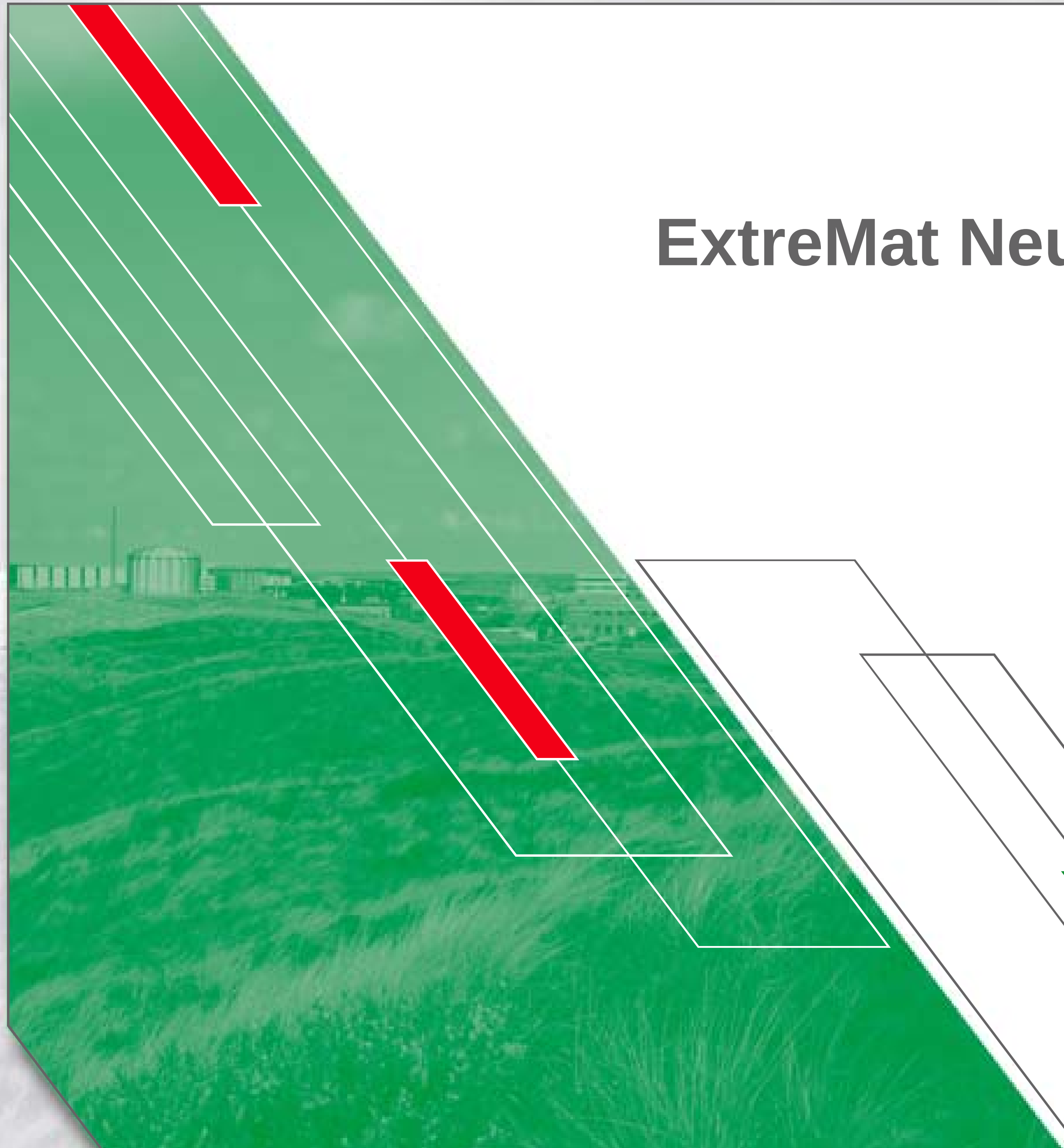


ExtreMat Neutron Irradiation Experiments

Onne Wouters
NRG, Petten
The Netherlands

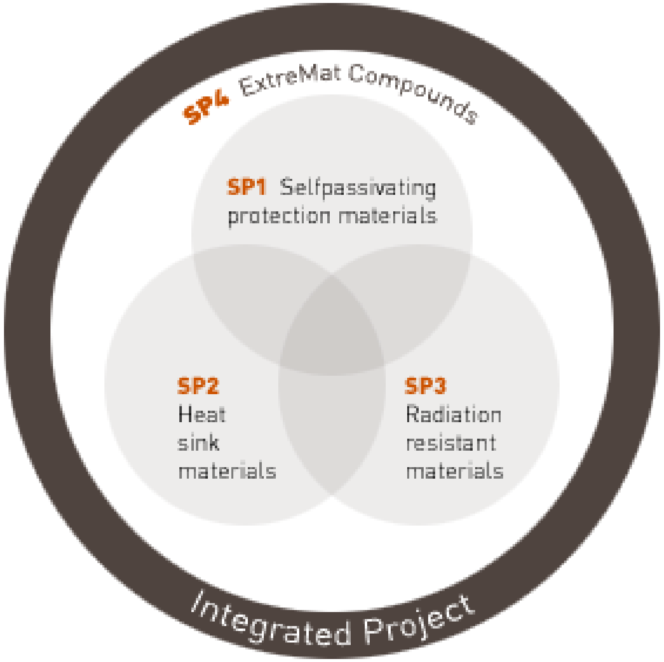
Content

- ExtreMat-IP
- NRG and its High Flux Reactor
- Materials and Applications
- Irradiation Experiment
- Irradiation results
- Post Irradiation experiments
- Outlook

ExtreMat Integrated Project

- Development of Materials that withstand extreme conditions
- Four Subprojects:

1. Self passivating protection materials
2. Heat sink materials
3. Radiation resistant materials
4. Compounds



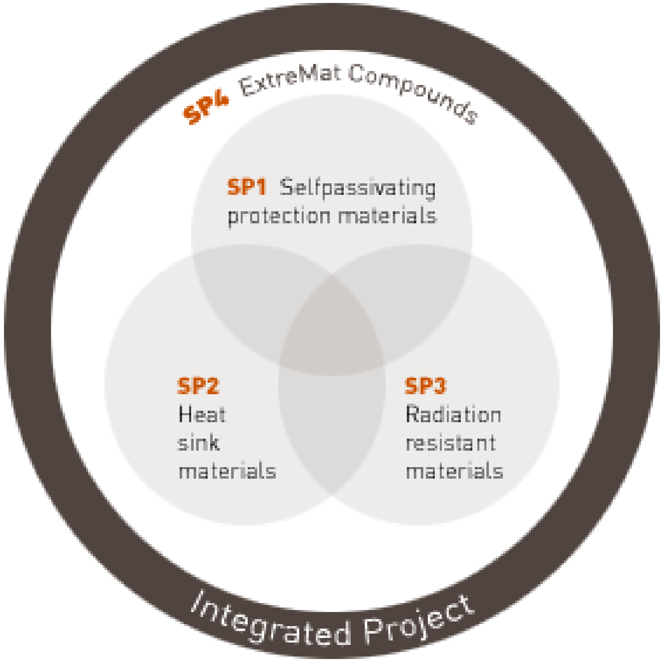
ExtreMat Integrated Project

Self passivating protection materials
- high thermal and mechanical loads
- operation in physico-chemically aggressive environments
- stability under off-normal conditions

Heat sink materials
- stable at high temperatures and large temperature fluctuations
- high thermal conductivity

Radiation resistant materials
- high neutron doses
- dimensional stability

Compounds
- stable interface



For most materials there are nuclear applications

NRG and the HFR

NRG: Nuclear Research and consultancy Group

- The Dutch centre for nuclear expertise
  - Fuel and materials research
  - Production of (medical) isotopes
  - Education and information
- Operates the High Flux Reactor

ExtreMat

ExtreMat at NRG

- NRG designs two irradiation experiments
  - ExtreMat-I: low dose, two temperatures: 300°C and 550°C
  - ExtreMat-II: high dose, two temperatures: 600°C and 900°C
- Material from 18 ExtreMat partners from all four Subprojects
- NRG performs large part of pre- and post-irradiation characterisation

Materials and Specimens

The two irradiation experiments are filled with a wide variety of specimen shapes and materials.

- (Doped) graphites
- SiC_fSiC, C_fSiC and C_fC composites
- Tungsten alloys
- CrRe
- ODS steels
- SiC, C and W-fibre reinforced copper
- Tungsted cladded on CuCrZr and on steel
- Bonded SiC_fSiC parts

These materials find applications in both advanced fission and future fusion reactors.

Materials and Specimens

Nuclear applications

- (Doped) graphites – Erosion resistant
  - For fusion first wall and possibly also applications in (V)HTRs
- SiC_fSiC, C_fSiC and C_fC composites
  - Temperature resistant for fusion first wall and divertor
  - In advanced fission: SiC_fSiC as fuel cladding in GCFR
  - As control rod or core restrainer material in (V)HTRs
- Tungsten
  - In fusion reactor as first wall material and in the divertor

Materials and Specimens

Nuclear applications

- ODS steels – Creep resistant at high temperatures
  - In fusion as blanket first wall material
  - As fuel cladding in SFR and GCFR
  - In primary circuit in VHTRs
- SiC, C and W-fibre reinforced copper
  - High thermal conductivity combined with good mechanical properties
  - As heat sink material behind fusion reactor's first wall
- Tungsted cladded on CuCrZr and on steel
  - For fusion first wall and divertor
- Bonded SiC_fSiC parts

Materials and Specimens

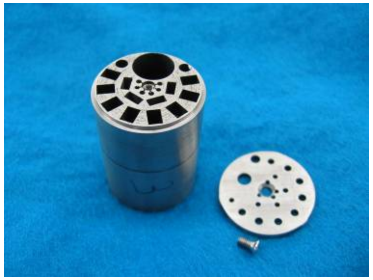
Specimen types

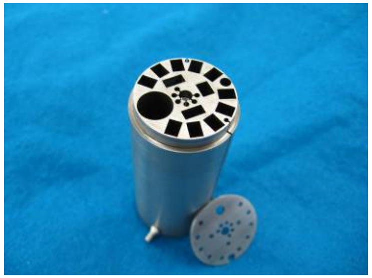
- Tensile bars
- Three point bend beams
- Pills for determination of physical properties
  - Thermal expansion
  - Thermal diffusivity / conductivity
  - Sonic velocity
- Mock-ups of plasma facing wall of a fusion reactor
- TEM discs

Total number of specimens: 493

Irradiation capsule

- Drum based design
- 11 drums in total
- 24 thermocouples, 2 or 3 per drum
- The drums are purged with extra pure Helium gas
- All specimen have to fit a 30 mm by 450 mm cylinder



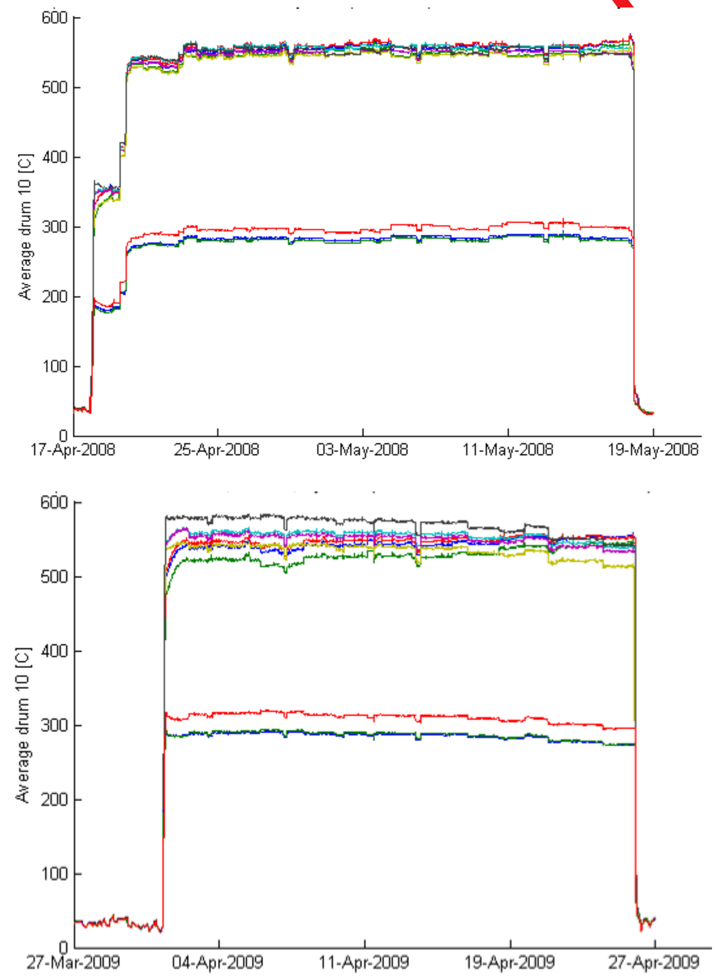


Irradiation results ExtreMat-I

- Irradiated from Feb. 2008 – April 2009
- Total irradiation duration: 6 months
- Total achieved doses (dose estimates in dpa):

	Steel	Graphite	Tungsten
Peak	1.85	1.97	0.51
Drum 1	0.98		0.27
Drum 2	1.2		0.35
Drum 3	1.5		0.42

- Temperatures are initially right on target
- Last cycle shows more deviation due to changing properties of the samples



Drum temperatures of ExtreMat-I at start (top) and end (bottom) of irradiation

Post-irradiation examination

Non-destructive measurements

- Photography
- Dimensional change
- Density
- Coefficient of thermal expansion
- Thermal diffusivity (indirect: thermal conductivity)
- Dynamic Young's modulus through sonic velocity determination

- Measurements are performed in glove boxes → no shielding for gamma-radiation → only possible on low dose rate material

Destructive measurements

- Three point bend testing
- Four point bend testing
- Tensile testing
- Interface strength tests

- Measurements are performed in hot cells → sufficient shielding for gamma-radiation → All samples can be measured

Post-irradiation examination

NRG

Dose rates samples from ExtreMat-I

1. Low contact dose rate (0 – 1 mSv/hr)
- Most undoped graphites
- Undoped C_fC's
- Most undoped SiC_fSiC's
- Si-doped graphite from UALI
2. Medium contact dose rate (1 – 5 mSv/hr)
- Ti-doped C_fC's from INCAR
- SGL reference 1µ graphite
- POLITO ceramic joining material
3. Medium / High contact dose rate (5 - 15 mSv/hr)
- Ti doped graphites from UALI
- Ti doped graphites from CEIT
4. High contact dose rate (> 15 mSv/hr)
- Zr-doped graphites
- All metallic samples and metal matrix composites

Have been measured

Are being measured in order of dose rate

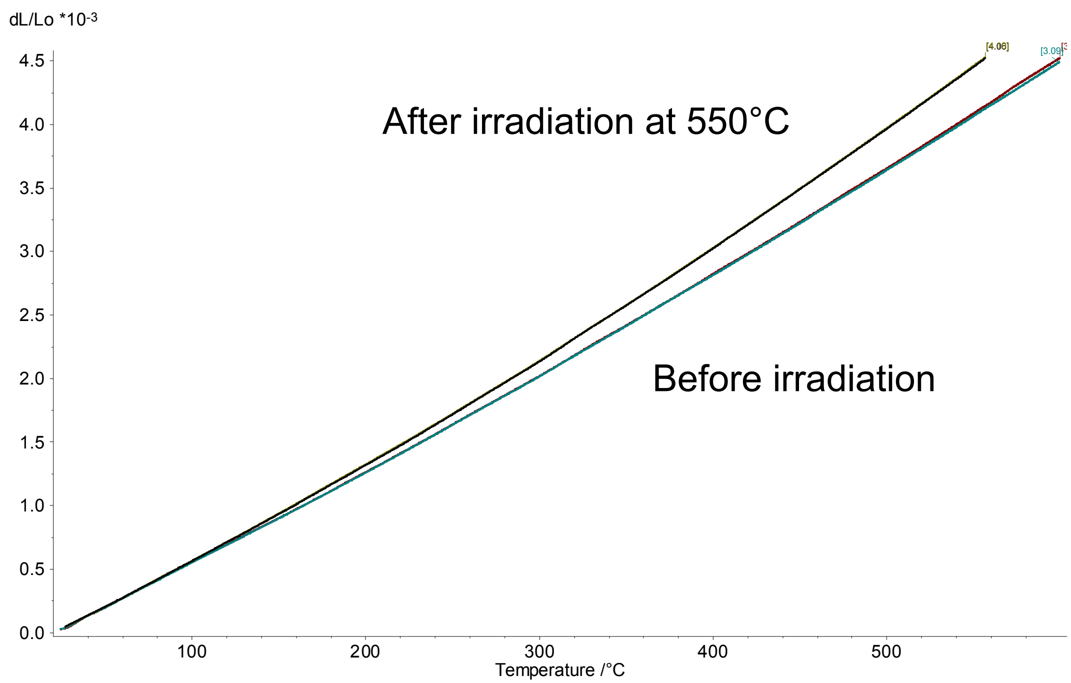
Cannot be measured
Wait for dose rate to drop (^{46}Sc: $T_{1/2}$=83 d)

Cannot be measured in glove box
(^{93}Zr: $T_{1/2}=1\cdot10^6$ y)

ExtreMat

Post-irradiation examination

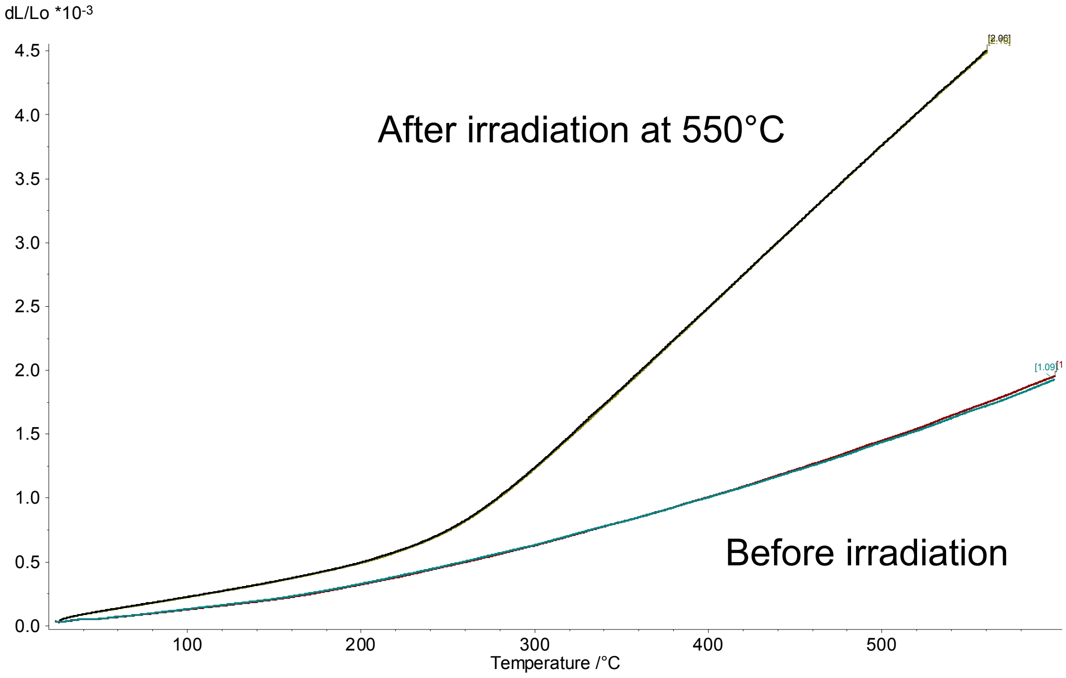
Selected results – 1. Coefficient of thermal expansion



X213: UALI Si-doped graphite

Post-irradiation examination

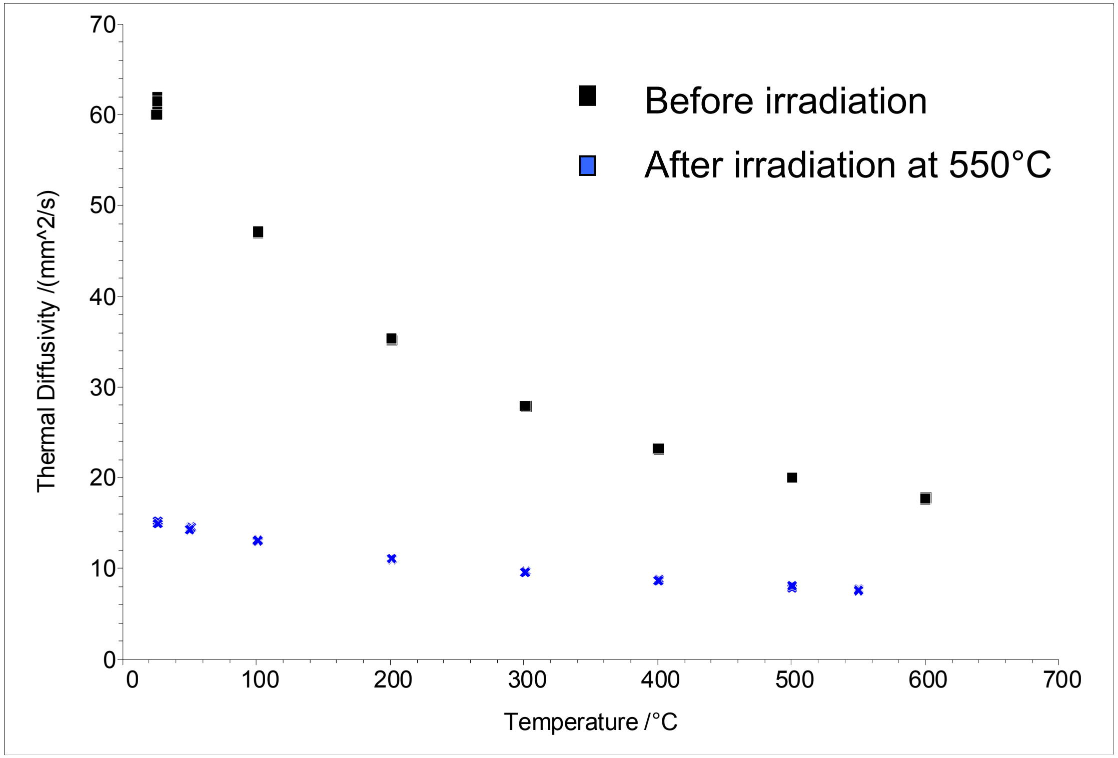
Selected results – 1. Coefficient of thermal expansion



X531: SGL C_fC CVI 3D

Post-irradiation examination

Selected results – 2. Thermal diffusivity

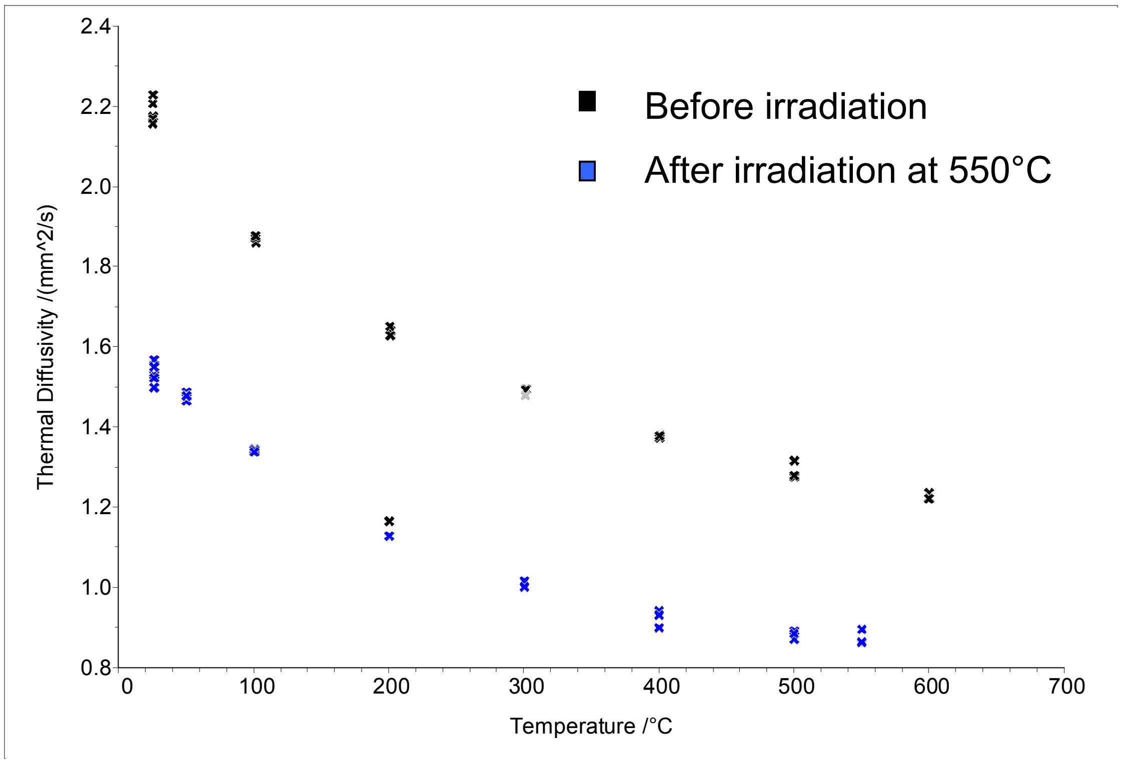


X377: CEIT AR mesophase pitch graphite

Post-irradiation examination

NRG

Selected results – 2. Thermal diffusivity



X560: SGL C_fC UD W4-9

ExtreMat

Post-irradiation examination

Selected results – 3. Dimensional change & Dynamic Young's modulus

Sample	Type	Before irradiation Length (mm)	Before irradiation Diameter (mm)	Before irradiation Density (g/cc)	Before irradiation DYM (GPa)	After irradiation Length (mm)	After irradiation Diameter (mm)	After irradiation Density (g/cc)	After irradiation DYM (GPa)
X198	UALI co-pyrolysis compound graphite	6.028	8.184	1.91	12.5	6.029	8.081	1.95	20.3
X213	UALI Si-doped graphite	6.030	8.119	2.01	21.8	6.029	8.070	2.03	28.1
X314	CEIT raw SGL graphite	6.067	8.099	1.74	12.8	6.036	8.008	1.79	20.6
X377	CEIT AR mesophase pitch graphite	6.002	8.089	1.84	9.3	6.003	7.999	1.88	14.1
X470	SGL reference material 3μ graphite	5.977	8.018	1.85	14.2	5.981	8.000	1.86	24.4
X483	SGL CfC 2D Pan fiber	5.353	8.029	1.59	--	5.421	7.709	1.69	5.1

- Small dimensional changes, samples shrink
- Large increase in Young's modulus

Outlook

Continuation PIE ExtreMat-I

- Mechanical tests
- Medium dose rate material

Extremat-II will be irradiated until Dec. 2009

- 600°C and 900°C
- Higher neutron dose
- PIE results will be available at the end of 2010