C&SiC Composites in the ExtreMat IP

Presentation to EuroMat 2005 – Symposium C33:

Materials for Advanced Fission Applications

Topical area C3: Materials for extreme environments

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Outline

- Nuclear Applications of C & SiC base materials
- Material response to neutron irradiation
- Extremat IP: New Materials for Extreme Environments
- Carbon/graphite base materials
- Fibre reinforced composites
- Work plan/outlook

Nuclear applications of C&SiC materials (1)

- Poly-granular Graphite has been applied as moderator/reflector in the early fission days, e.g. in the 1941 Chicago Pile
- Near isotropic graphites are widely used in gas cooled reactors, cooled by either air (low T), CO_2 (medium T) or helium (high T). At present the UK is running tens of CO_2 cooled power plants, and 2 small demonstration reactors are operating in Japan and China. Various helium cooled concepts are considered for near term construction, of which PBMR (South Africa) appears most advanced, with a modular design for power generation.
- Further R&D is in progress for Very High temperature Reactor, that would enable hydrogen generation, and a Gas cooled Fast Reactor. This is mostly part of the 'Generation-4' initiative.
- This paper summarizes the activities in ExtreMat-IP, involving C & SiC base materials for high radiation applications

Nuclear applications of C&SiC materials (2)

- Graphites have been widely used in large tokamaks for their low Z, and absence of melt phenomena on plasma impact. Plasma compatibility and tritium retention behaviour can improve when dopant like B, Ti or Si are used.
- With increased thermal shock loadings, CFC has become the dominant choice for high heat flux components, mainly for the high thermal shock resistance and damage tolerance.
- SiCSiC composite is being developed for breeding blanket structures, requiring mostly 3D material; although one concept uses 2D SiCSiC as an insulator sheet.

Nuclear applications of C&SiC materials (3)

Moderator/reflector	Isotropic nuclear graphite
Support structures	Graphite; CFC, SiCSiC?
Ducts	CFC or SiCSiC
Control rod VHTR	CFC or SiCSiC
HTR Fuel kernel coating	PyC/SiC ('triso')
Fuel matrix (compact/pebble)	Graphite
Pebble coating	SiC, ZrC?
Plasma facing wall	Graphites/CFC
Insulator ('Dual Coolant')	2D SiCSiC
Blanket structures	3D SiCSiC

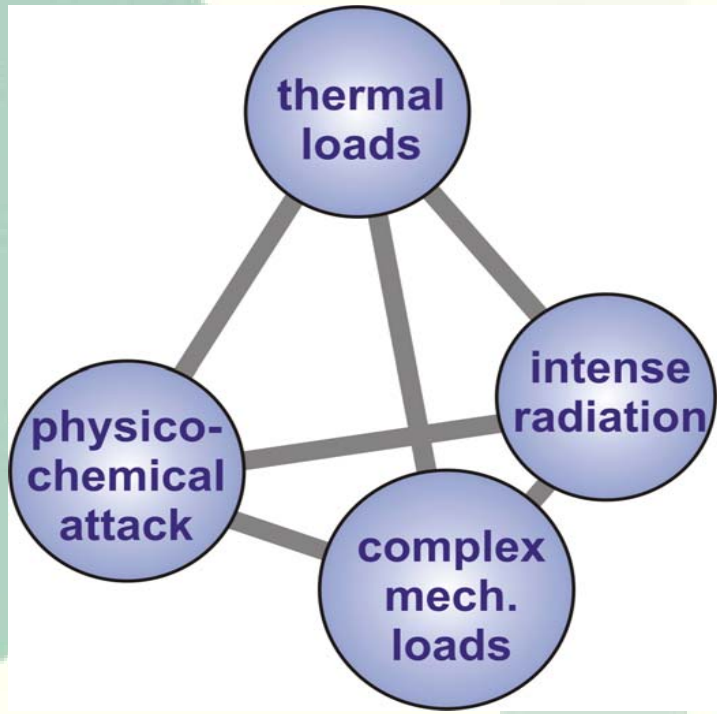
Irradiation behaviour

- Strong dimensional changes shrinkage/swelling
- Neutron irradiation dramatically reduces thermal conductivity of C & SiC base materials, in particular at lower T.
- Effects on strength, modulus and rupture properties
- Optimisation through system analyses and interface design

The ExtreMat IP

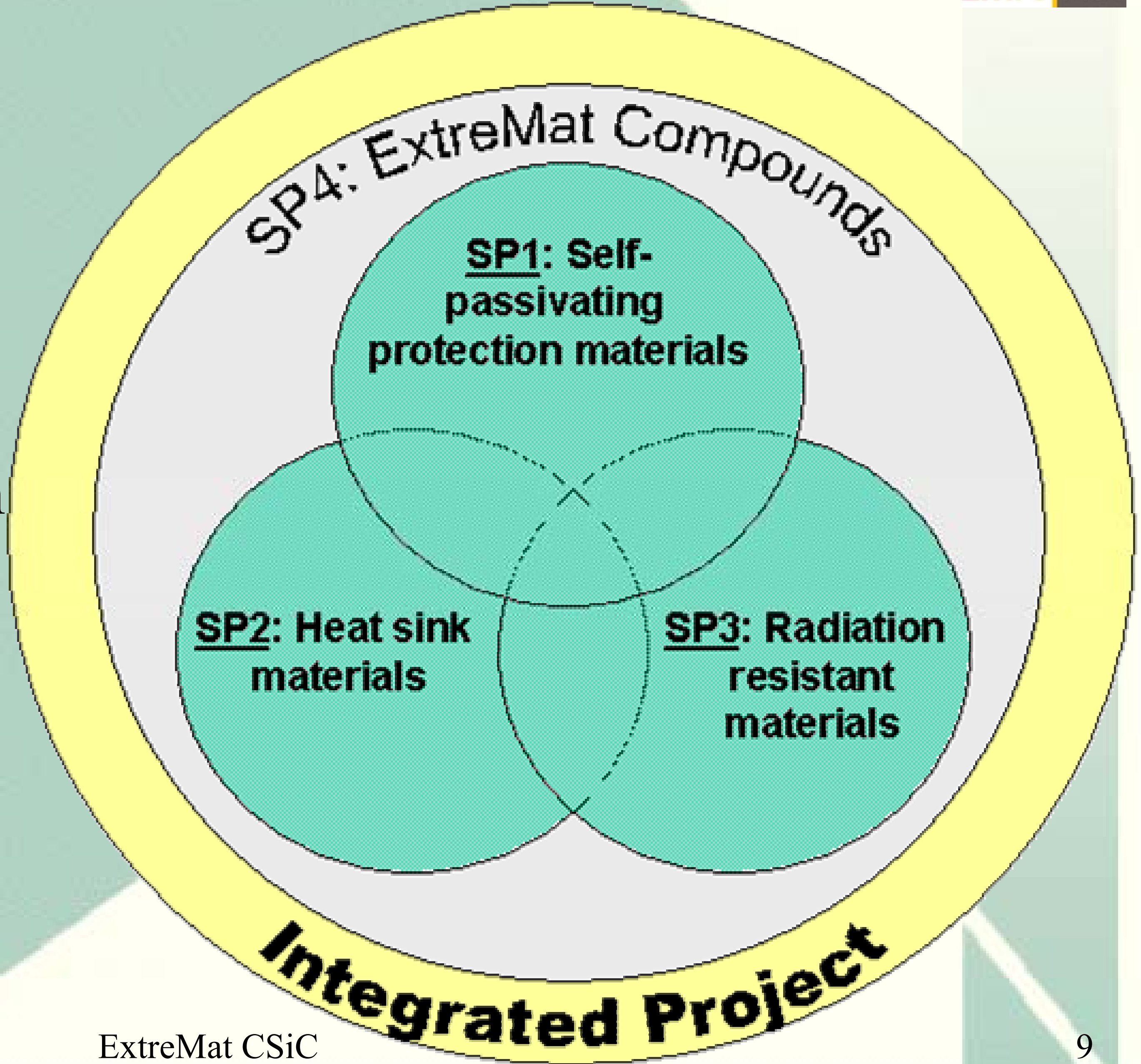
→ Pursuing **common materials issues** for **different applications**, in which materials have to sustain an **extreme environment** → merging materials-related expertise dispersed in different fields (space industry, power generation research, radiation facilities...) ⇒ fundamental need for multifunctional new materials, which :

- Provide protection mechanisms
- Provide capability of removing extreme heat fluxes
- Can endure radiation doses far beyond now available
- Have to form heterogeneous compounds



The ExtreMat IP

- Consortium with 38 partners; coordinated by IPP Garching, D
- > 30 M€ budget, with 17€ M€ EC funding
- Runs to end 2008/2009
- Functional combination of industry, institutes and universities
- Cross-cutting R&D character: new materials for extreme environments



Partners on radiation resistant C/SiC

- NRG: 2 irradiations + post-irradiation testing
- *CEA: nano-SiC powders*
- FRA-DE: VHTR materials characterization
- FZJ: high heat flux experiments on neutron irradiated materials
- PSI: implantation, microstructure, characterization, + post-irradiation testing

and:

- University of Manchester: microstructure, modelling, e.g. x-ray tomography
- Multi-interactions with other ExtreMat subprojects
- Interactions with EFDA: exchange of material and data
- Interactions with Euratom VHTR and GFR projects

Fusion applications

- V/W/Ti doped C-based materials with enhanced thermal stability and improved thermal shock resistance
- Nano-structured C-based materials for high mechanical strength
- V/W/Zr doped graphite self-passivating properties against chemical erosion by hydrogen
- CFC base material with TiC, VC, ZrC, WC doping
- 2D and 3D SiCSiC, with tyranno SA + CVD SiC, fine weave/small porosity
- SiCSiC with C fibers for enhanced conductivity
- Interactions with EFDA: exchange of material and data

Fission applications

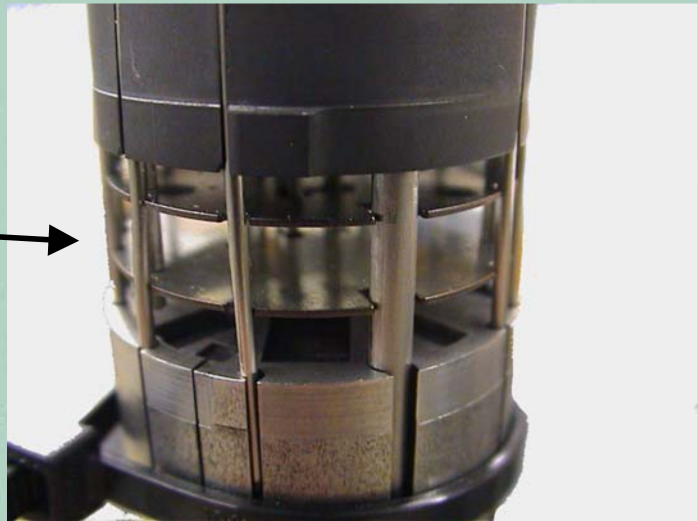
- Doped graphite for core structures ?
- **CFC for Control Rods, and support structures**
- **SiCSiC for Control Rods, and support structures**
- SiC at high temperature cladding for GFR fuel

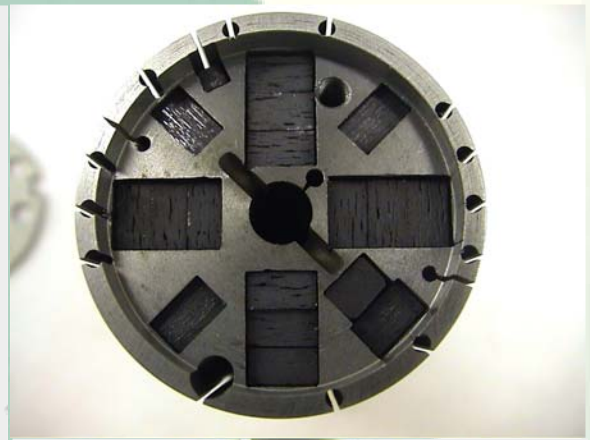
Practical point:

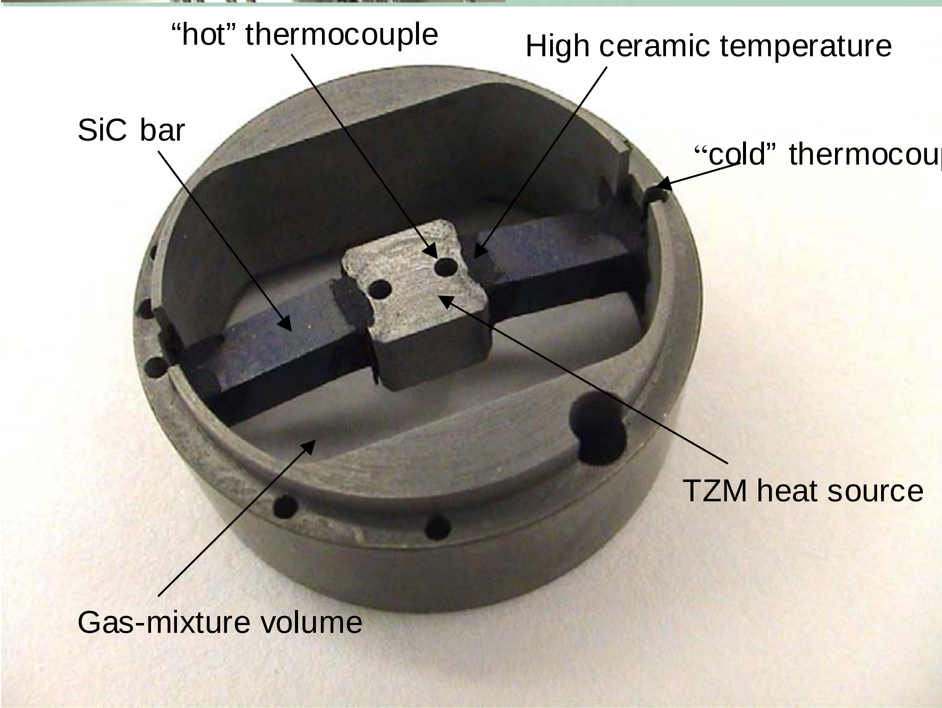
Choice of irradiation temperature and dose, differs significantly for given Alternative Concept

Irradiation tools – multi T-level rig

Thermal barrier







ExtreMat CC-CSiC-SiCSiC (2)

- Applications identified
- Materials specification being defined, detailing ongoing Consolidation of irradiation test matrix by 2005 Q4
  - Emphasis on screening vs. qualification
  - Compromise for dose/temperature/spectrum
  - Only materials in irradiation that are ready by mid 2006
  - Necessity to have a supporting modelling activity and make use of ‘model’ materials
- P.I.E. Results available by mid 2009
  - Prepare strategy for demonstration of new materials available beyond 2006

Key testing in WP3.3

- Dimensional stability (anisotropy)
- Mechanical properties:
  - Modulus, strength (bend – tensile ? - toughness?)
  - RT testing, limited HT tests – link with SP1 tests
  - Irradiation creep/stress relaxation
- Physical properties
  - Thermal diffusivity/conductivity
  - CTE (for C containing mat’s)
- Composites irradiation programme has to be ‘designed’ – existing data + modelling
- (e.g. interaction of graphite swelling in stiff SiC matrix); interface requirements fiber/matrix

Future Programme (FP6 Raphael IP) – 2

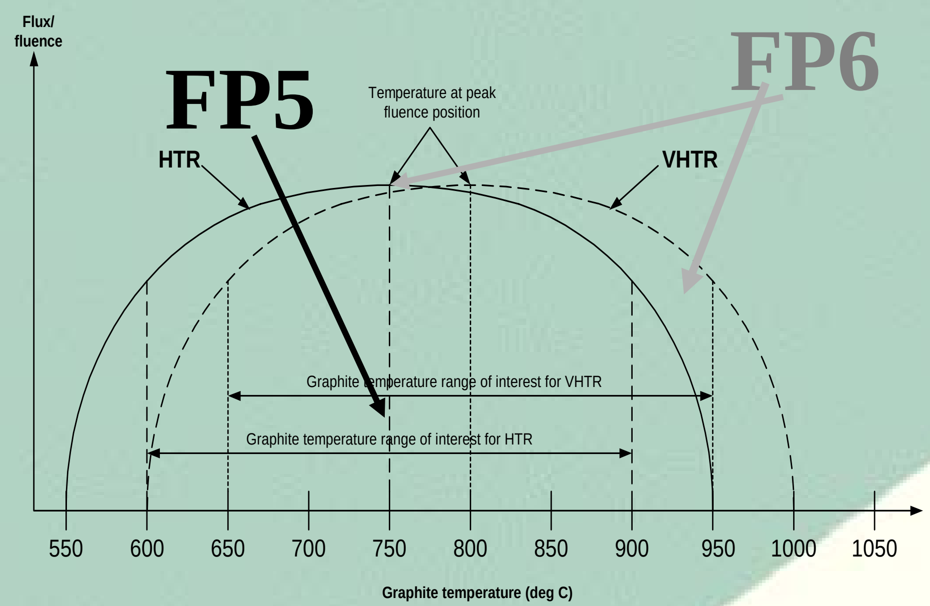
NRG
Extre Mat

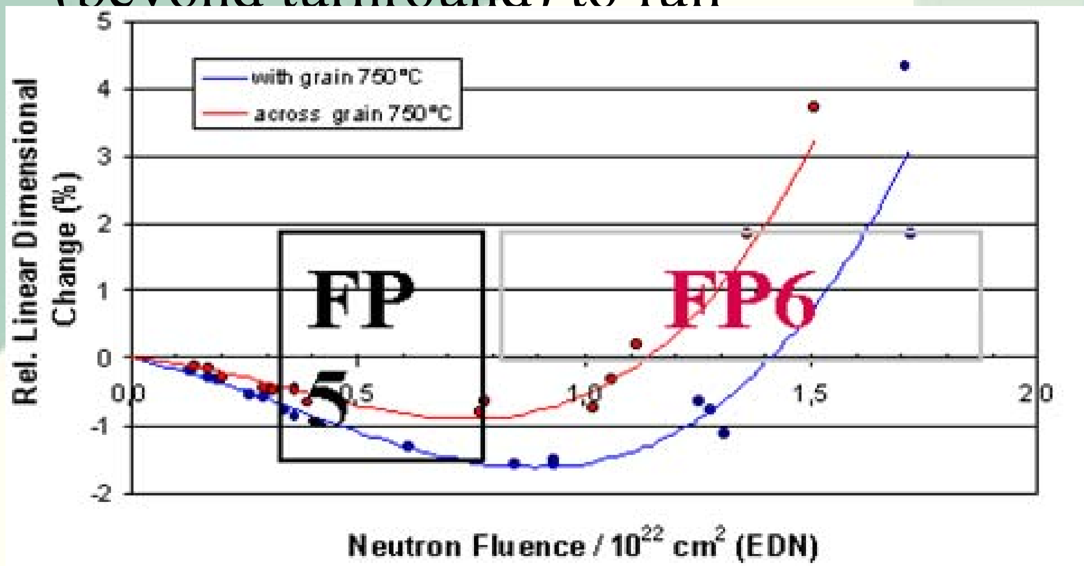
C-Composite Material

- Preliminary Testing
- Selection with manufacturer
- Irradiation of few samples in HFR
- PIE & initial evaluation

Graphite

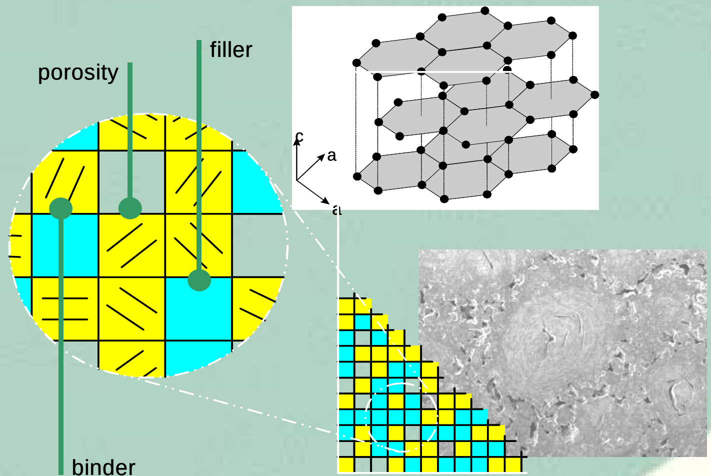
- Building on the 5FP data through tests at upper end of VHTR core temperature window (~ 900/950°C)
- Continuing the 750°C graphite irradiation tests to full fluence (beyond turnround) to full

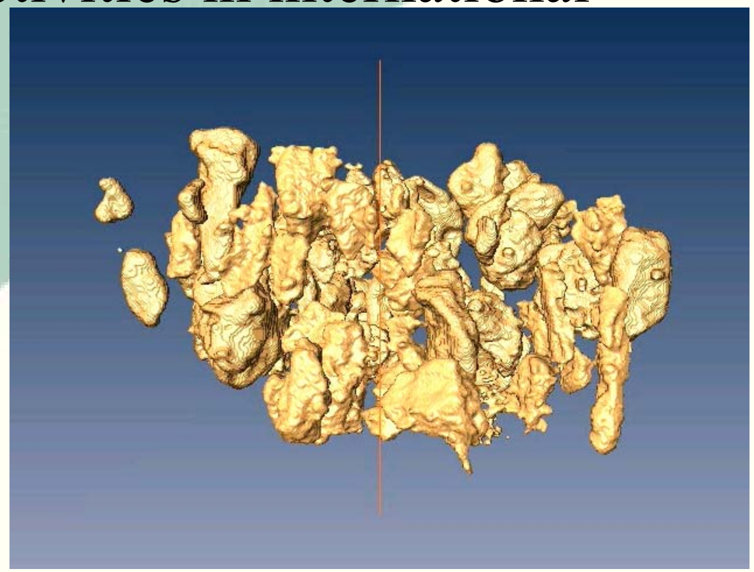




Modelling & opportunities

- Development of graphite modelling techniques to reduce the necessity for large scale testing (of new graphites) in the future and to substantiate a specification for longer term graphite development
  - Current activity in FP5 aimed at data for modelling, pre-irradiation measurements, single crystal samples in 750°C irradiation
  - Connect ongoing work with related activities in international community (Gen4, Fusion)





Courtesy: NGRG (Manchester)

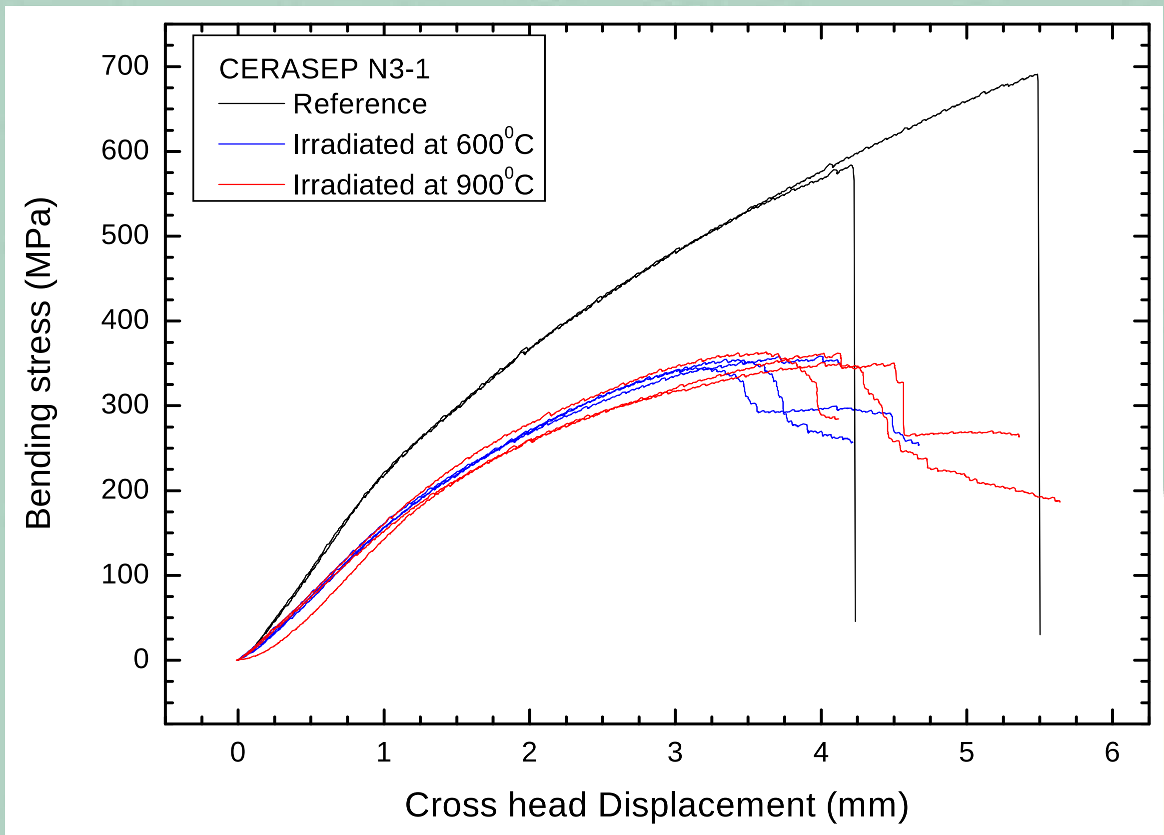
C & SiC base materials

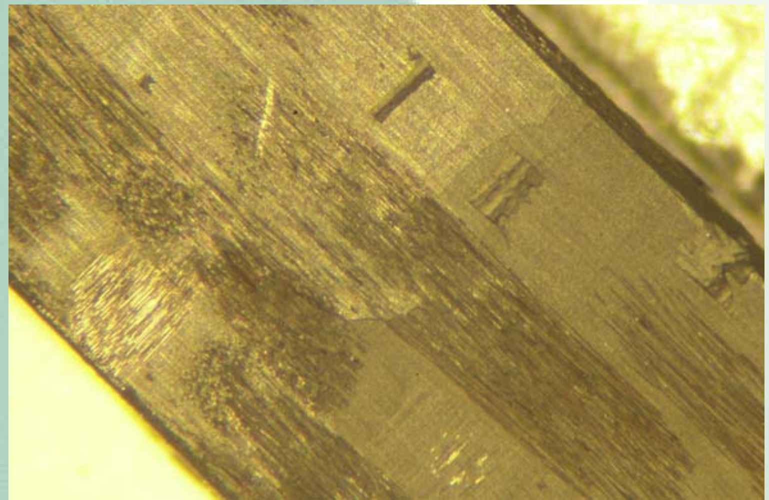
- V/W/Ti doped C
  - Th. Conductivity
  - CTE/E
  - Dimensional stability
  - (Strength)
- V/Ti/Zr doped graphite
  - Th. Conductivity
  - CTE/E
  - Dimensional stability
  - (Strength)
- V/Ti/Zr doped CFC
  - Th. Conductivity
  - CTE/E
  - Dimensional stability
  - Strength
- CFC (PFM; Control Rod)
  - (Th. Conductivity)
  - Dimensional stability
  - CTE
  - Strength
- C-SiC
  - Th. Conductivity
  - Dimensional stability
  - CTE
  - Strength
  - Irrad. Creep
- SiCSiC
  - Th. Conductivity
  - E
  - Dimensional stability
  - Strength

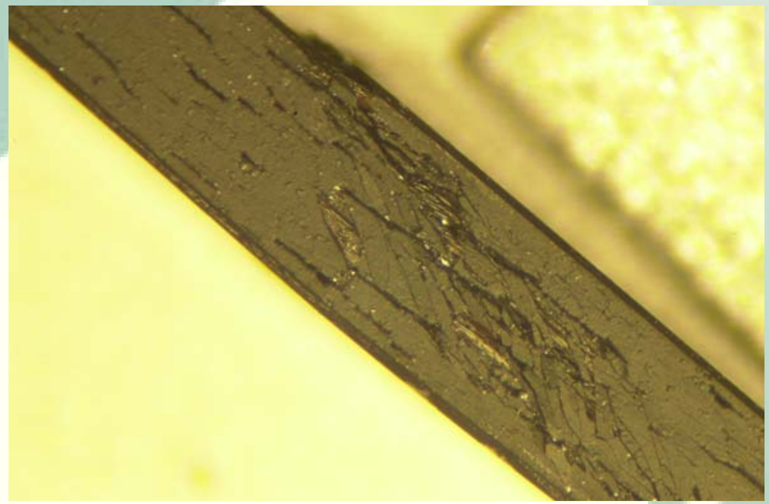
Model inputs : Fibers + Pyrolytic graphite, Irrad. Creep

Bending to fracture – CERASEP N3-1

- strength before: 645 ± 55 MPa
- strength after irradiation:
  - 900°C 349 ± 15 MPa
  - 600°C 334 ± 38 MPa

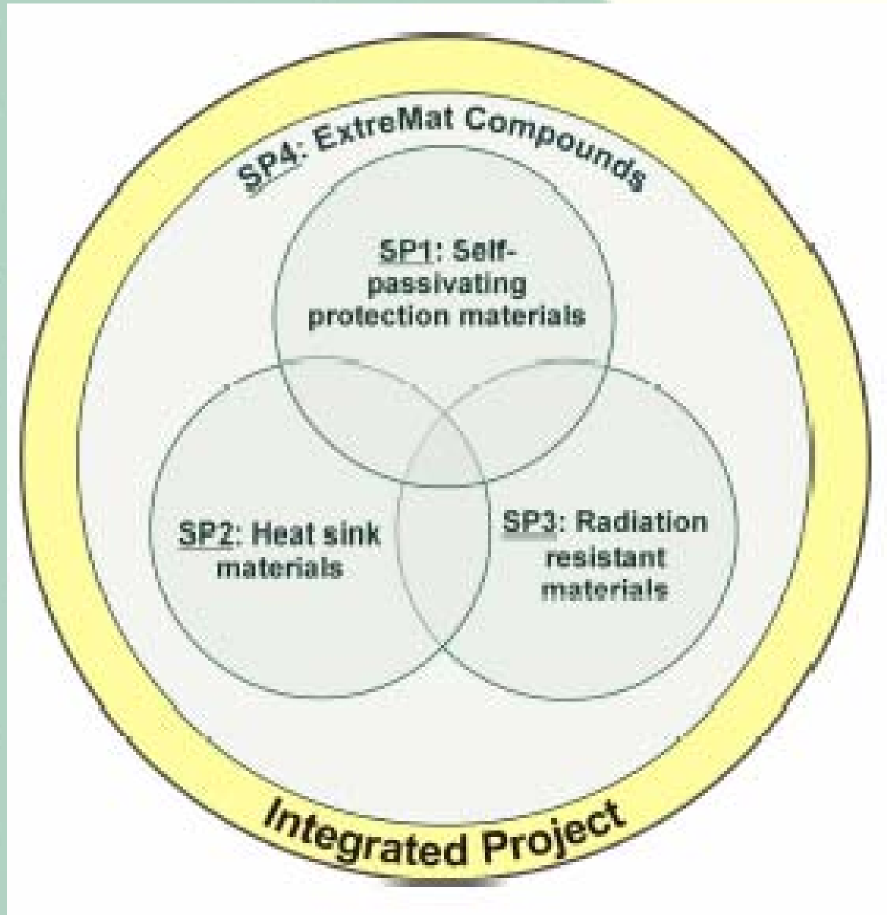






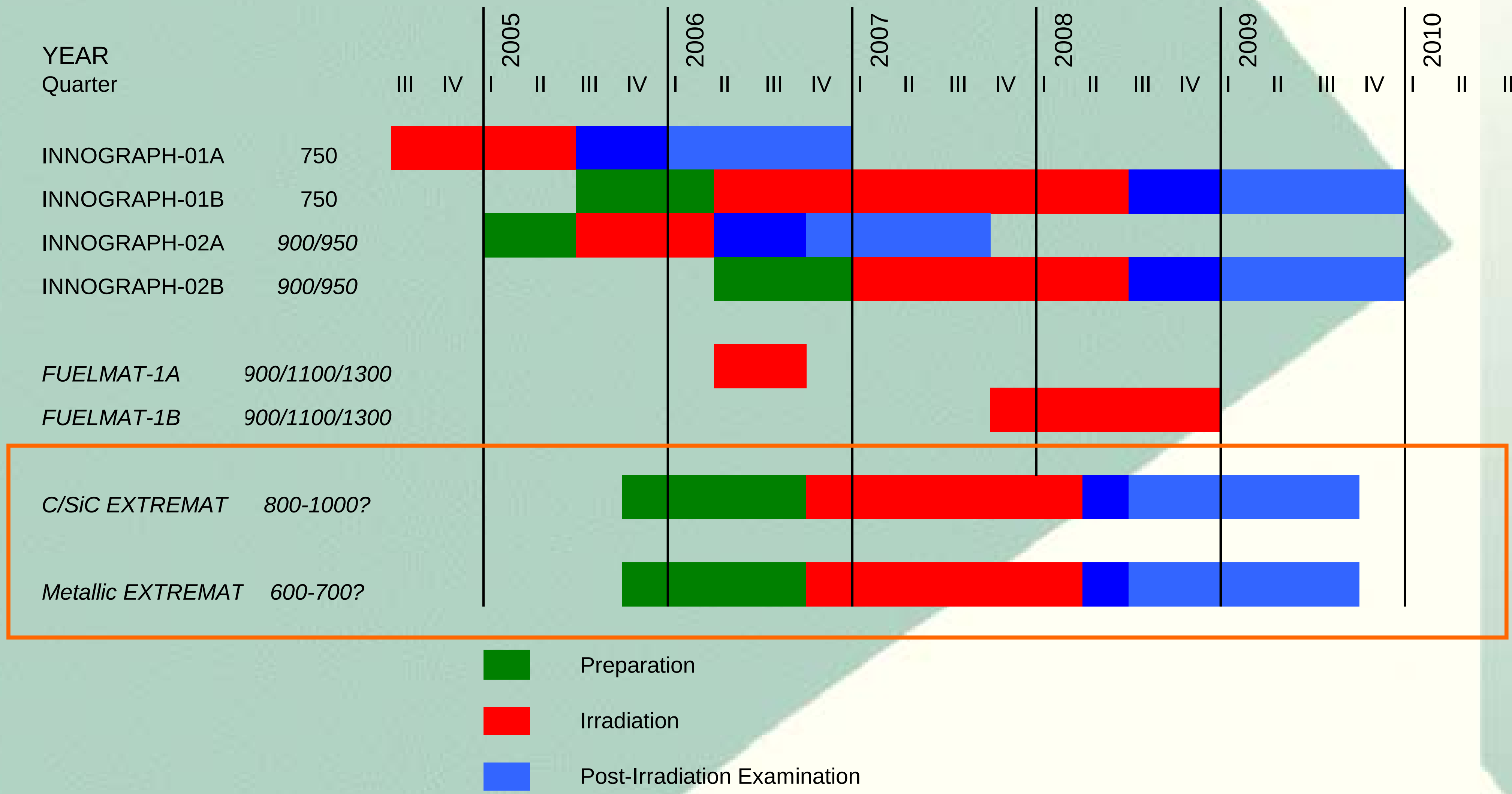
Composites (CC; CSiC; SiCSiC)

- Composites applicable for Control Rod sheath, support structures etc., fusion devices
- CC piggy backs in graphite irradiations
- SiCSiC also in fusion long term programme
- ExtreMat-IP, aims at novel materials for Gen4 and other applications with high irradiation environment, linked with VHTR-IP, now RAPHAEL-IP



→ Strengthen the basis for **“material design”**

Tentative Irradiation schedule



- Thank you for your attention
- Further info can be obtained through vanderlaan@nrg-nl.com
- Please note further HTR-M/M1 related papers in afternoon and poster session
- The paper is now open for discussion

Thermal diffusivity (1)

Morton CVD SiC

- Diffusivity drops with 85% and to 72% for the 600°C and 900°C irradiation respectively measured at 700°C
- Higher irradiation temperature, lower drop of diffusivity

CERASEP N3-1 SiC_f/SiC

- 3D/Nicalon/ CVI SiC
- Diffusivity drops with 70% to 80% for the 900°C and 600°C irradiation respectively