ANCRE ALLIANCE: ROADMAP FOR NUCLEAR MATERIALS

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MINOS Workshop, Materials Innovation for Nuclear Optimized Systems
December 5-7, 2012, CEA – INSTN Saclay, France
ANCRE alliance

Research organizations

Founders: CNRS, CEA, CPU, IFP

Associates: ANDRA, BRGM, CDEFI, CIRAD, CSTB, IFREMER, INERIS, INRA, INRETS, INRIA, IRD, IRSN, ONERA...

Coordination committee

Programmatic groups

Ressources

Users

Transverse prospective

Financing agencies

Public authorities

Competitiveness clusters, industrials

CEA – DEN

MINOS Workshop - December 5-7, 2012, CEA – INSTN Saclay, France
5 groups “Energy sources”
- Biomass energy (GP1)
- Fossil and geothermal energy (GP2)
- Nuclear Energy (GP3)
- Solar energy (GP4)
- Marine, water, wind energy (GP5)

3 groups “users”
- GP6 Transports
- GP7 Buildings
- GP8 Industries & Agriculture

Expected answers
- Focused objectives
- Optimal paths
  - Techniques
  - Economics
  - Environment
  - Capacities
- Scientific, technical and societal breakthroughs
- roadmaps

Energetic prospect (GP9)
GP3 systems

- 2nd and 3rd generation reactors systems
- Fuels and fuel cycle for PWR
- 4th generation reactor and cycle: FBR and GFR
- Watch on nuclear cogeneration + international prospective studies (RSF, Th, ADS)
- Fusion: ITER and R&D DEMO

GP3: key research area

- Reactor physics and numerical simulation
- Nuclear Material
- Nuclear chemistry
- Instrumentation
- R&D for fusion
Nuclear material: **extreme operating conditions**
=> sound knowledge of the materials, to the finest scale

**advances in materials science**: observation means, irradiation tools, simulation

new objectives for **reliability and security**
=> prevent and securely manage external aggressions (earthquake, aircraft impact, etc.) and severe internal accidents.
Nuclear Material challenges
(fission and fusion)

Challenges for nuclear reactors (CEA, IRSN, AREVA, EDF)
- Characterization of material ageing: PWR reactors and cycle facilities
- Margins prediction under extreme conditions (environmental, loading)

Scientific breakthroughs
- Multi-scale and multi-physics coupling simulation of materials, including dedicated experiments and qualification
- Development of new materials for fission reactors (steels, ODS, fuels, ceramics, glass, concrete, clay ...) and fusion (W alloys ...)

=> 2011: ANCRE roadmap for nuclear material
For each industrial challenge : deadline, scientific breakthrough =>
R&D program

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<thead>
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<th>challenge</th>
<th>horizon</th>
<th>breakthrough</th>
<th>R&amp;D</th>
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<tbody>
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<td>REP 900 et 1300 MW, life extension</td>
<td>2015-2020</td>
<td>• Validation of the 60 years extrapolation (reactor vessel evaluation methods)</td>
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<td>• Predictive modeling of swelling (austenitic materials)</td>
<td>• Vessel and internal structure steels</td>
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<td>• Predictive modeling of general corrosion and stress corrosion</td>
<td>• Corrosion mechanism</td>
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<td>• Modeling of seismic behavior “from the fault to the structure”</td>
<td>• Surface engineering in extreme environmental conditions</td>
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<td>• Instrumentation reliability under extreme conditions</td>
<td>• vibrations, dynamics</td>
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ANCREE program proposals

- material for reactor vessel or internal circuits,
- corrosion mechanisms,
- zirconium alloys, fuel materials,
- nano reinforced steels,
- surface engineering,
- advanced metallurgical process,
- composite materials,
- materials for fusion,
- refractory materials,
- containment materials (concrete, glass, clay),
- structural mechanics,
- Multi-scale modeling and simulation,
- experiments.
Main objectives

Progress in materials modeling at **different scales**, taken into account **physical bases**:
- Irradiation
- Temperature
- Corrosion
- Mechanical, thermal loading

Integrate more recent advances in **applied Mathematics, software Engineering** and **High Performance Computing**

Develop **smart experiments** as well as **global** qualification devices

**All structure or fuel materials:**
- Steel, alloys, ODS, ceramic, composites, Glass, concrete, UO2, …
**Irradiation means**

**Particle beams facilities**
- JANNUS
- GANIL
- Electrons, ...

**Mechanical tests**

**Experimental reactos**
- MTR - Osiris, RJH, ...
- RNR - Phénix, BN 600, ASTRID, Allegro, ...

**Material law**
- Fracture mechanics
- Homogenization

**Irradiation means**
- Dislocations and irradiation defects

**Characterization**
- Dislocation networks, defects clusters evolution

**Modeling**
- Monte Carlo
- Clusters dynamics

**TEM**

**EBSD**

**MEB**

**Structure**

**Material law**
- Fracture mechanics
- Homogenization

**Crystalline plasticity (CP)**

**Finite element (EF)**

**Electronic structure**
- Ab initio

**Molecular dynamics**
- Monte Carlo
- Kinetic Monte Carlo

**Scale**
- Atoms
- Electrons
- 1 nm
- 1 μm
- 1 mm
- 1 m
Research priorities include

- diffusion properties in actinide oxides: experimental and simulation
- controlling the behavior under irradiation of the fuel matrix: thermal effects, defect behavior and fission products …
- general properties of fuel materials for Generation IV nuclear systems: thermodynamic properties and irradiation effects,
- the role of additives, doping product and burnable poisons on the transport properties and the damaging effects,
- Development and validation of atomic scale and mesoscopic modeling
1 – PWR : core and vessel
   VD3 REP-1300
   VD4 REP-900
   Toughness prediction tool
   Extension > 60 years

2 – ODS for FBR
   ODS choice
   Industrialization & design rules
   ASTRID

3 – Composite ceramique for FBR
   Irradiation characterization
   Composite choice
   Elaboration and assembling
   Industrialization

4 – fusion material
   Material qualification for ITER (Eurofer, Tungstène…)
   IFMIF development (neutrons 14 MeV)
   Qualified materials for ITER
   IFMIF

5 – modeling and numerical simulation
   Multi scale modeling for steel
   Multi scale modeling for ODS
   Multi scale modeling for ceramic
Structuring initiative

- identify existing, or future, **structures** of the research community, in the term of permanent organization (with or without wall laboratories) or short term projects (national, European or international):

- Research organization initiatives : NEEDS, MAI, MINOS, JANNUS, EMIR
- French initiatives : LASIPS, PALM, UPSa material network (Paris Saclay University)
- European initiatives : SPIRIT , CECAM
Structuring initiative

- tighten links between research and **education**: masters (MANUEN - Materials Science for Nuclear Energy / INPG, “Matériaux de structure pour l’énergie” / INSTN, MNE/paritech and al., ...) , doctorate level (UPSa, ...).

- tighten links between research organizations and **competitiveness clusters** (MATERALIA, ICB, EMC2, ...).
ANCRE roadmap for nuclear materials concludes on the necessity to use multi-scale and multi-physics modeling and simulation tools, based on the most accurate physical knowledge, accessible to a wide community of researchers and engineers, and associated with characterization tools at the same scales.

Snapshots of a thermal spike initiated with a 66 keV/nm energy in a polycrystal UO₂

Swelling of REP internal structures

JANNUS irradiation

CRESCEPDO modeling

Reactor vessel

DD modeling