IAEA 60 Years
Atoms for Peace and Development

IAEA Activities in Support of the Accelerator Based Simulation and Modelling of Radiation Damage Effects

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Outline

- IAEA at glance
- Physics Section
- Accelerator based simulation of radiation effects:
  - structural nuclear materials for fission reactors
  - structural nuclear materials for fusion reactors
  - structural materials for waste storage matrices

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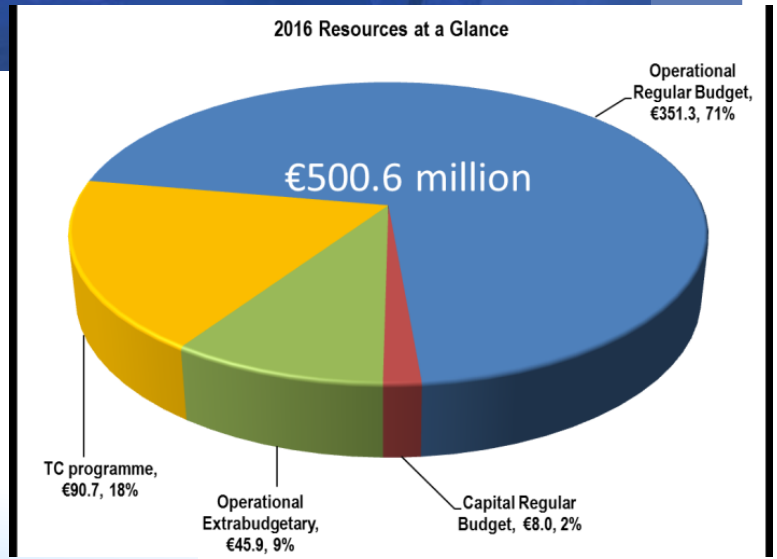
After 60 years…

- HQ in Vienna
- **Laboratories** in Seibersdorf and Monaco + Vienna
- **Regional offices** in Toronto and Tokyo.
- **Liaison offices** in New York and Geneva



Organization

- Director General's Office for Coordination (DGOC) includes the secretariat of the policy-making organs, legal affairs, internal oversight services and press and public information.
- Departments (6)

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Three Pillars - Main Areas of Activity

Safeguards & Verification

Safety & Security

Science & Technology

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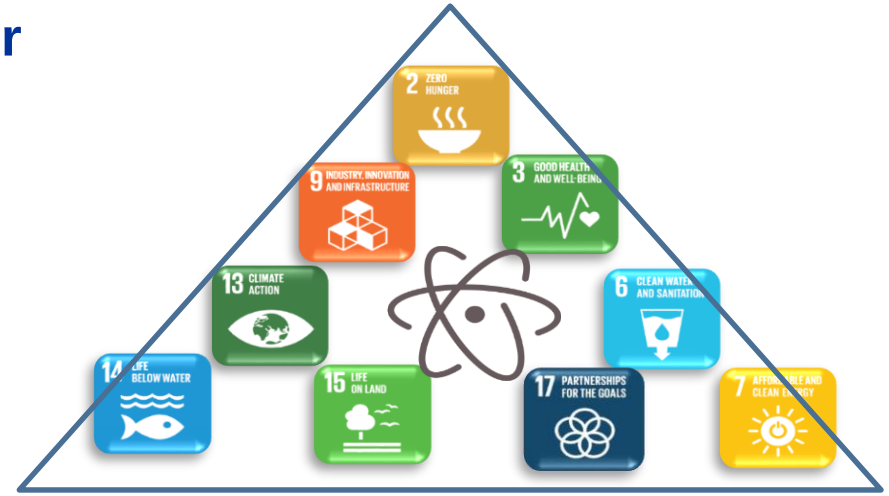
The IAEA: *Atoms for Peace and Development*

IAEA 60 Years Atoms for Peace and Development

Statute: The Agency shall seek to accelerate and enlarge the contribution of atomic energy to peace, health and prosperity throughout the world.

Mission: To assist its Member States, in the context of social and economic goals, in **planning for and using nuclear science and technology for various peaceful purposes**.

2005 : Nobel Peace Prize



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Science and Technology

Food & Agriculture

Promoting food security and sustainable agricultural development

Human Health

Improving the diagnosis and treatment of diseases and nutrition

Science & Industry

Providing knowledge & expertise for science & industry

Water Resources

Making more, and cleaner water available to more people

Environment

Understanding and protecting the environment

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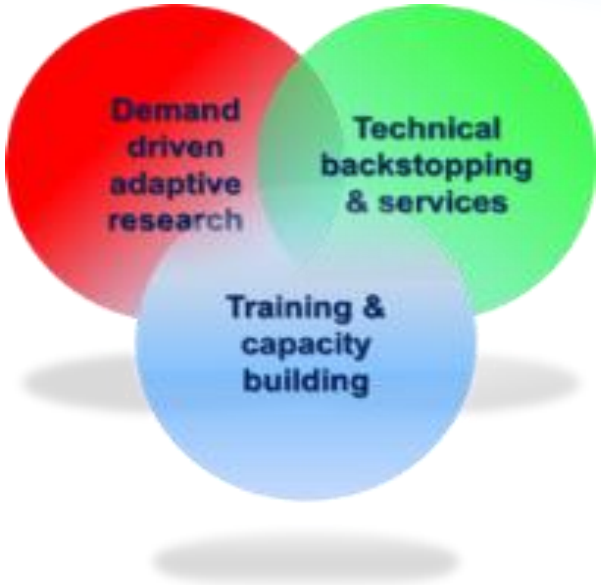
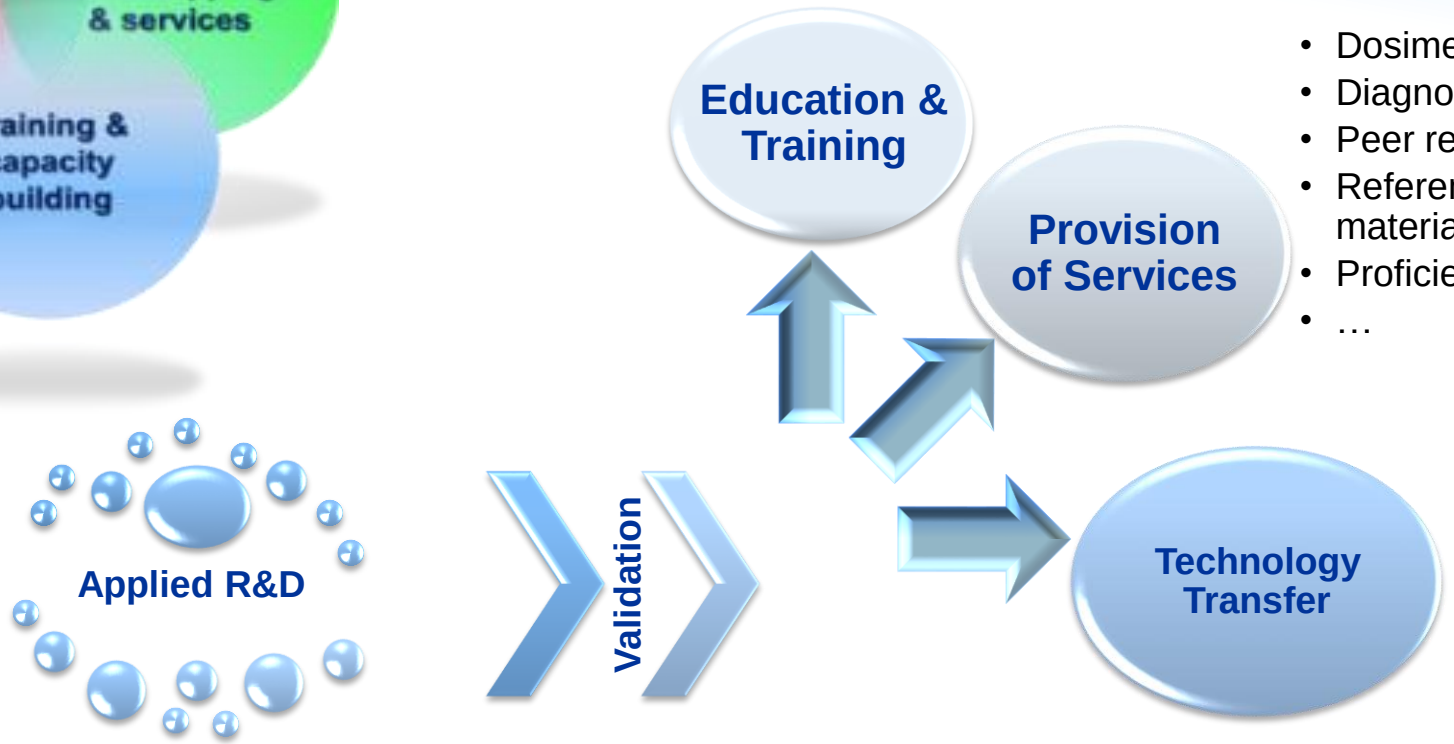
Serving Member States



- Guidelines; curriculum
- E-learning materials
- >400 trainees per year at NA labs



- Dosimetry
- Diagnostic kits
- Peer reviews
- Reference materials
- Proficiency tests
- …

- NA laboratories (12)
- Collaborating Centres (>20)
- Coordinated Research Projects (~100)

- TC PROGRAMME

- >130 developing Member States
- ~ €50 million (or ~57%) by NA

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Division of Physical and Chemical Sciences

Nuclear/Radiation Sciences & Applications

Nuclear Data

- Data Development
- Data Services
- Atomic and Molecular Data

Physics

- Accelerator Applications
- Nuclear Instrumentation
- Nuclear Fusion
- Research reactor applications

Radioisotope products and Radiation Technology

- Radioisotope production, radiotracers in industry
- Radiopharma-ceuticals
- Radiation technology applications

Water resources management

Isotope Hydrology

- Isotopic (3H) methods for Ground water assessment; prediction; models etc.

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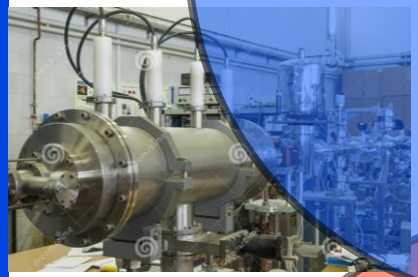
Physics Section - Programmatic Structure

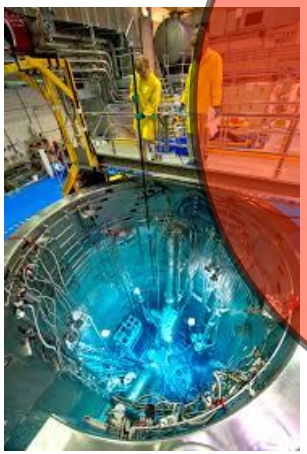
Accelerators



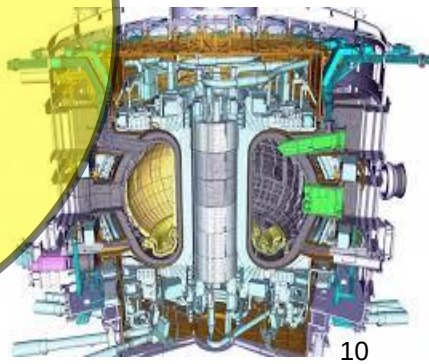
Instrumentation

Research Reactors

(Applications)



Fusion



Physics Section in Numbers

- **Staff:** 21 positions, 11@HQs & 10@Seibersdorf; plus consultants, interns, fellows; ~30-35 in total
- **Budget:** ~4M Euros RB under 3 sub-programmes; plus similar amount implemented under TC
- **TC projects:** >60 active in ~50 Member States
- **Meetings/Workshops/Schools**: >40/year
- **Coordinated Research Projects:** 15 active/new
- **Data bases/portals:** accelerators, RRs, fusion
- **Major Conferences:** Accelerators, RRs, Fusion
- **Collaborating Centers:** ANSTO and TU Delft
- **Cooperation agreements:** ITER, ELETTRA, RBI, JINR

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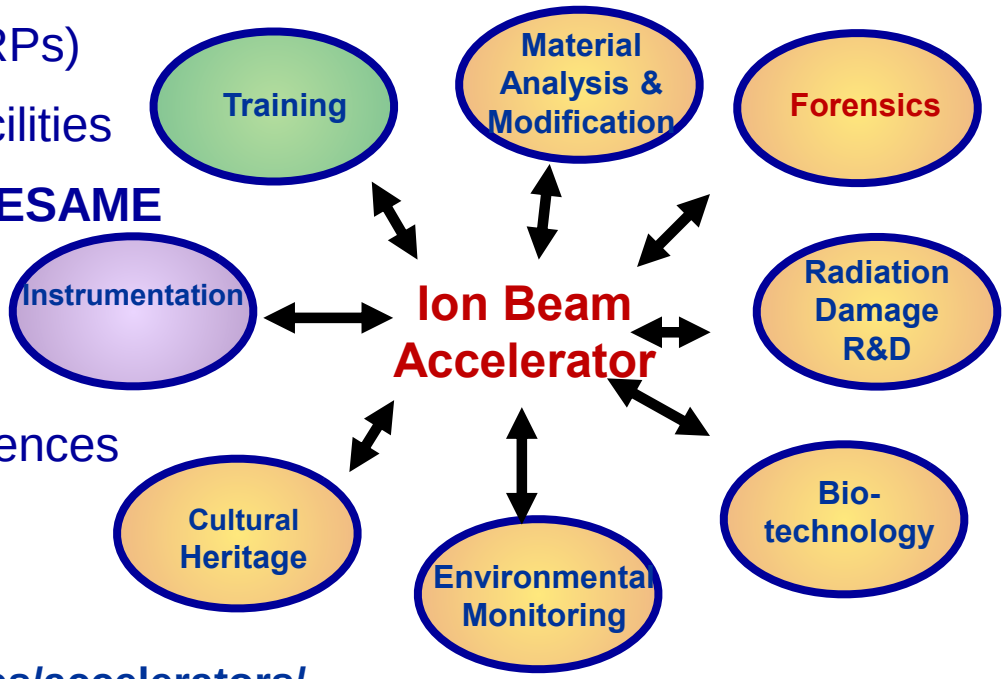
Accelerator Applications

- **Promoting benefits of the applications of particle accelerators**
  - ~ 30,000 accelerators world wide operational - 500 B$/y Business.
  - ~ 2/3 in industrial applications, 1/3 in medicine - and **~1% in basic research**
- **Focus**
  - Coordinated Research Projects (CRPs)
  - Facilitated access to accelerator facilities
    - **ANSTO & RBI; ELETTRA & SESAME**
  - Support to TC Projects
  - Outreach: Technical events; Conferences
  - Acc. Knowledge Portal – data base



https://nucleus.iaea.org/sites/accelerators/

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Background

- Future reactor designs (fission and fusion) have harder neutron spectra than “traditional” PWRs, BWRs, PHWRs etc.

- New fast reactor structural materials need to be tested that can withstand perhaps 100-150 dpa

- Need to develop materials (e.g. for fuel cladding, wrappers, plasma wall, etc.) capable of withstanding such exposure

⇒ Very few fast neutron test reactors available for irradiation of candidate materials

⇒ No compatible fusion (14MeV) irradiator yet

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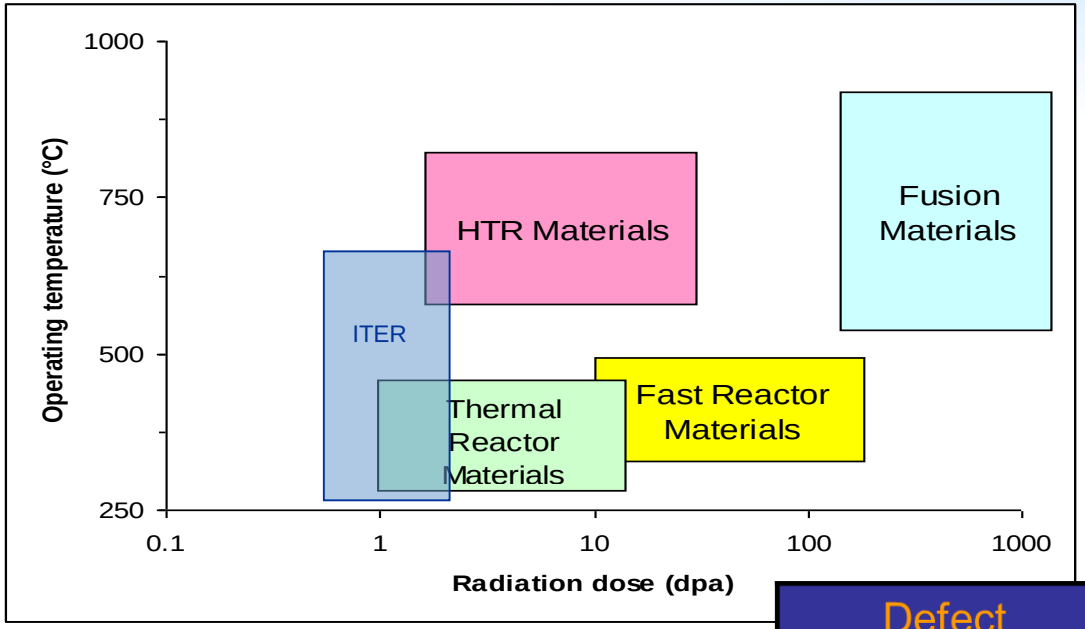
Materials challenges



Defect poduction (in steels)	Fusion neutrons (3-4 GW reactor, first wall)	Fission neutrons (BOR 60 reactor)
Damage rate [dpa/year]	20-30 ☺	~ 20
Helium [appm/dpa]	10-15 ☹	≤ 1
Hydrogen [appm/dpa]	40-50 ☹	≤ 10

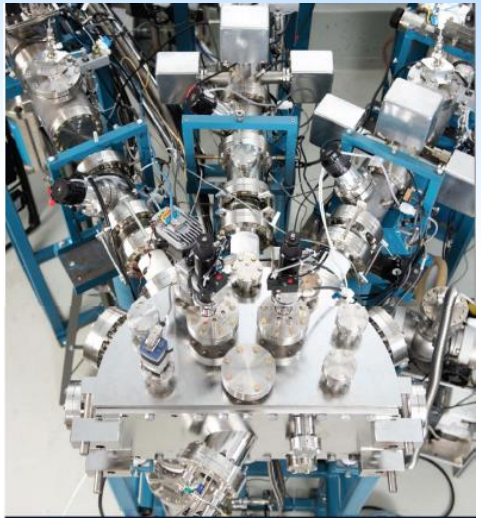
Possible solution?

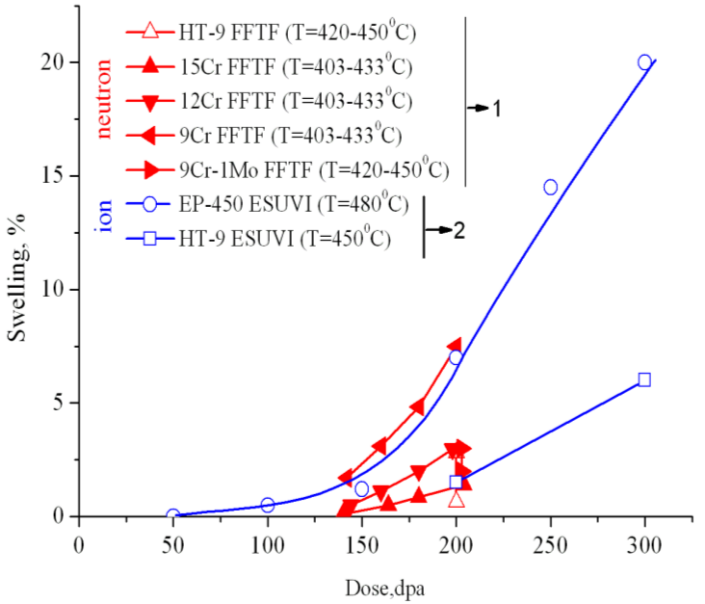
Accelerated testing with ion beams:

- Very high dose rates possible
- Good control over *T,* etc.

- Capable of generating the equivalent responses: dislocation loop densities, swelling, etc.

- Capable of simulating displacement & gas production in various proportions as a proxy for variable neutron spectra: H_2 for (n,p), He for (n,α) via simultaneous heavy ion, proton, alpha beams



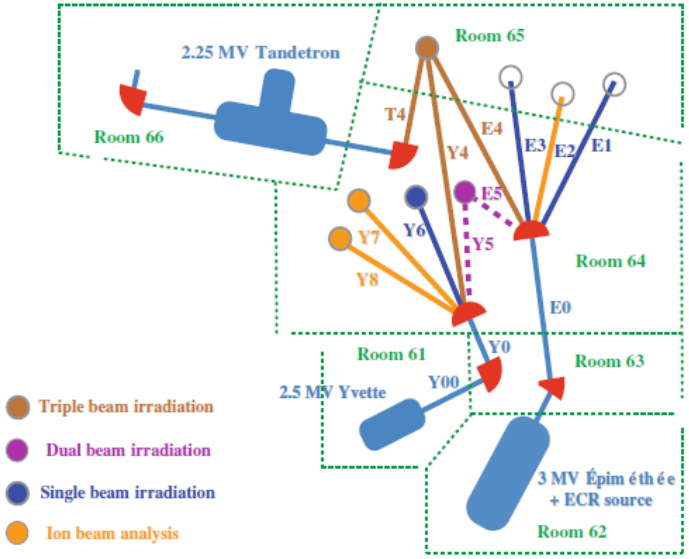


V. Voyevodin et al, KIPT, Ukraine

JANNuS

The project gathers two independent ion beam facilities:

A triple irradiation facility at **Saclay**:



3 MV PelletronTM from NEC (Épiméthée)

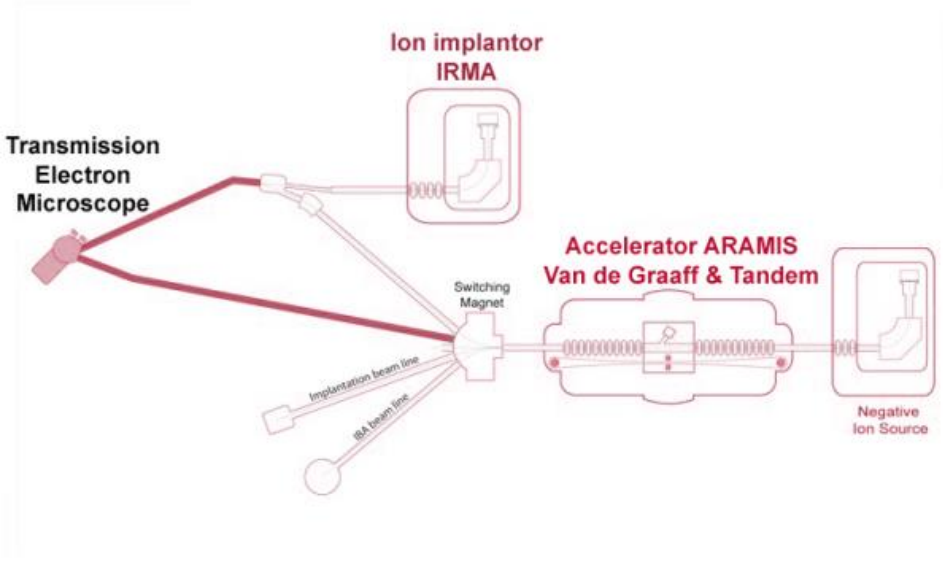
+

2.5 MV Van de Graaff (Yvette)

+

2.25 MV tandem (Tandetron)

A TEM-coupled dual beam facility at **Orsay:**



200 kV TEM TECNAITM from FEI

+

2 MV Van de Graaff/tandem (Aramis)

+

190 kV ion implantor (Irma)

Irradiations performed in relation with Fusion programs

EFDA:

- Single beam (Fe) and dual beam (Fe + He) irradiations of W alloys (collaboration with M.F. Barthe CEMHTI Orléans)

  One week, - 80°C, 6 x 10^{15} Fe/cm^2, 1 x 10^{16} He/cm^2

- Single beam (Fe) and dual beam (Fe + He) irradiations of Fe-Cr alloys (collaboration with R. Schaüblin CRPP/EPFL Villigen)

  Two weeks, room T and 500°C, 0.7 – 5 dpa (Fe), 75 – 1000 He appm/dpa

FEMAS:

- Single beam (C) irradiation of SiCf/SiC (collaboration with M. Ferraris POLITO Torino)

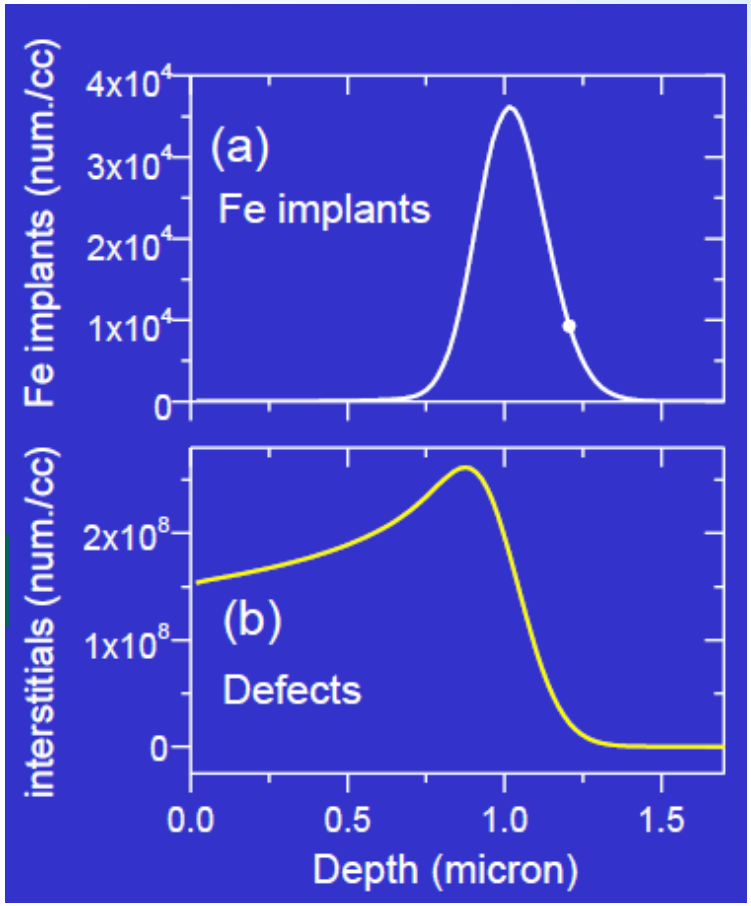
  Two days, room T and – 100°C, 1 x 10^{15} C/cm^2

- Single beam (Fe) irradiation of Fe-12Cr ODS prepared by T. Leguey (Univ. Carlos III Madrid)

  24 hours, room T, 5 x 10^{15} Fe/cm^2

Some open issues remain…

- Dose rate - dose -*T* relationships
- Injected interstitials
- Shallow penetration
- Surface versus bulk stress states
- Surface as a sink for defects



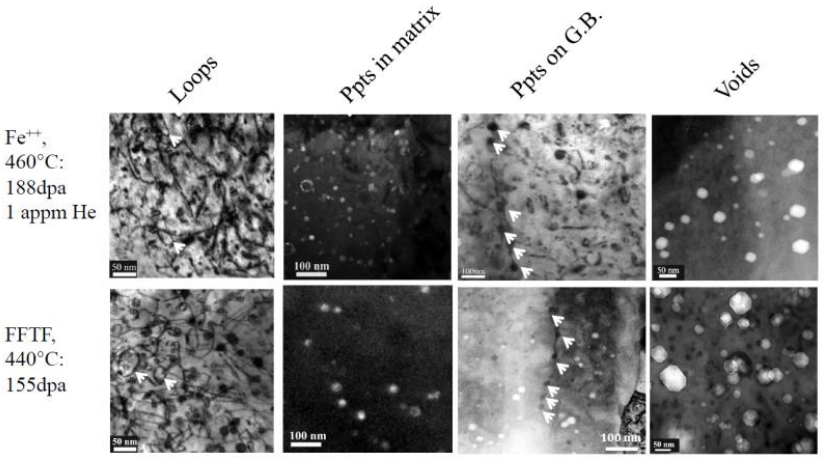
Many processes not fully understood ⇒

need for more comprehensive study through combination of experiments, simulation, theoretical models, basic cross-sections, etc.

Nutshell: Ion beam irradiation as a proxy for accelerated reactor testing

The idea is well known and long standing. But, very few well-controlled tests around.

Success in matching neutron-irradiated microstructure:
FFTF and Fe^{++}



Need for Round Robin inter-comparison under controlled testing of various parameters to determine best practices for (i) study of radiation damage (ii) reactor irradiation emulation

For selected materials there is one distribution source

Every material is irradiated at multiple different sites around the world

For every selected PIE technique, there is one laboratory

IAEA CRP on Accelerator Simulation and Modelling of Radiation Effects (SMoRE-2)

- **Status**
  - IAEA CRP T114003 (2016-2020), based on results of CRP SMoRE-I (2008-2012)
  - Jointly by NA and NE Departments
  - Consultants Meeting was held in January 2016
  - RCM-1: March 27-30, 2017 in Vienna
  - RCM-2: November 24-28, 2018 in Vienna
  - Collection and preparation of all data (SMoRE Project website): https://nucleus.iaea.org/sites/nefwprojects/CRPT14003/SitePages/Home.aspx.
- **Participants** (17 organizations from 11 MSs)

  Australia (ANSTO), Belgium (SCK-CEN), France (CEA, CNRS), Germany (Helmholtz-Zentrum Dresden-Rossendorf), India (IGCAR), Japan (Kyoto University), Russia (IPPE, ITEPh, KI), Spain (CIEMAT), Ukraine (KhIPT), UK (UKAEA, University of Manchester), USA (Texas A&M University, University of Michigan, University of Tennessee)
- **Observers**

  OECD-NEA

SMoRE-2: Round Robin (1/3)

Aims:

- Determination of the reproducibility of microstructures under “identical” ion beam irradiations around the world. (Group 1- standard protocol);
- Variation induced by slight changes to the irradiation protocol (Group 2);
- **Inter-comparison of microstructures produced under irradiation by ions (single and dual beams) and fast neutrons;**
- Summarize best practices for ion beam irradiation from analysis of project’s results.

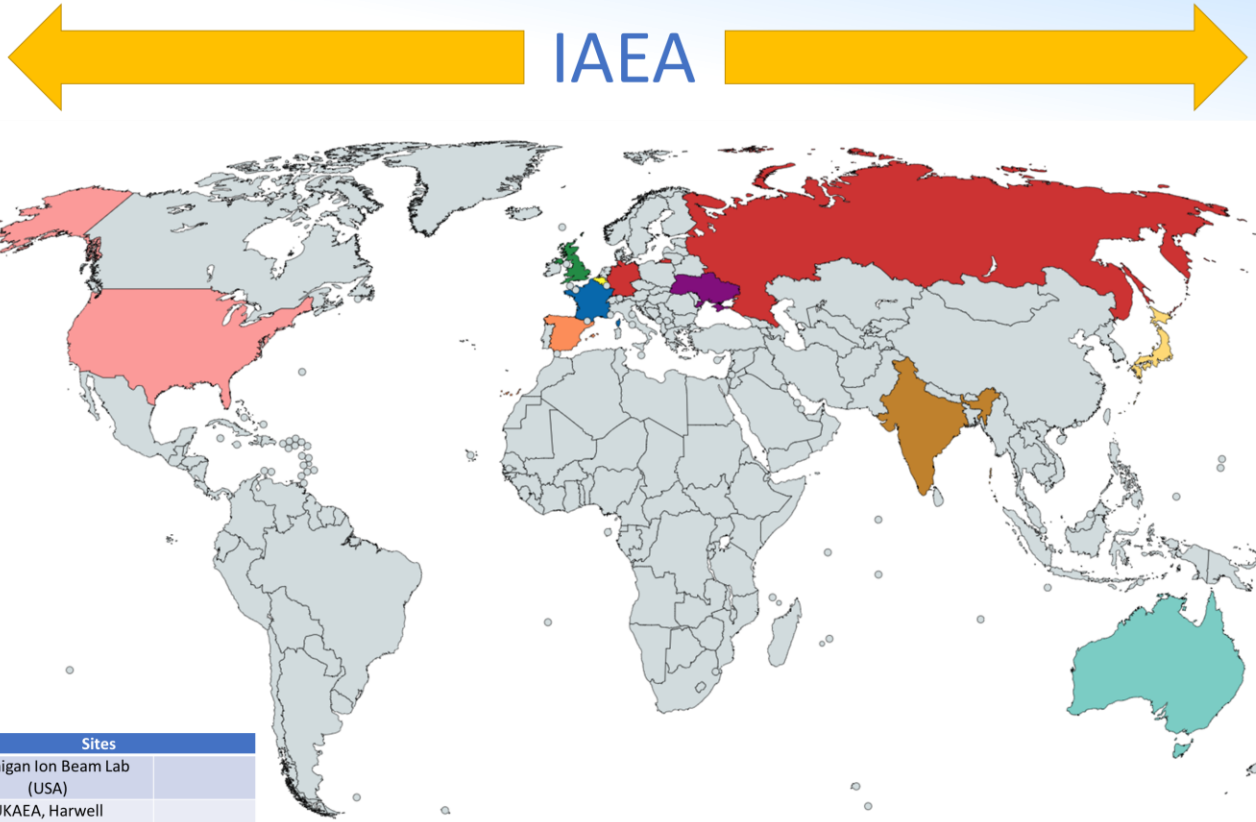
Material Selection

- BOR-60 irradiated sample available;
- Unirradiated material from the same billet available (G Was, MIBL);
- Broad interest: potential applications of **T91** include LWR, fast reactors, and fusion.

Dose selection

- **35 dpa (available from the BOR-60 sample)** is high enough to generate several defect types and a complex microstructure for comparison.

SMoRE-2: Round Robin (2/3)



17 organizations from 11 Countries

Analysis	Sites	
NRA-C	Michigan Ion Beam Lab (USA)	
Fine FIB/ion polish	UKAEA, Harwell (UK)	
TEM (obs, analysis)	CIEMAT (Spain)	SCK.CEN (Belgium)
PAS, APT	Université de Rouen (France)	

Radiation	Sites						
Neutron	BOR-60 (Russia)						
Standard Ion Beam Protocol	Jannus (France)	Helmholz-Zentrum Berlin (Germany)	DuET (Japan)	Dalton Cumbrian Facility (UK)	University of Tennessee (USA)	Michigan Ion Beam Lab (USA)	Texas A&M (USA)
Modified Ion Beam Protocols	Kharkov Institute of Physics and Technology (Ukraine)	ANSTO (Australia)	Institute of Physics and Power Engineering (Russia)	Institute for Theoretical and Experimental Physics (Russia)	Indira Gandhi Centre for Atomic Research (India)	Kurchatov Institute (Russia)	

SMoRE-2: Round Robin (3/3)

Protocol:

Ions: 5 MeV Fe^{2+} ions

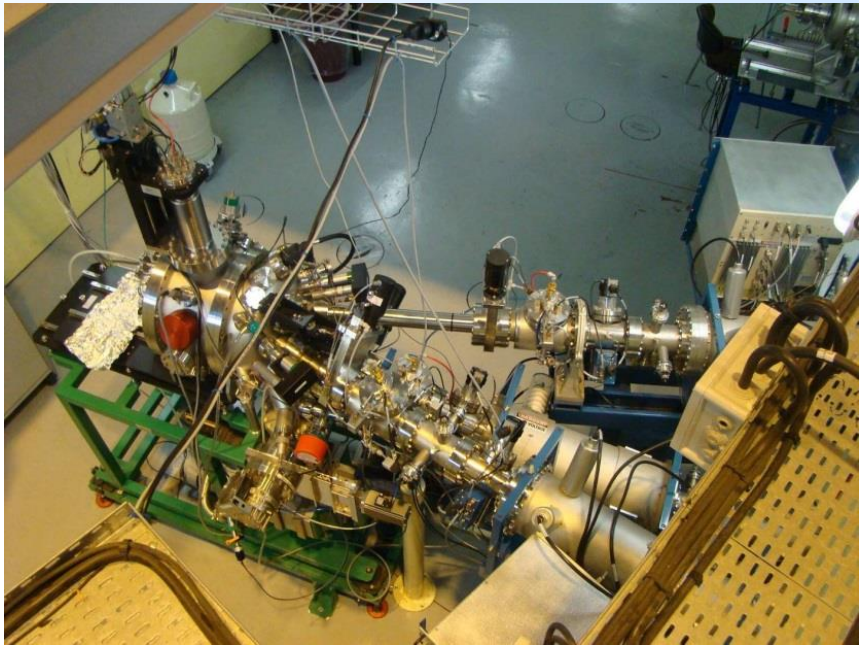
Dose rate: 10^{-3} dpa/s

Dose: 35 dpa (NRT)

Peak dose depth: 500 nm

Temperature: 445°C

Vacuum < 10^{-7} Torr



Current status:

Most irradiations are complete

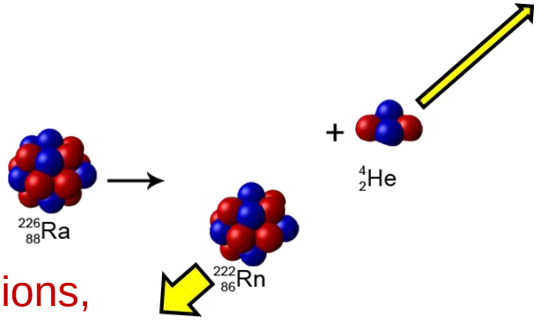
Samples are currently being prepared for PIE

Completion: Expected in 2019

CRPs are meant to focus on problems of world interest and bring together parties who otherwise may have few chances to work together. Such studies are only possible due to the great willingness of the CRP participants at all stages of the project: design, material provision, and donation of time.

Outlook (1/3)

- Start of a new IAEA CRP **Ion Beam Irradiation for High-Level Nuclear Waste form Development**
- Better understanding and predictability in the behaviour of high-level waste forms through their operational lifetimes due to the damaging effects of self-irradiation



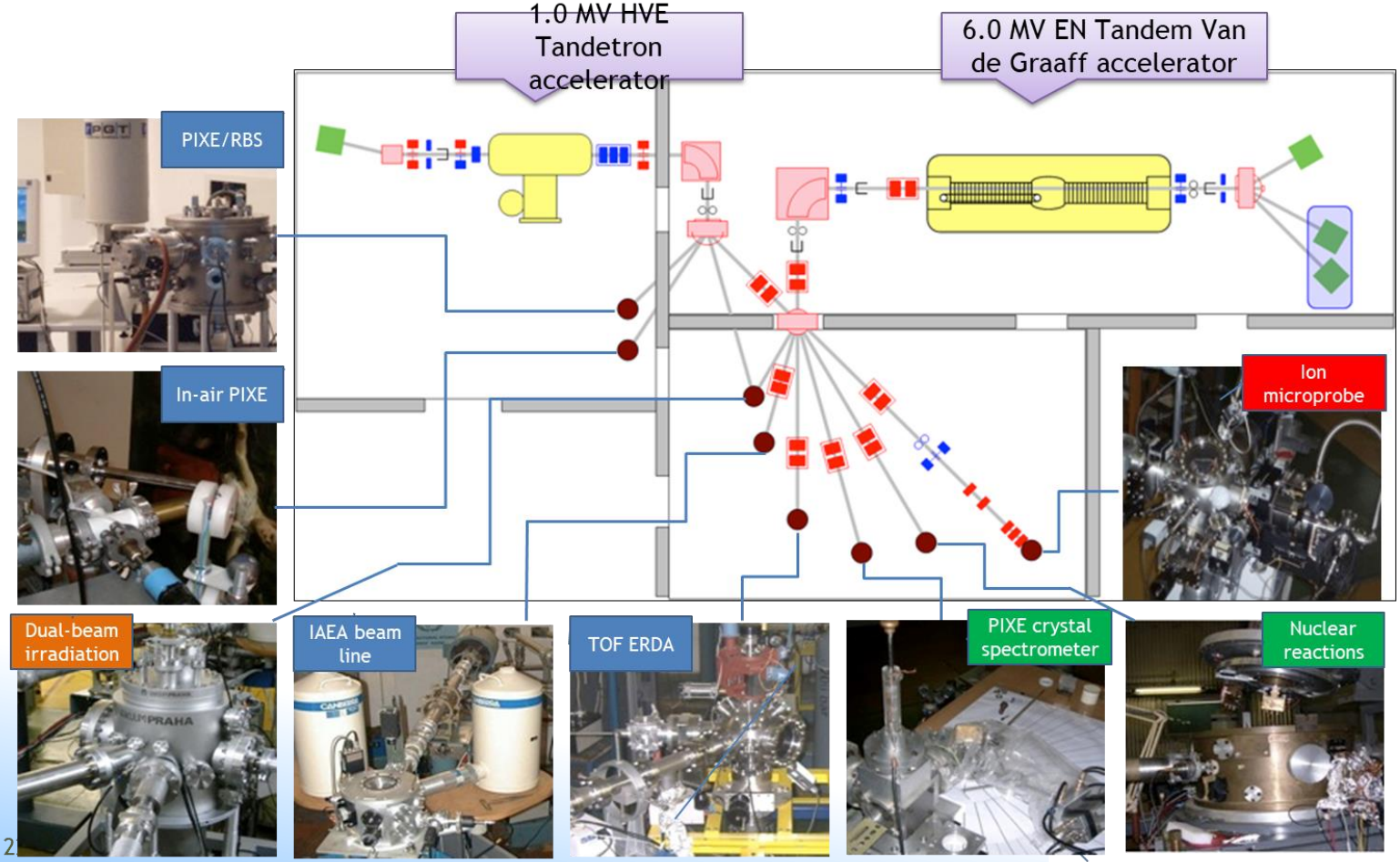
α particle: $^{4}He^{2+}$
High energy, electronic *E* transfer + nuclear near end
Low volumes. Few hundred atoms displaced, over an extended range (~10,000 nm)

Recoil nucleus:
Lower energy, more nuclear collisions, large damage (~1000 atoms displaced), short range (~10nm)

- Expected Results:
  - Understanding of evolution of damage in candidate waste forms
  - Comparison of ion-irradiated and natural/historical samples
  - Inter-comparison of dual vs single beams (alpha and recoil emulation)
  - Development of protocols for future studies

Outlook (2/3)

- Agreement with Ruđer Bošković Institute (RBI) in place in order to:
  - Develop dual beam (e.g. He+Fe, He+W) capability in Zagreb
  - Facilitate access to the dedicated beam lines for applied research, hands-on-training and capacity building using MeV ion beams



Outlook (3/3)

- Feasibility study to establish MeV Ion Beam Accelerator at Seibersdorf, accessible for IAEA member states in order to:
  - Provide capacity building through education and training
  - Foster R&D with MeV ion beams, and
  - Offer specialized services both to internal &external users

Phase 1: Decide!

Phase 2: Prepare!

Phase 3: Implement!

https://www.iaea.org/about/organizational-structure/department-of-nuclear-sciences-and-applications/division-of-physical-and-chemical-sciences