Possible applications of SiC-based technology for durable design in Concentrated Solar Power (CSP)

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JRC, Petten, JPNM workshop, 25-26 Nov. 2015
About strategy and cross-cutting opportunities called by the SET-PLAN
The JPNM role in the landscape of energy initiatives: at a glance

- **ETEU**
- **Public Research Org.**
- **EERA** (ren. energy)
  - JP energy
  - JP energy x
  - JPs
  - Common materials issues
  - Ongoing dialogue to create link (harmonisation of workplan)

- **European Industrial Initiatives**
  - TRL < 5
  - EERA = research!

- **JPNM**
  - Provides research support on materials for SNE

- **SET-plan (low carbon energy)**
- **SNETP**
  - (sustainable nuclear energy)

- **GenIV**
- **GenII/III**
- **HT**
- **ESNII**
- **NUGENIA**
- **NC2I**
- **TA4 integrity assessment**
- **TA6 innov. LWR**

- **www.eera-jpnm.eu**
The JPNM is the unifying framework for several projects

EU projects on GenIV materials ...

GETMAT

MATTER

MatISSE

Nat. Prog. & Pilot Projects

(H2020) ...

“NON-NUCLEAR CROSS-CUTTING” HAS ALSO VALUE FOR JPNM

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The JPNM role in the landscape of energy initiatives: excerpts from the strategic roadmap

The implementation of:

- **relevant parts** of the *Materials Roadmap Enabling Low Carbon Energy Technologies* (SEC(2011)1609);
- **relevant objectives** of the SET-Plan (COM(2009)519);

→ Offer cross-cutting opportunities for JPNM (SP3 in the specific case, but not limited to)

For CSP:

- The Materials Roadmap invokes a *comprehensive research and development programme on low-cost, high mechanically stable absorber materials* suited also for higher temperature.

- The objectives include *scale-up material development* to industrial scales by technology pilots to test /validate material performances under real market conditions in the areas of [...] porous ceramic or metal structures for *central receivers*.

**ADVANCED SiC-based** materials are good candidates, along with coatings, and an important opportunity to JPNM-SP3.
Part II

DESIGN PROBLEMS WITH CERAMICS AND COATINGS IN CSP
Reference CSP Architectures

Figure 1. Main STE technologies and maturity levels

Credit IEA – ‘New Policies Scenario for STE’
Reference CSP Architectures

**SOLAR TOWER** (900°C max target $T$; 10-15 MWe) - ON GRID

- Receiver 1
- Storage
- Steam generator
- Steam turbine
- Chemical process

Credit CIEMAT

**RESIDENTIAL** (900°C max target $T$; up to 500 kWe) - OFF GRID

- Receiver 2
- Recuperator
- Micro gas turbine

Credit ENEA

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Indications from SET-PLAN for CSP

HORIZON CALLS FOR REDUCTION IN:

• LOWER LEVELIZED COST OF ELECTRICITY (LCOE)

• TARGET LCOE BELOW 10-12 c€/kWhe (credit ESTELA)

IMPLICATIONS FOR POSSIBLE SOLUTIONS:

• Lifetimes of the order of 20 to 25 years, with minimal down and service time

• Large investment may be acceptable but is a potential downside for smaller systems ...
  CAPEX reduced by achieving economy of scale

• Condition the choice of the ADVANCED MATERIALS we can select/design for this application

• Efficiency can be improved by a T raise only to a certain extent (e.g. emissivity losses, convection, etc.)

ENPHASIS IS ON RELIABILITY AND LOW COSTS (rather than a radical increase in T...)

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Issues in SOLAR TOWER CSP RECEIVER

THERE ARE THERMAL GRADIENTS & THERMAL SHOCK ON MATERIALS

Credit PSA - CIEMAT

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Issues in SOLAR TOWER CSP RECEIVER

1st generation CUPS made of Si-SiC and suffer from early failure:

- Fail in “intragranular” mode
- Fail at the interface between CUPS and TILES

(* results from the SOLAIR FP7 PROJECT and EU FP5 HitRec from our sister program JP-CSP)

1. We need materials with 99% survival probability at thermal gradient $> 80^\circ\text{C/cm}$
2. Both BULK & JOINING ARE KEY !!!!
Part III

SOME POSSIBLE SOLUTIONS
POSSIBLE REQUIREMENT

1. Meet given thermal gradient strength

2. High conductivity

3. Manufacturing: low cost, high-throughput & high control (low defects)

1. Oxidation resistant

2. Reliable joining

3. Modeling and inspection/NDE

2 solutions based on monolitic SiC-based, e.g. Si-SIC or All-SIC
POSSIBILITY #1: (Si)SIC + hetero-joining

1. High thermal conductivity due to Si phase
2. High toughness due to Si phase
3. Cheap
4. Could be produced from powders using additive manufacturing
5. Joining by many oxides
POSSIBILITY #2: All SIC

1. High thermal conductivity
2. High oxidation resistance
3. Cheap Enough
4. Could be produced from powders in large Q.
5. Joining by crystalline SiC

LIQTECH: Vapor Phase Sintering (VPS) of SiC at 2600-2800° C, in a controlled atmosphere

Credit LIQTECH
Controls and optimization/NDE  (from JPNM SP3)

1. Multiscale modeling & characterization
2. X-ray tomography and ultrasounds

MULTISCALE MODELLING AND MULTIDISCLINARY APPROACH FOR IMPACS MATERIALS DURABILITY AND OPERATIONAL LIFE TIME PREDICTION

3D IMAGING AND VISUAL ANALYSIS
3D/2D TAC IMAGING MICROSCOPY (SEM, (3D) TEM, AFM-RAMAN)

FEMME MODEL IMPACS MATERIALS & COMPONENTS
- AGING & FAILURE OPERATION
- CRACK NUCLEATION AND PROPAGATION
- THERMAL INDUCED FATIGUE
- CORROSION

MECHANICAL PROPERTIES ANALYSIS OF MATERIAL PROBES
- SMALL PUNCH TESTS, IMPACTS TESTS ...
- NANO IDENTATION / NANO MECHANICS

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ECONOMIC COMPARISON

Monolithic options (from powders):

SiSiC: <50€/Kg (conductivity/ductility)  Vs.  All-SiC: 50-100€/Kg (better oxidation)

Both are technically valid and economically viable

CMC options (from fibers+CVI):

SiC/SiC: 5000€/Kg  Tolerated thermal gradient > 120°C/cm

Leap engine effects? economy of scales and increased T operations may make it worthy the extra performance offered by the CMC

Emphasis is on reliability and low costs rather than a radical increase in T !!!

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CONCLUSIONS: we have a trajectory for SiC-based materials

- High thermal conductivity → TH. GRADIENT STRENGTH
- High oxidation resistance
- Cheap and scalable, yet flexible & reliable
- Reliable Joining (even by crystalline SiC)
- Additive manufacturing can be used
- Multiscale modeling/testing and NDE to support design
- More performing solutions offered by CMC may be at reach soon through economy of scale “leap forward” + introduction of LM storage options

Thermostructural SiC based materials and composites are unfolding nicely and gaining momentum, offering opportunity for technological deployment and transfer for the nuclear community (where the market will never reach the scale of aerospace of wide spread CSP).
THANKS

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