

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 ($E_n > 1\text{MeV}$) and ion beam simulation of high dpa damage in metallic structures.
- ❖ Multi-scale modeling and application of available tools in order to study processes and phenomena at atomic-level, 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.

- 1) 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;
- 6) Irradiation effects (incl. He) on mechanical properties (embrittlement, hardening, creep...)

Coordinated Research Project (**on-going**)

(2) IAEA CRP on Benchmarking of advanced materials pre-selected for innovative nuclear reactors, Joint NA-NE (2011 – 2014)

Critical review of recently developed ODS steels in terms of macro- and 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, 1st meeting took place 2-6 May 2011, Vienna!**



Coordinated Research Project (**on-going**)

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:

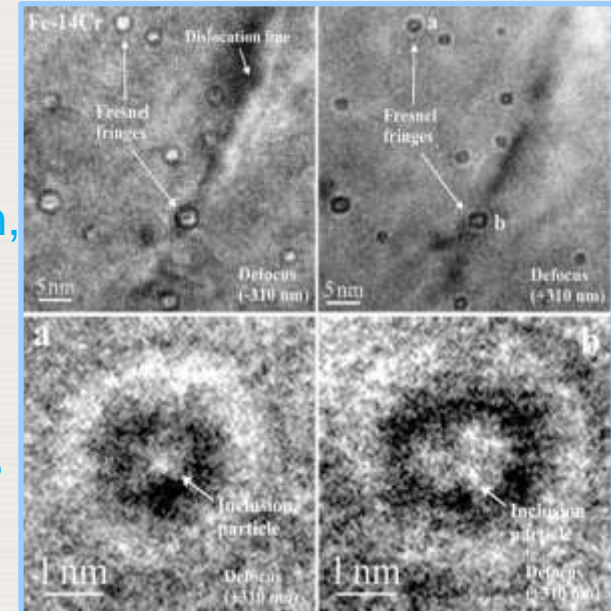
ORNL (14YWT), Bochvar (EP450 ODS), KAERI (12Cr), IGCAR (9Cr), Kyoto Uni (9 and 16Cr), USTB (12, 14, 18Cr), KIT (EUROFER ODS).

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

Coordinated Research Project (on-going)

- **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), phase-structure 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)

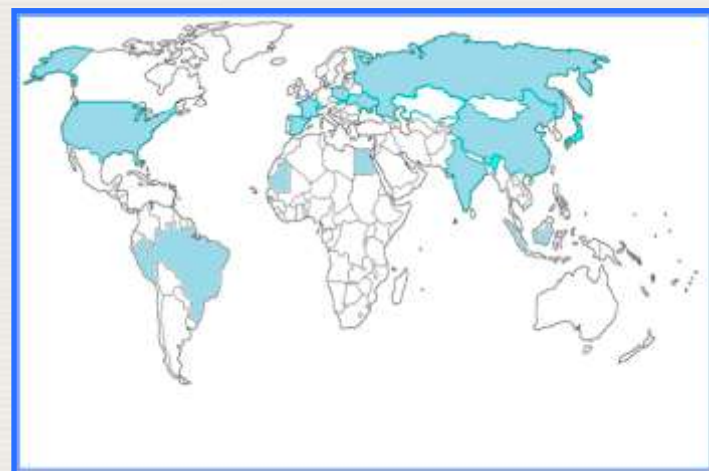


Coordinated Research Project (**on-going**)

(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



Coordinated Research Project (**on-going**)

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 environments.



Coordinated Research Project (**on-going**)

(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:

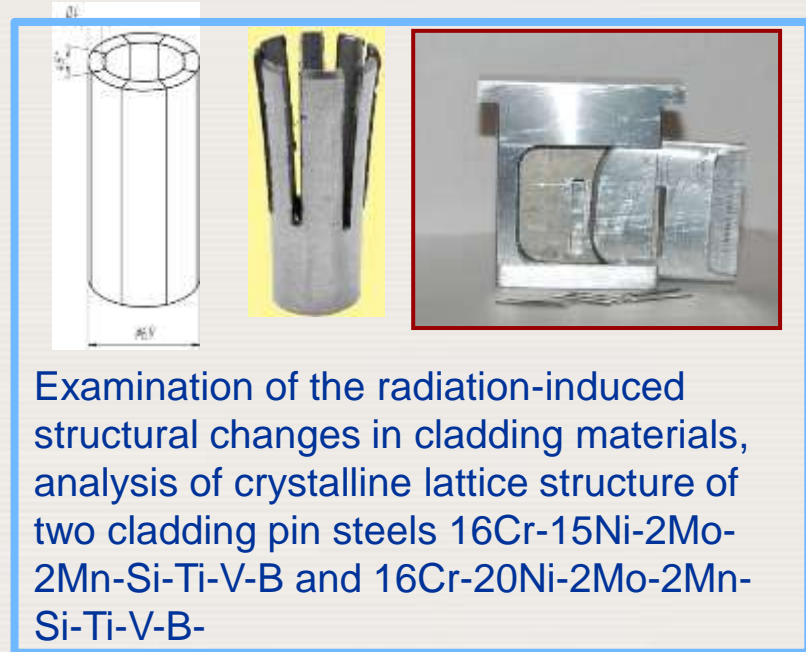
- ❖ Investigation and characterization of materials relevant to nuclear energy applications
- ❖ Optimization and validation of experimental and modelling methods creation of a database of reference data for nuclear materials research
- ❖ Enhancement of the capacity of research reactors for nuclear materials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

Expected output:

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

Coordinated Research Project (on-going)

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



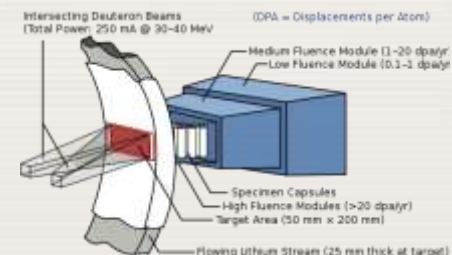
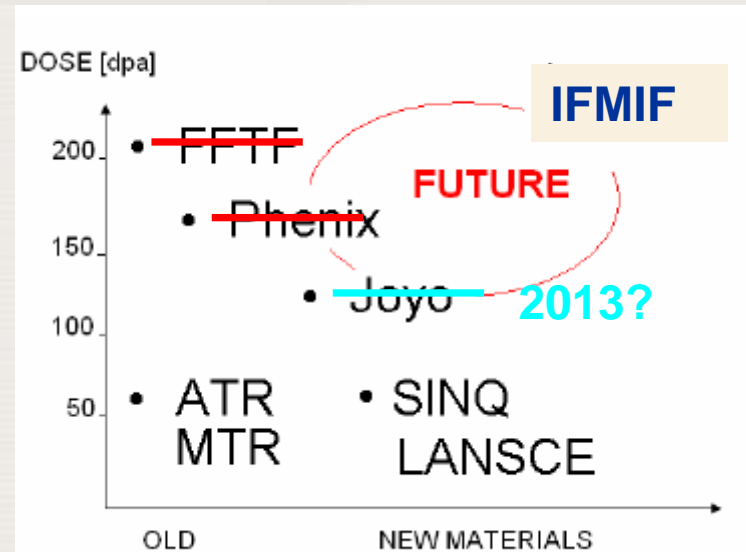
Examination of the radiation-induced structural changes in cladding materials, analysis of crystalline lattice structure of two cladding pin steels 16Cr-15Ni-2Mo-2Mn-Si-Ti-V-B and 16Cr-20Ni-2Mo-2Mn-Si-Ti-V-B-

Activities:

- ❖ Perform neutron diffraction and SANS 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.

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>).

THANK YOU FOR YOUR ATTENTION