Toward High-Performance Structural Materials for the Next Generation of Nuclear Reactors

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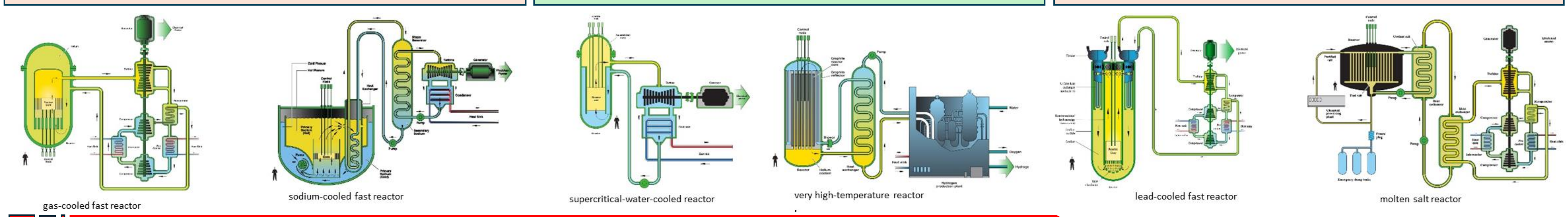
Next-generation reactors offer improved sustainability, safety, and fuel efficiency, but their deployment is limited by the performance of structural materials under extreme conditions. Key challenges include high-temperature mechanical strength, radiation resistance, compatibility with aggressive coolants (such as lead or molten salts), and long-term microstructural stability. Candidate materials and advanced protective coatings have shown promising potential in enhancing corrosion resistance while preserving mechanical integrity at elevated temperatures. European initiatives such as CONNECT-NM - a new co-funded partnership aiming to accelerate research and innovation – focusing on material development, qualification, standardization, non-destructive evaluation, and digital knowledge management.

Challenges for Gen IV Reactor Deployment

Technological Readiness
High temperatures, high neutron doses, non-aqueous coolants create degrading conditions for materials and components.

Material Limitations
Essential components lack the reliability and availability required for economical and commercial viability

Need for Advanced Materials
Developing materials with superior resistance to irradiation and corrosion over a wide temperature range is crucial



- GenIV liquid-metal cooled reactor: outlet temperature 600–700 °C or even beyond;
- Molten-salt cooled plants: outlet temperature 700 °C or higher;
- Gas-cooled systems outlet temperatures: 850 °C or beyond:

- Severe thermal and mechanical stress.
- Corrosion, dissolution, or erosion

Candidate materials

Technology	Material
LFR/ADS	AISI 316
	15-15Ti
	FeCrAl ODS
	AFA steels
	Mo Alloys
	MAXTHAL and MAX phases
MSR	Stainless Steel
	Nickel based alloys
	Nickel based ODS alloys
	AFA steels
	HEA & CCA
Fusion	EUROFER
	Tungsten
	CuCrZr Alloys

Performance Selection Criteria

Material	Maturity	Thermal stability	Fabricability and weldability	Corrosion Resistance (LFR/ADS, MSR)/ Compatibility (fusion)	Resistance to radiation damage
AISI 316	High	Low	High	Low	Low
15-15TI	High	High	High	Medium	Medium
AFA steels	Medium	Low	Medium	High	Low
FeCrAl ODS	Medium	High	Medium	High	High
Mo Alloys	Medium	High	Medium	High	Medium
MAXTHAL/ Max Phases	Medium	Medium	Low	High	Medium
Ni-based alloys	High	High	High	Low	Medium
Ni-based ODS alloys	High	High	Low	Low	Medium
HEA & CCA	Low	Medium	Low	Medium	Low
EUROFER	High	Low	Medium	Low	High
Tungsten	High	Medium	Low	High	High
CuCrZr alloys	High	Medium	High	Low	Medium

Characterization

- Physical properties
- Mechanical properties
- Environmental resistance
- Radiation effects
- Coating evaluation

Testing

- Round-robin interlaboratory campaigns
- Aging simulations
- Microstructural analysis

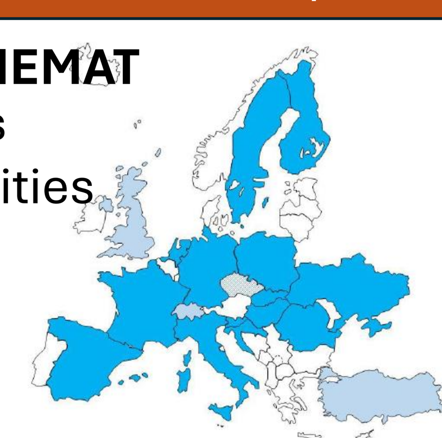
European partnership CONNECT-NM - research, development, and innovation in the field of nuclear materials

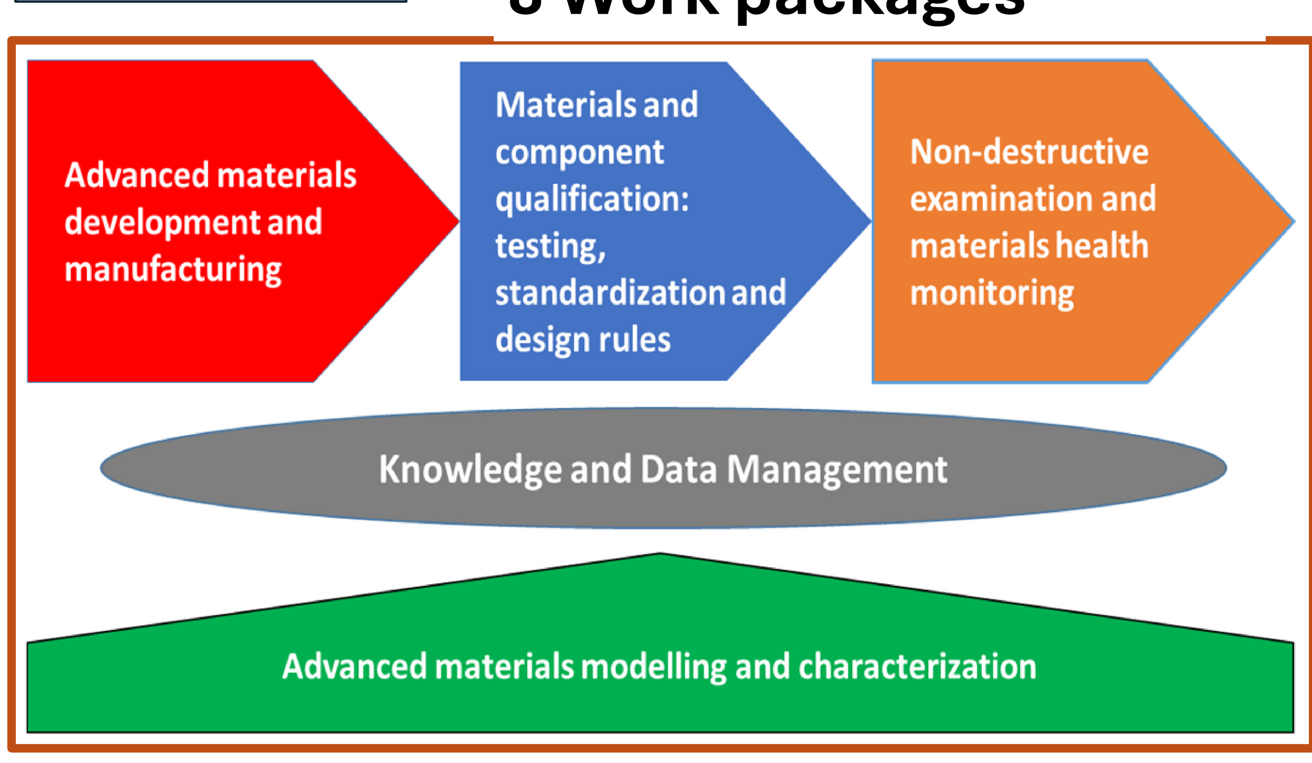
Co-funded by the European Union

https://www.connect-nm.eu/

5 Research Lines
8 Work packages

Coordinator: CIEMAT
20 Beneficiaries
19 Affiliated Entities





- Nuclear materials acceleration platforms
- Nuclear materials' test-beds
- Intelligent materila health monitoring
- Advanced predictive methodologies
- European nuclear materials' FAIR database

2025 -CONNECT-NM Open Call for Projects

ENEA is a partner in the following proposed Projects:

- ✓ **NEO4MAT** - Nuclear Energy Ontology for MATerials (RL1)
- ✓ **ICE-COLD** - Non-destructIve CharactErizations on COatings for LeaD fast reactors (RL4)
- ✓ **ANIMATE** - Additive maNufacturing Innovative MATerials for Energy applications (RL2-RL5)

RL1 (WP4) – Knowledge and Data Management

Objective

Nuclear materials knowledge organisation system

RL Leader: M. Pecelerowicz (**NCBJ**)
RL Advisors: E. Ghedini (**UNIBO**), I.M. Paponetti (UNIBO), M.S. Perez Hernandez (**UPM**), J. Arenas Guerrero (UPM), B. Ferrucci (**ENEA**)

Ambition and vision of CONNECT-NM

CONNECT-NM aims to enhance the safety and sustainability of nuclear energy by advancing materials capable of withstanding extreme conditions. It promotes a shift **from** the traditional "**observe and qualify**" approach **to** a "**design and control**" paradigm, aligning with EU goals for materials that are safe and sustainable by design. The partnership leverages digital tools—like machine learning, data analytics, and digital twins—alongside advanced manufacturing and lifecycle assessment methods.

AKNOWLEDGMENT

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