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Innovative Gen-IV Fuels and Materials: EERA-JPNM, Fission and Fusion

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GenIV systems for nuclear energy sustainability

- GenIV reactors and associated fuel cycle facilities can
  - produce more fuel than they consume, guaranteeing low-carbon energy production for centuries through recycling, without additional mining, in a circular economy;
  - offer ~50% higher thermal efficiency and increased standards of passive safety than current reactors, thereby becoming both societally and economically attractive
  - reduce significantly the volume and radiotoxicity (decay time < 1000 years) of nuclear waste
- However materials pay the price
  - high levels of temperature (up to 1000ºC depending on system) and irradiation (up to several tens of dpa), in contact with aggressive non-aqueous coolants
  - 60 year operation reactor design
  - high burnups to be reached, including the possibility of burning minor actinides

Thermonuclear fusion as long term inexhaustible energy source

- Fusion promises very high standards of sustainability, efficiency and safety
  - wide availability on earth of deuterium and lithium
    - tritium is self-produced by nuclear reaction in the reactor itself
  - inert nature of the reaction products
    - the main wastes in fusion are activated structural materials
  - high density of energy provided by the fusion reaction
  - inherently safe system
    - main safety concern is tritium: reduce inventory and avoid release
- However materials will be subjected to unprecedented conditions
  - thermal shocks on the order of several MW/m2
  - high radiation dose (tens of dpa), exposure to high temperature (up to 500ºC) and contact with potentially aggressive coolants/tritium breeders

Development, qualification and modelling of structural and fuel materials in connection with safety and efficiency issues are crucial to make sustainable nuclear energy a reality

Several materials and safety issues are common to advanced fission and fusion systems

Here highlights are given on 6 projects dealing with structural and fuel materials for advanced nuclear systems and/or cross-cutting between fission and fusion

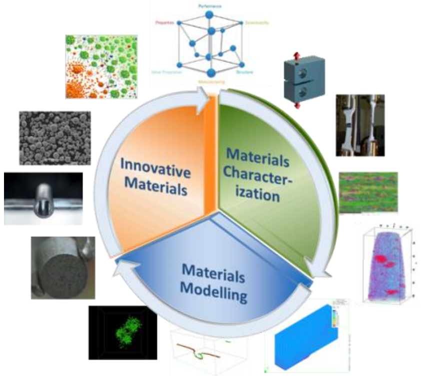
Four of them are under the umbrella and part of the research portfolio of the EERA JPNM

EERA Joint Programme on Nuclear Materials: one of 17 JPs of the European Energy Research Alliance

Overarching objective:
improve **safety & sustainability** of nuclear energy, focusing on **materials issues**

- **Better knowledge of materials behaviour** under operating conditions, to select the most suited materials and define safe design rules, allowing for radiation and temperature effects and caring for compatibility with coolants
- **Development of new materials solutions** for better resistance to high temperature, irradiation and aggressive environments, through either advanced fabrication and processing methods or adoption of new types of materials

Approach and grand challenges

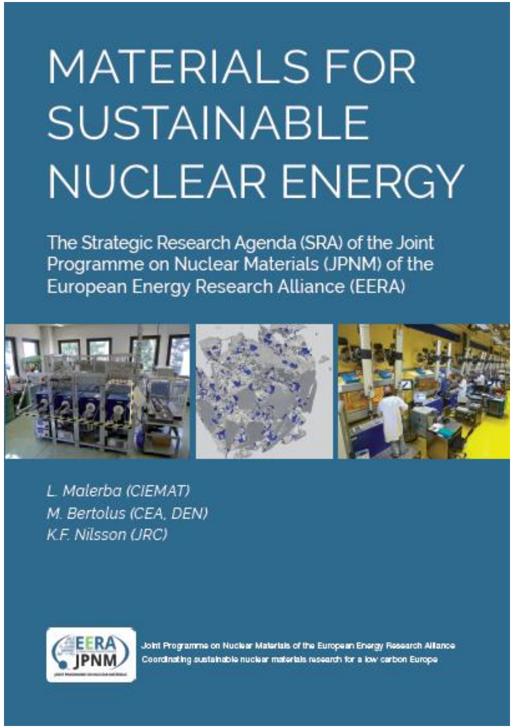


Elaboration of design rules and procedures for assessment and testing of the materials envisaged, at the expected operating conditions (high T, prolonged irradiation, aggressive environment).

Development of new materials of nuclear-relevance, with superior thermo-mechanical properties: radiation-, temperature- and corrosion-resistance

Development of physical models coupled to advanced microstructural characterization to achieve high-level understanding and predictive capability

Strategic Research Agenda


MATERIALS FOR SUSTAINABLE NUCLEAR ENERGY

The Strategic Research Agenda (SRA) of the Joint Programme on Nuclear Materials (JPNM) of the European Energy Research Alliance (EERA)

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EERA JPNM
Joint Programme on Nuclear Materials of the European Energy Research Alliance
Coordinating sustainable nuclear materials research for a low carbon Europe

More than 50 organisations from 17 countries contribute to at least one of the 6 subprogrammes of the EERA JPNM devoted to qualification, modeling and development of structural and fuel materials - http://www.eera-jpnm.eu

FP7 Project (2012-2017): 7.2/3 M€, 12 participants, coord. F. Delage (CEA)

Objective: investigate minor actinide (americium) bearing fuels shaped as pellets and beads for GenIV Sodium Fast Reactor

- Both minor actinide (MA) homogeneous and heterogeneous recycle were considered
- Work included both fabrication and characterization, extended to behaviour under irradiation, of both pellet and sphere-packed fuel, providing a safety performance pre-assessment under normal operating conditions, during transient and in case of severe accident
  - Several promising bead fabrication routes have been explored
  - PIE results on $(Am,U)O_{2-x}$ related to He and FG release, fuel swelling and fuel microstructure evolution at 1000,1200 & 1300°C were produced
    - No significant swelling observed
    - All He is released at all temperatures, while Kr and Xe release are strongly temperature dependent
  - Specific models & correlations have been produced for MA-bearing fuels and sphere-packed fuels, thereby improving the predictive capabilities of fuel codes
- The project thus contributed to improve significantly the knowledge on Am-bearing fuel behaviour, both for the fuel driver and the fuel bearing blanket concepts, highlighting that the main differences do not come from these two concepts, but from the existence or absence of fuel-clad interaction, depending on whether the fuel is in pellet of sphere-packed form

MatISSE: Materials' Innovation for Safe and Sustainable Nuclear in Europe

FP7 Project (2013-2017): 8.6/4.7 M€, 29 participants, coord. P.F. Giroux (CEA)

EERA JPNM – European Energy Research Alliance – JOINT PROGRAMME ON NUCLEAR MATERIALS

Structure in 2013

Better structure the EERA JPNM in terms of networking, implementation, communication, research strategy, knowledge management (CSA in WP1)

Fund the EERA JPNM research on modelling, refractory materials, advanced steels, support to ESNII systems (actual collaborative project, WP2-5)

Integrated research programme

MATISSE – Materials' Innovations for Safe and Sustainable nuclear

Project Structure

SP1 - Materials for ESNII demonstrators and prototypes

SP2 – Innovative high temperatures steels

SP3 – Refractory materials: ceramics and metals

SP4 – Physical modelling and modelling oriented experiments for structural materials

WP2: Modelling of irradiation induced hardening and creep in F/M alloys

WP3: Characterization of ceramic composites for GFRs and LFRs

WP4: Characterization of ODS alloys for LFR and SFR cladding

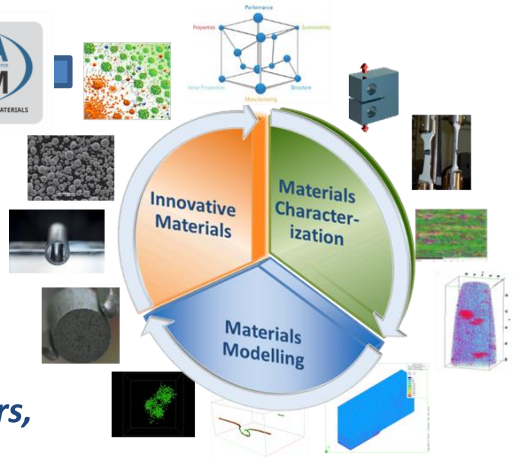
WP5: Support to design, selection and qualification of materials and components for the ESNII reactors

Too many results to be summarised

H2020 Project (2017-…): 6.6/4.0 M€, 23 participants, coord. P. Agostini (ENEA)

GEMMA deals with EU GEN IV material issues, reflecting the EERA JPNM three-fold approach to materials studies

	Compatibility with coolants	Neutron irradiation effects
Materials Characterization in view of codification	WP2: Welding development and characterization; WP4: Compatibility with HLM and He coolant	
Materials Modelling	WP4: Compatibility with HLM and He coolant	WP3: Irradiation effects: modelling and experiments
Innovative Material Solutions	WP1: Advanced corrosion mitigation strategies	



Large amount of experimental data are generated.

Useful rules, for system and component designers, will be deduced.

The data are expressed in a suitable way for inclusion in the Design Rules of the RCC-MRx code

The generated data will be stored in JRC repository MAT-DB http://www.eera-jpnm.eu/gemma

H2020 Project (2017-…): 9.4/4.0 M€, 14 participants, coord. M. Bertolus (CEA)

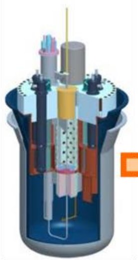
STRATEGIC OBJECTIVES

- Make major breakthrough in understanding and describing fast reactor MOX behaviour under irradiation in a large variety of conditions by coupling
  - Separate effect experiments
  - Multiscale and thermodynamic modelling
  - PIE results on neutron-irradiated fuel from past campaigns
- Focus on four operational issues: Margin to fuel melting; atom transport and fission product behaviour; mechanical properties; fuel thermochemistry and interaction with the cladding
- Advance predictive capabilities of fast reactor fuel performance codes by:
  - Transferring knowledge acquired into operational tools
  - Bringing together experts to develop and capitalize on the synergy between the various approaches
- Transfer results and approach of proposal to users and develop training to prepare next generation of researchers

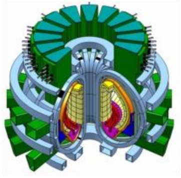
http://www.eera-jpnm.eu/inspyre/

H2020 Project (2017-…): 6.5/4.0 M€, 20 participants, coord. L. Malerba (CIEMAT)

GUIDING OBJECTIVES



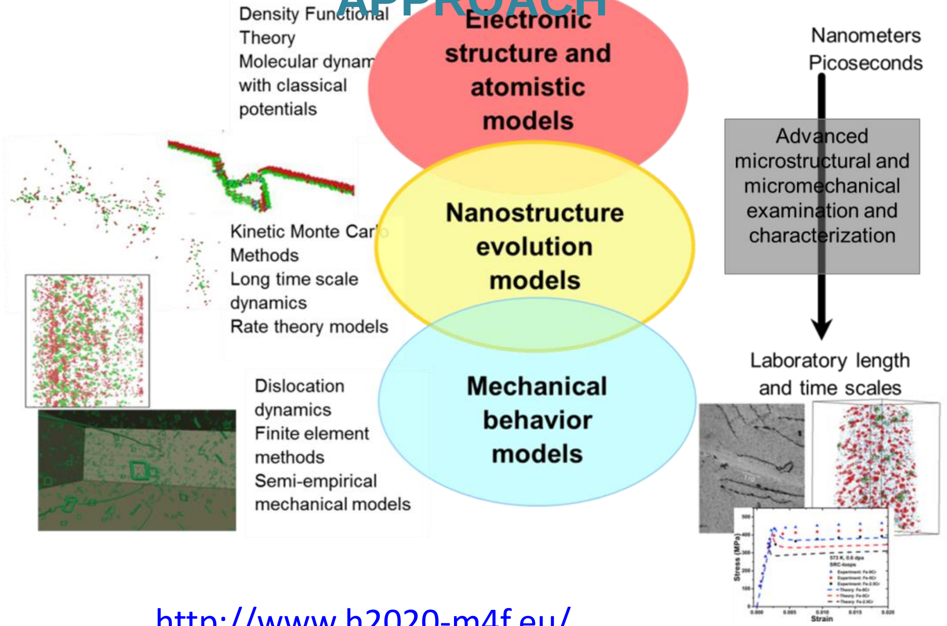
Bring together fusion & fission materials communities



Develop physical understanding and predictive models of the origin of **localised deformation** under irradiation and its consequences on the mechanical behaviour of components

Develop a methodology to use **ion irradiation as a tool** to evaluate radiation effects on microstructure and mechanical behaviour of materials, minimising artefacts with respect to neutron irradiation experiments

MULTISCALE MODELLING APPROACH



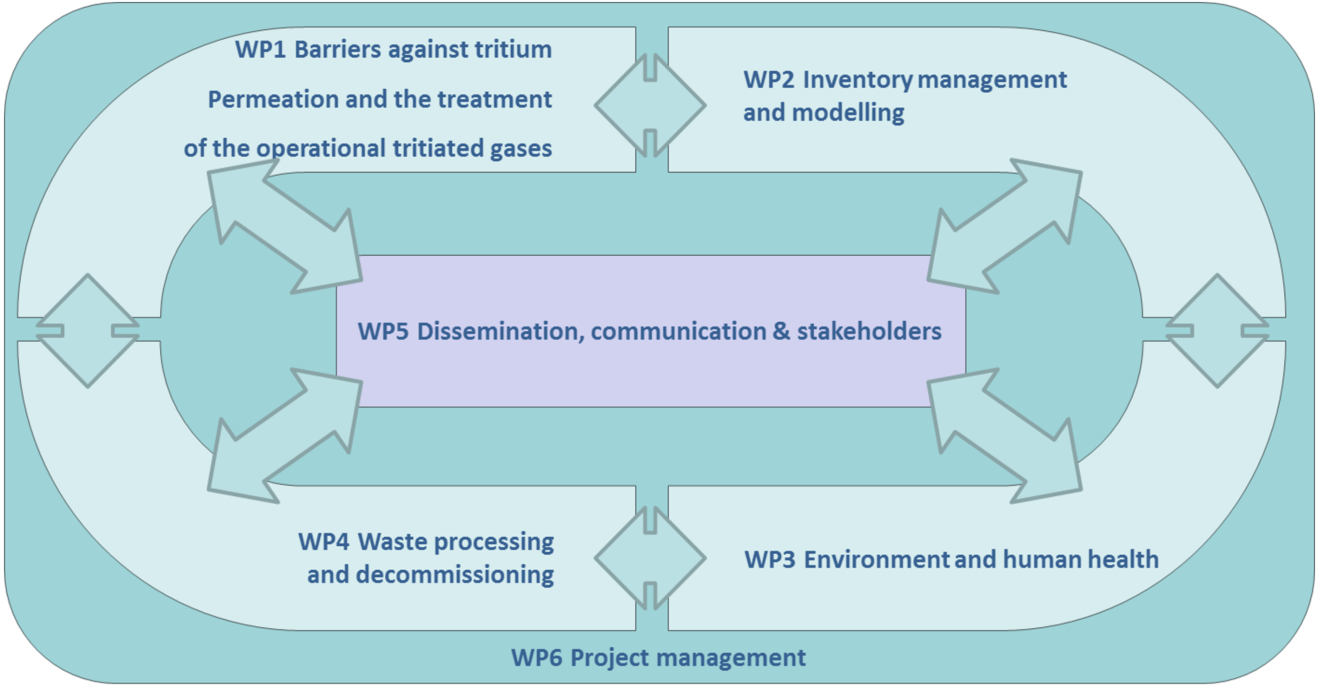
http://www.h2020-m4f.eu/

H2020 Project (2017-…): 4.0/4.0 M€, 18 participants, coord. C. Grisolia (CEA)

Cross-cutting support to improved knowledge on tritium management in fission and fusion facilities

1. Tritium permeation control
2. Assessment of the tritium inventory using state-of-the-art modelling tools
3. Engineering solutions for detritiation techniques and waste management
4. Refinement of the knowledge on outgassing, radiotoxicity, radioecology, radiobiology, dosimetry and metrology of tritium

http://transat-h2020.eu/



Conclusions

- The EERA JPNM coordinates European activities on qualification, modelling and development of structural and fuel materials
  - Projects are the result of bottom-up alignment of national projects
  - Institutional funding integrates Euratom support
- This provides solid bases to build a European Joint Programme on nuclear materials
  - Earmarked funds from Member States and Euratom for nuclear materials
- Fission-fusion cross-cutting projects are a valid instrument to optimise the use of resources, benefitting from cross-fertilisation
  - Materials and safety offer several topics on which fission and fusion can valuably collaborate