MATERIAL IRRADIATION STUDIES
BNL AGS/BLIP/Hot Cell FACILITY

STATUS

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PHASE-II TARGET MATERIAL STUDY

Material Matrix

Carbon-Carbon composite

GRAPHITE (IG-43)

Titanium Ti-6Al-4V alloy

Toyota "Gum Metal".

VASCOMAX

AlBeMet

Nickel-Plated Aluminum

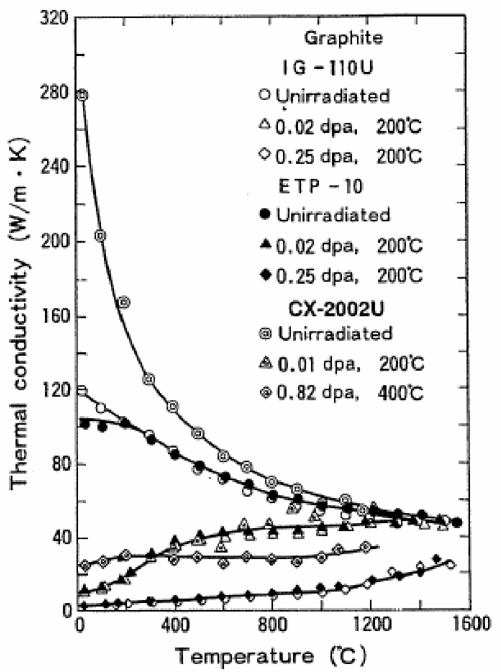
TESTS (on-going + upcoming)

Mechanical property changes
- Ductility loss
- Strength loss/gain
- Fracture toughness

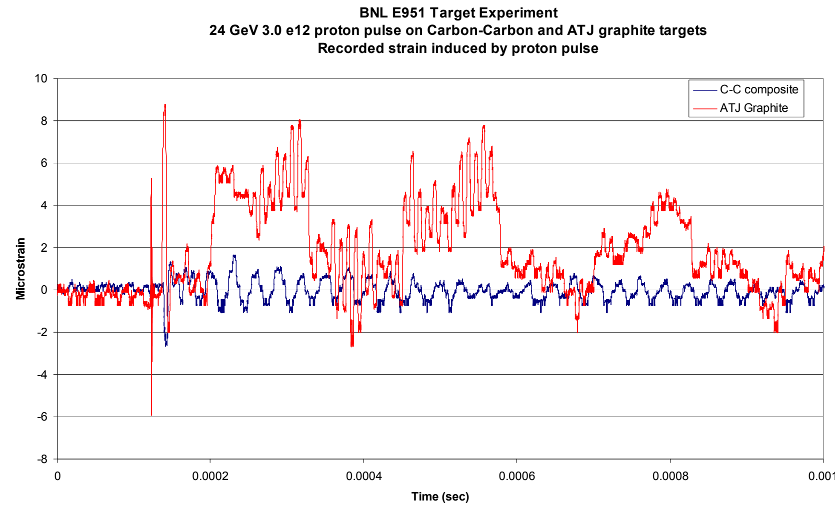
Physical property changes
- CTE
- Diffusivity
- Heat capacity

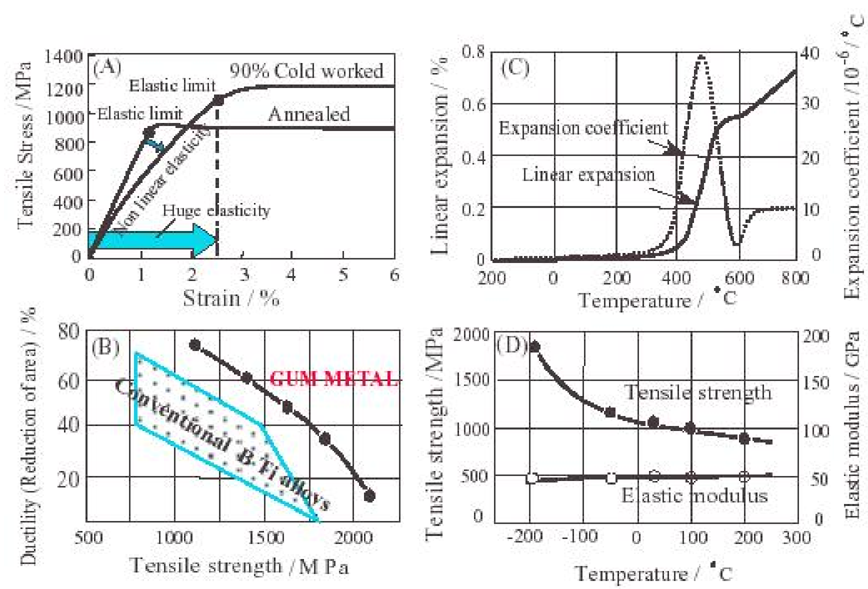
Shock resilience

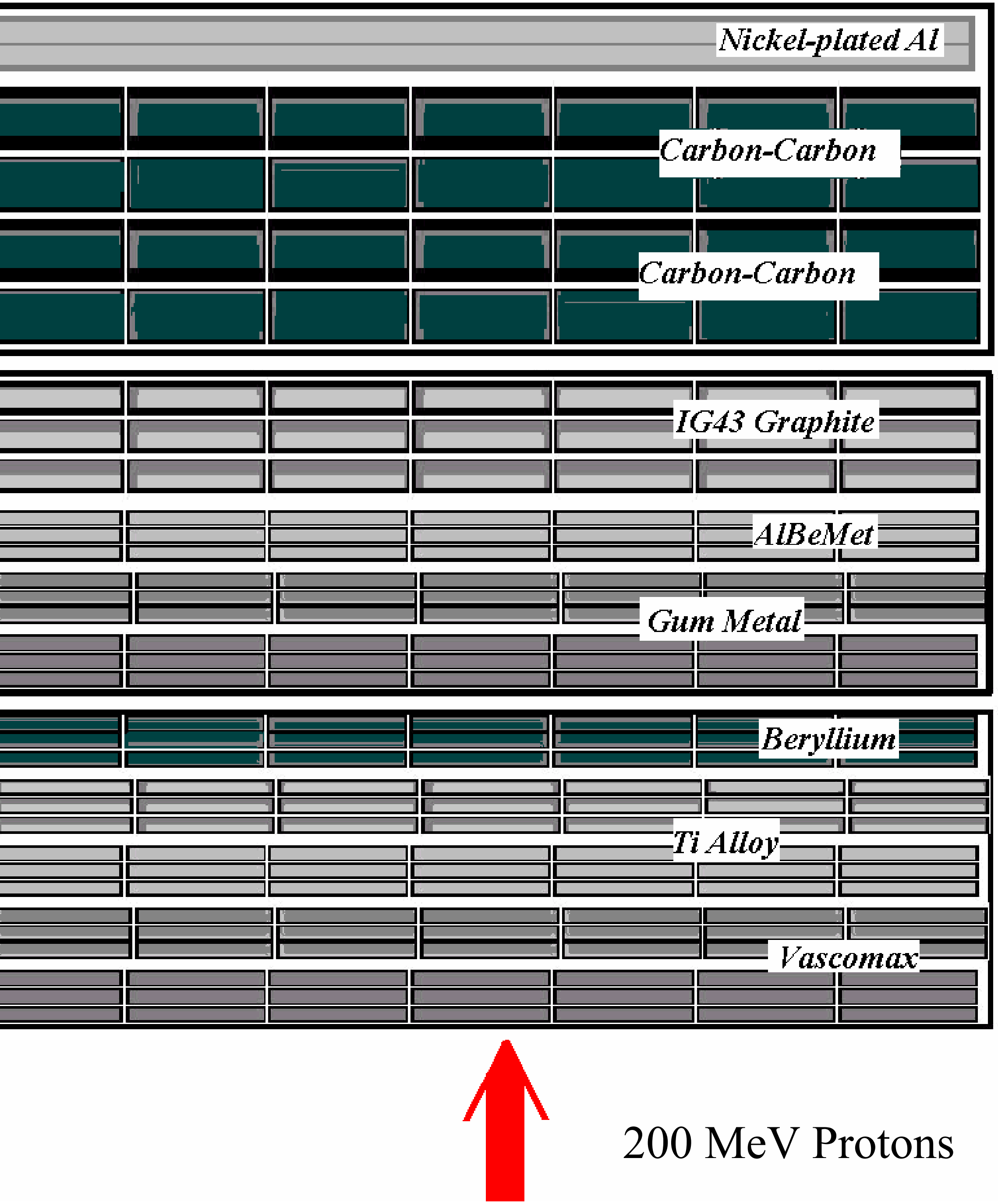
WHY DO WE WANT TO DO THESE TESTS?



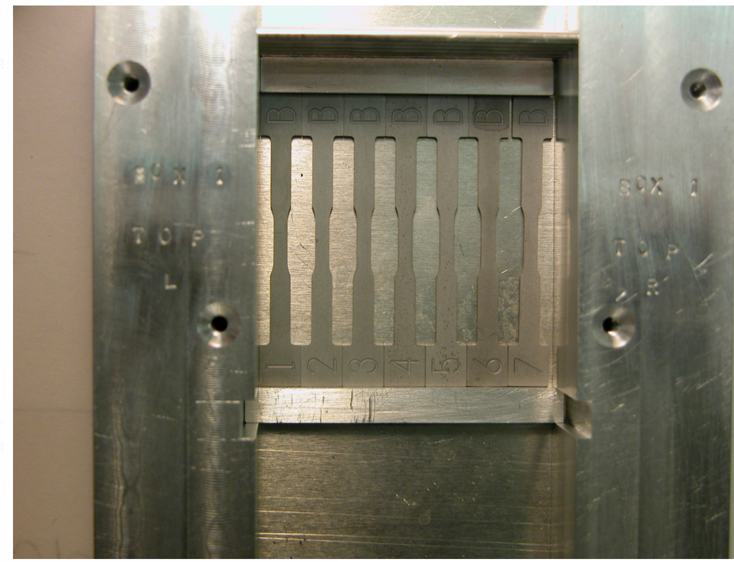
Thermal conductivity of neutron-irradiated graphites.

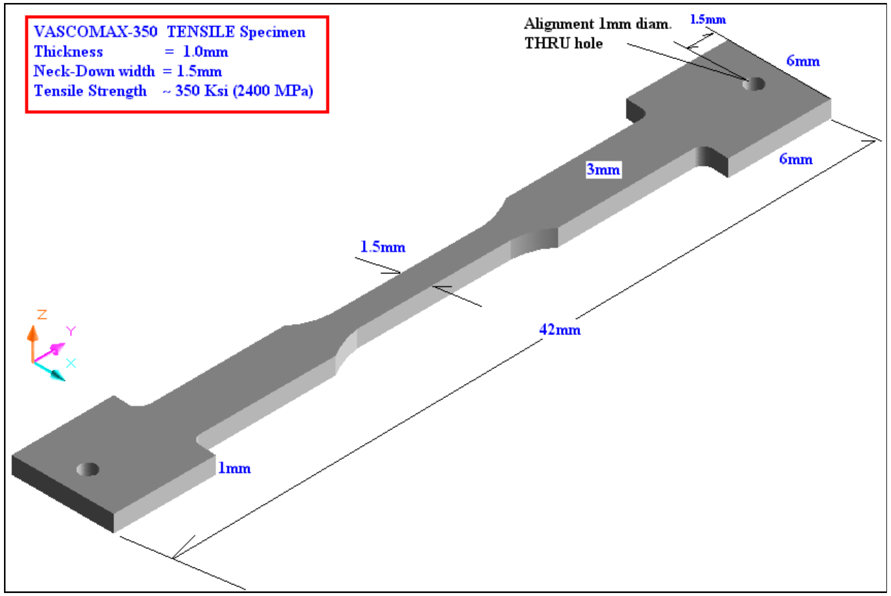




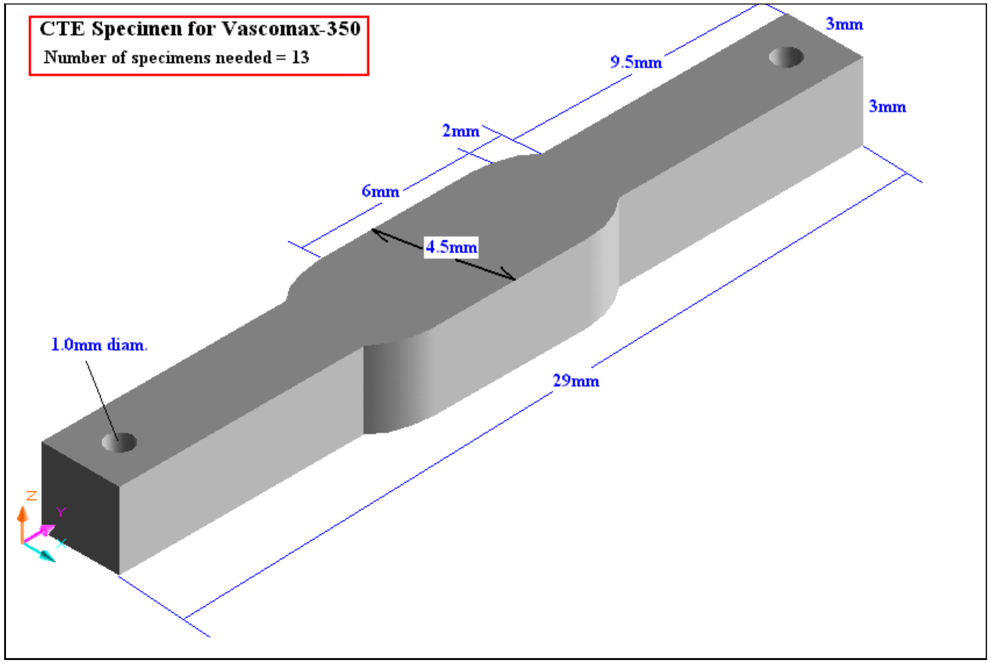


200 MeV Protons

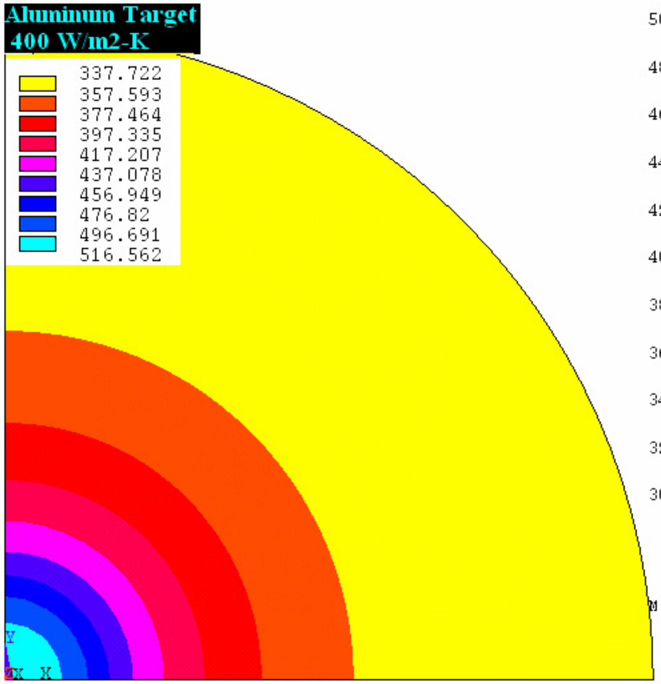


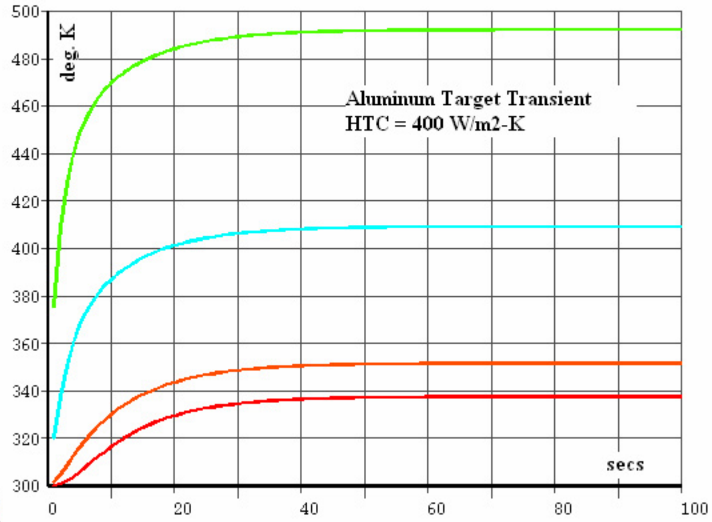


VASCOMAX-350 TENSILE Specimen
Thickness = 1.0mm
Neck-Down width = 1.5mm
Tensile Strength ~ 350 Ksi (2400 MPa)
Alignment 1mm diam. THRU hole
1.5mm
6mm
6mm
3mm
1.5mm
42mm
1mm



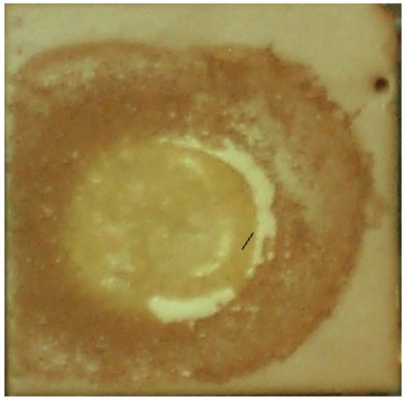
CTE Specimen for Vascomax-350
Number of specimens needed = 13
3mm
3mm
9.5mm
2mm
6mm
4.5mm
1.0mm diam.
29mm

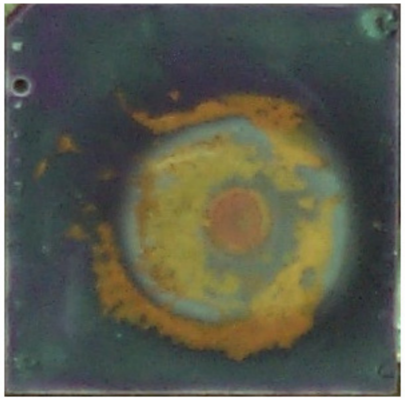


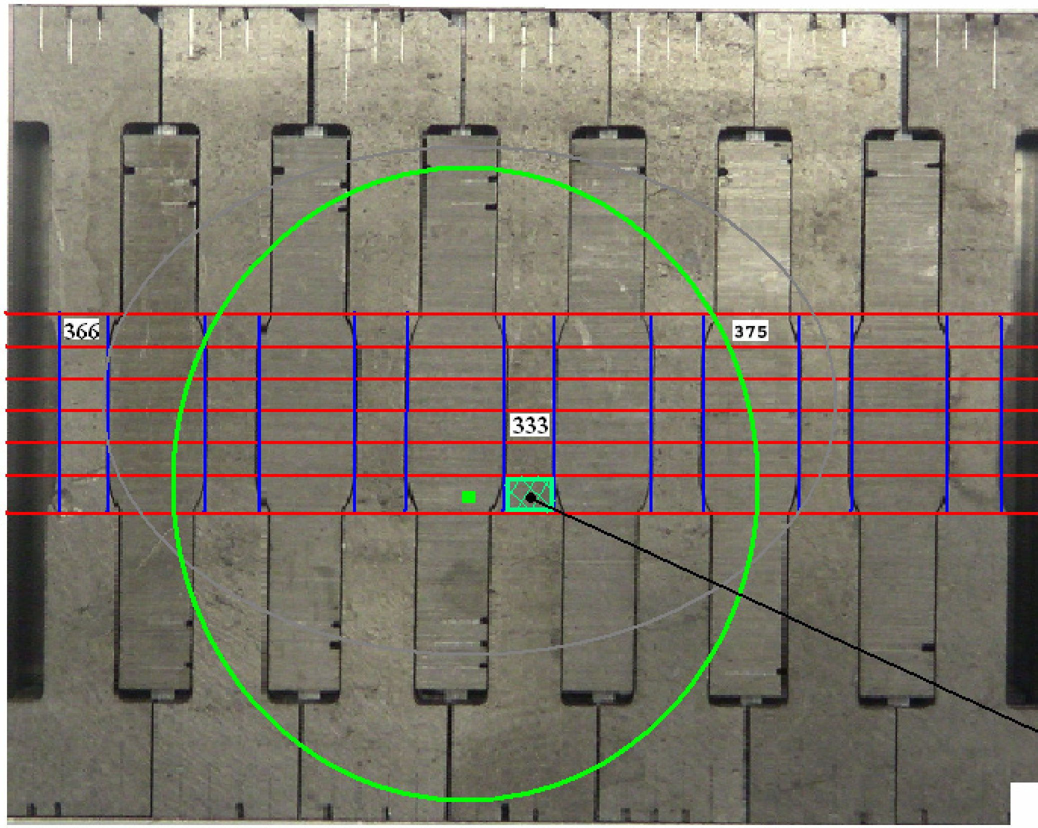


Establishing Irradiation Temperature

Thermal Sensitive Paint Technique







Results of autoradiographic beam profile measurements for the 2004 BLIP irradiation, using the “downstream” nickel foil.

Horizontal position looking at the surface where the beam enters the foil	Vertical position	Horizontal rms width (σ)	Vertical rms width (σ)
2.9 ± 0.5 mm left of center	4.5 ± 0.5 mm below center	8.1 ± 0.3 mm	8.4 ± 0.3 mm

Irradiation Damage Analysis (dpa) showed that this cell associated with the tensile specimenn experiences most damage

266	267	268	269	270	271	272	273	274	275	276	277	278
253	254	255	256	257	258	259	260	261	262	263	264	265
240	241	242	243	244	245	246	247	248	249	250	251	252
227	228	229	230	231	232	233	234	235	236	237	238	239
214	215	216	217	218	219	220	221	222	223	224	225	226
201	202	203	204	205	206	207	208	209	210	211	212	213

VASCOMAX SAMPLE ACTIVATION

CTEs: 7.52 mCi - 151.2 mCi
Tensile: 5.59 mCi - 42.6 mCi

166	167	168	169	170	171	172	173	174	175	176	177	178
153	154	155	156	157	158	159	160	161	162	163	164	165
140	141	142	143	144	145	146	147	148	149	150	151	152
127	128	129	130	131	132	133	134	135	136	137	138	139
114	115	116	117	118	119	120	121	122	123	124	125	126
101	102	103	104	105	106	107	108	109	110	111	112	113

Tensile Vsc#s 1;8;15

CTE Vsc# 5

Tensile Vsc #s 4;11;18

VASCOMAX SAMPLE dpa estimates

Cell 133:
from neutrons : 0.011336 dpa
from protons: 0.222335 dpa

Cell 233:
from neutrons: 0.013827 dpa
from protons: 0.2214 dpa

Cell 220:
from neutrons: 0.0157 dpa
from protons: 0.24377 dpa

Irradiation Damage in Gum Metal

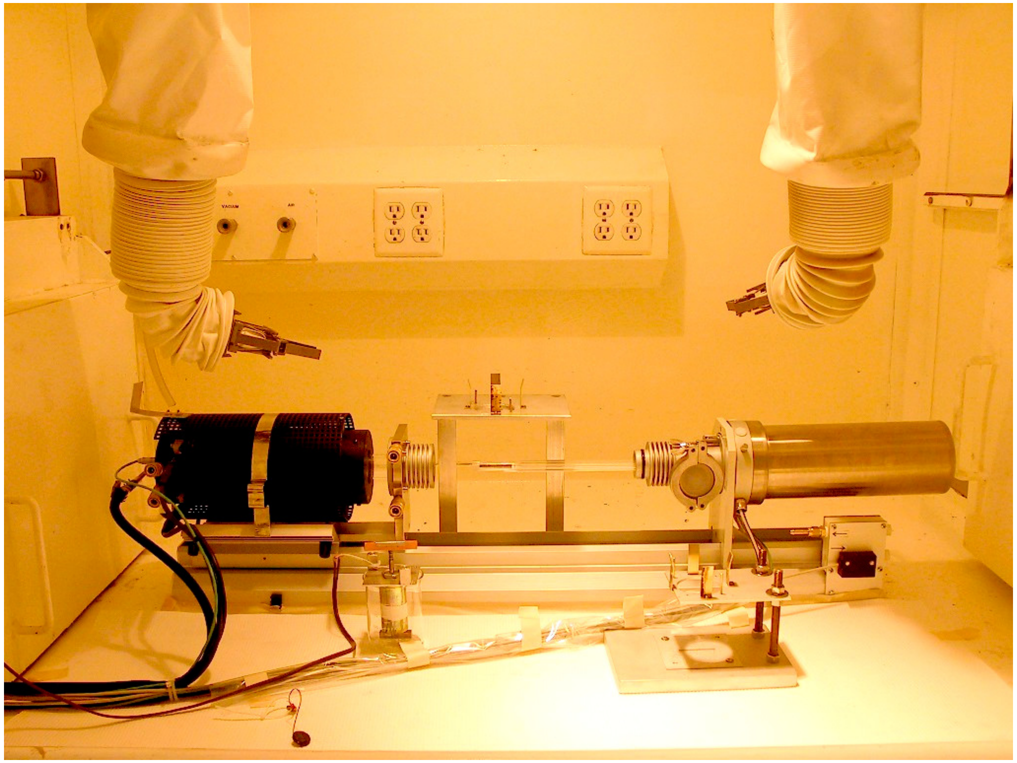
Highest dpa values estimated also near the bottom half of the tensile specimen “gauge” as in Vascomax.

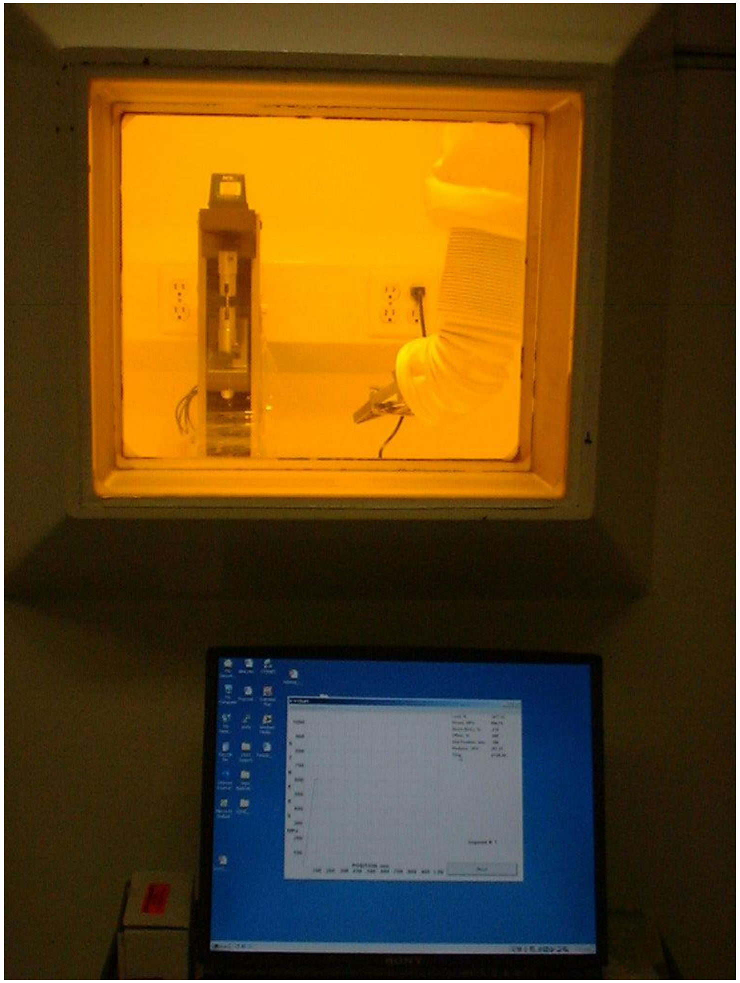
GUM $(dpa)\_max = 0.242$ (protons) + 0.0132 (neutrons)

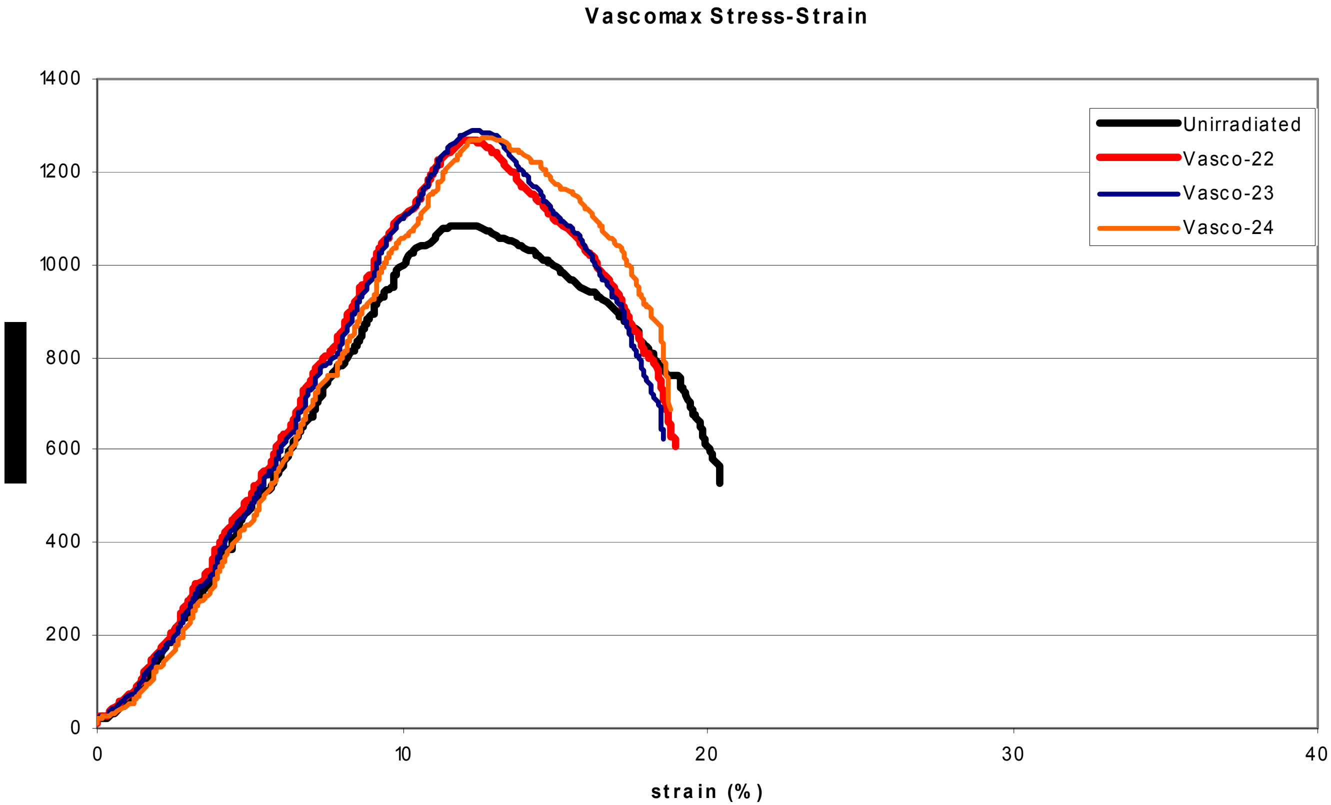
For the rest of the materials appropriate dpa cross sections are being sought to be introduced into the model.

Post-Irradiation Study at BNL Hot Cell

Dilatometer – Mechanical Tester

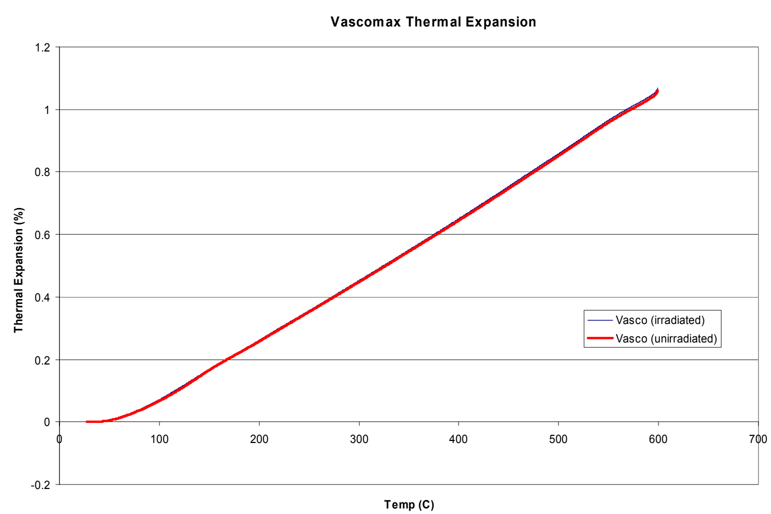


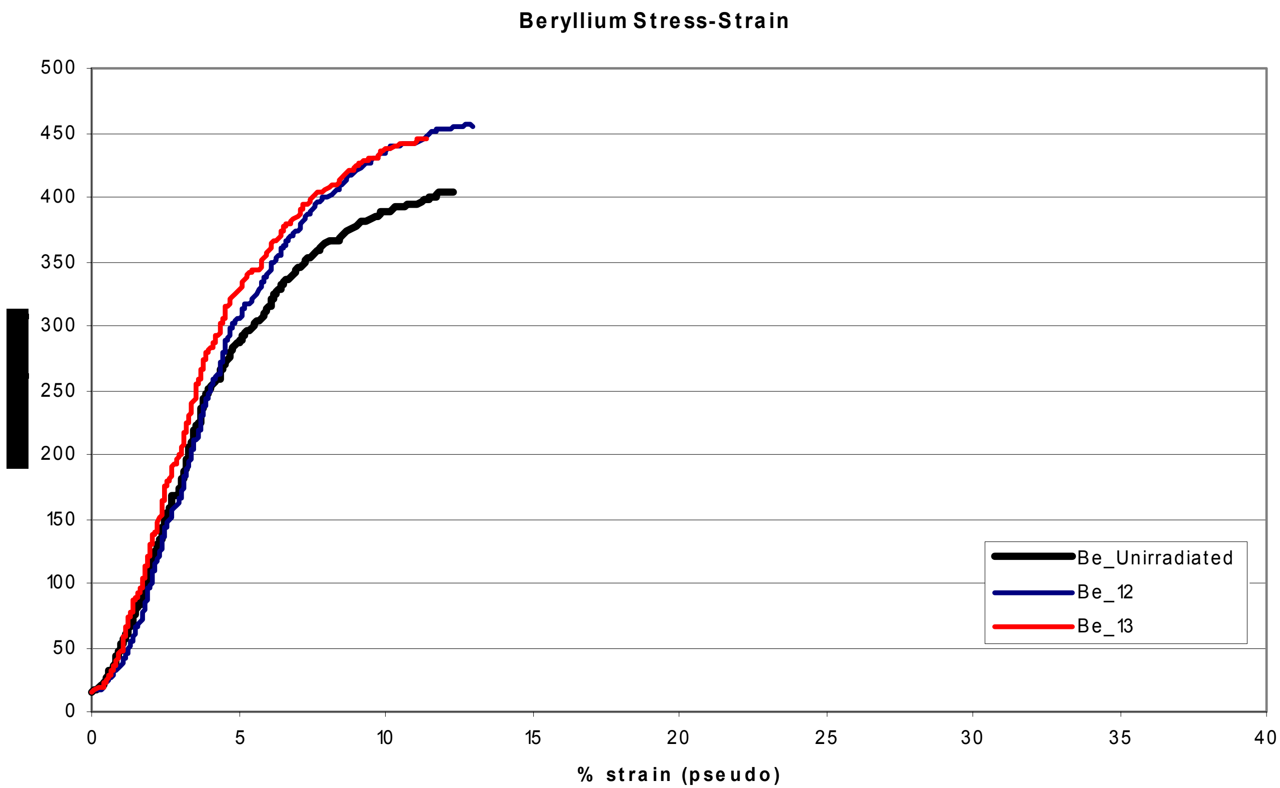


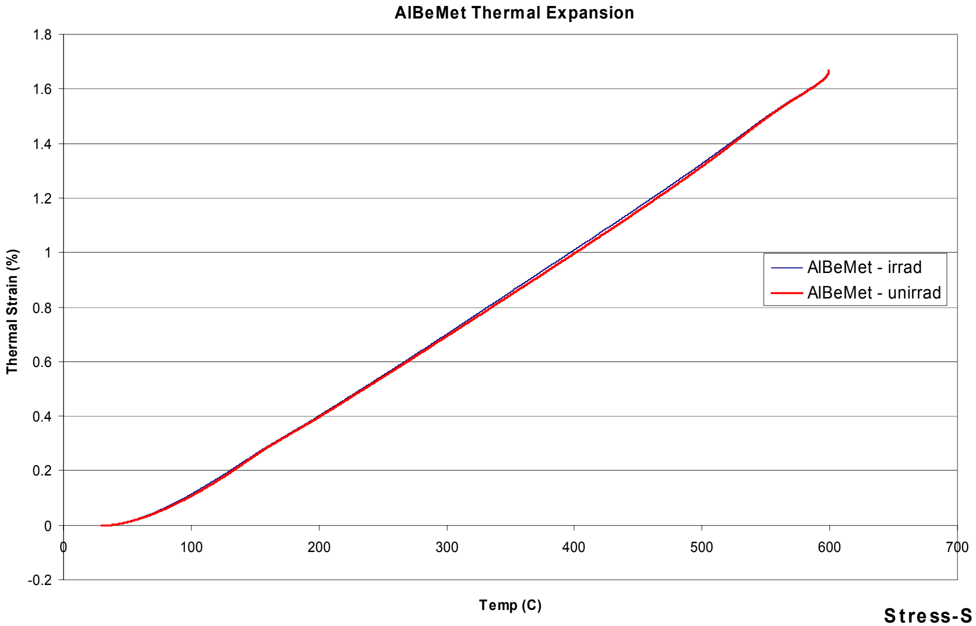


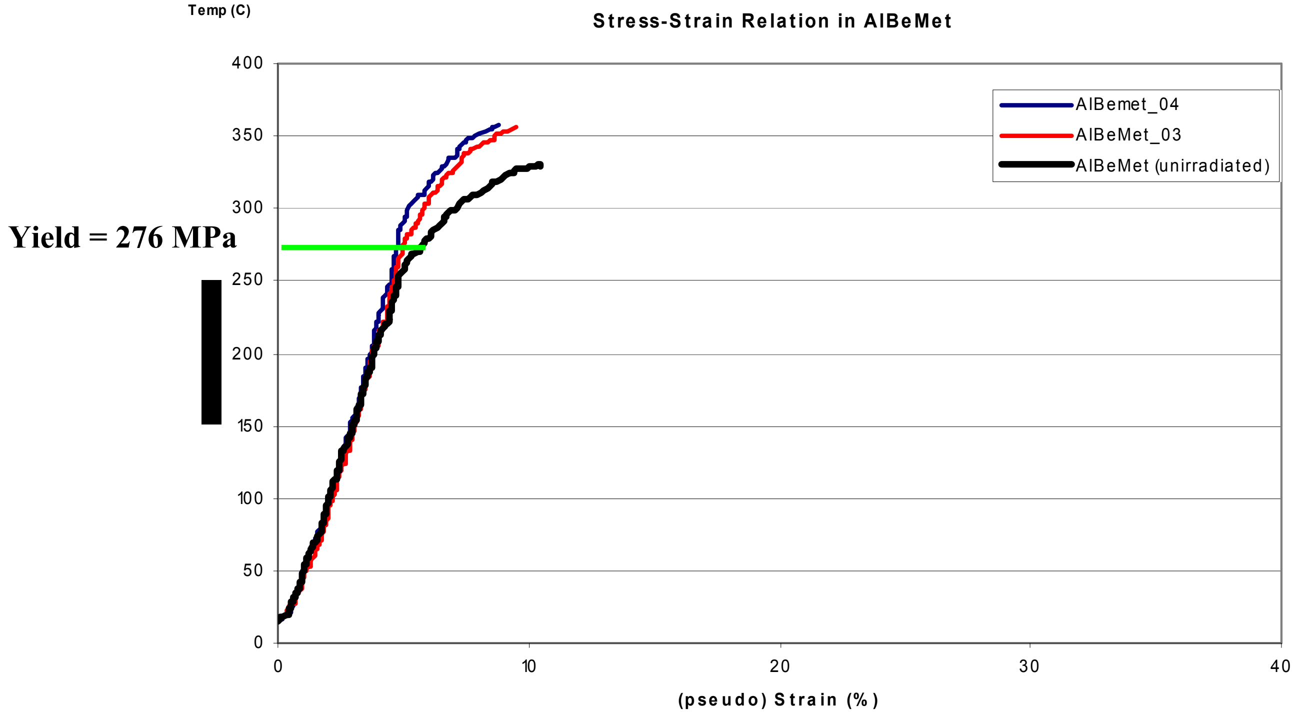
Vasomax is a very interesting Material

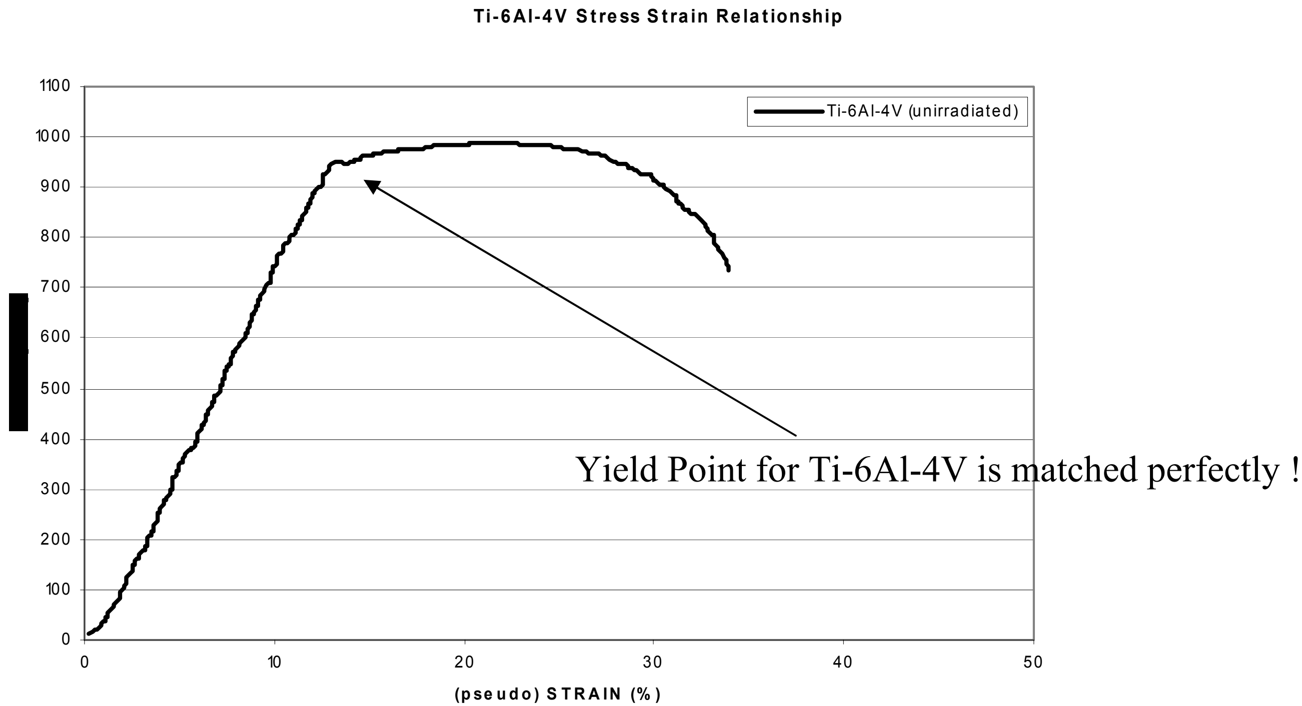
- It strengthens with irradiation without turning brittle
- CTE is not affected by irradiation

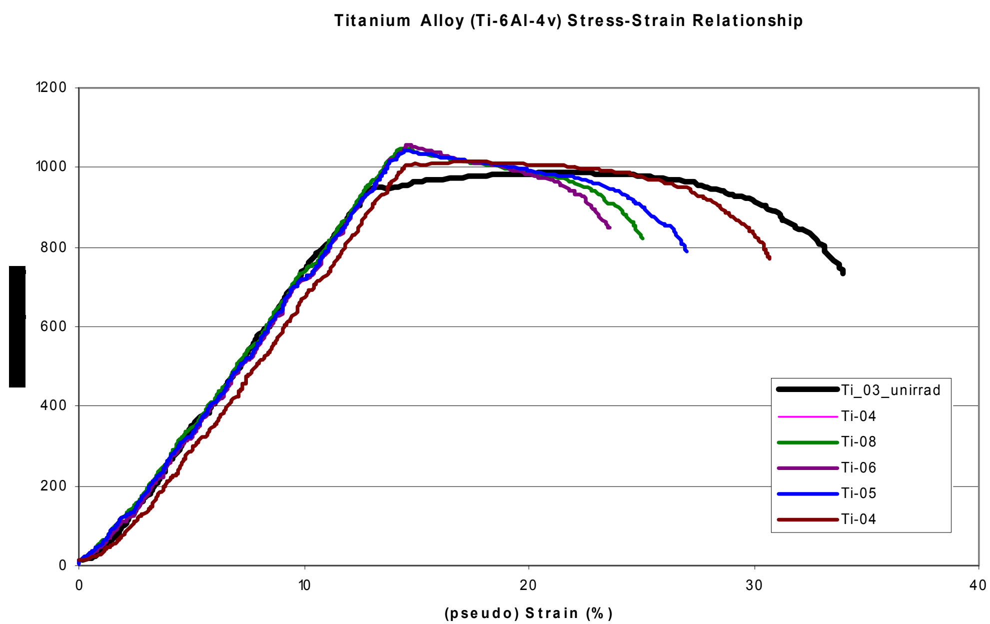


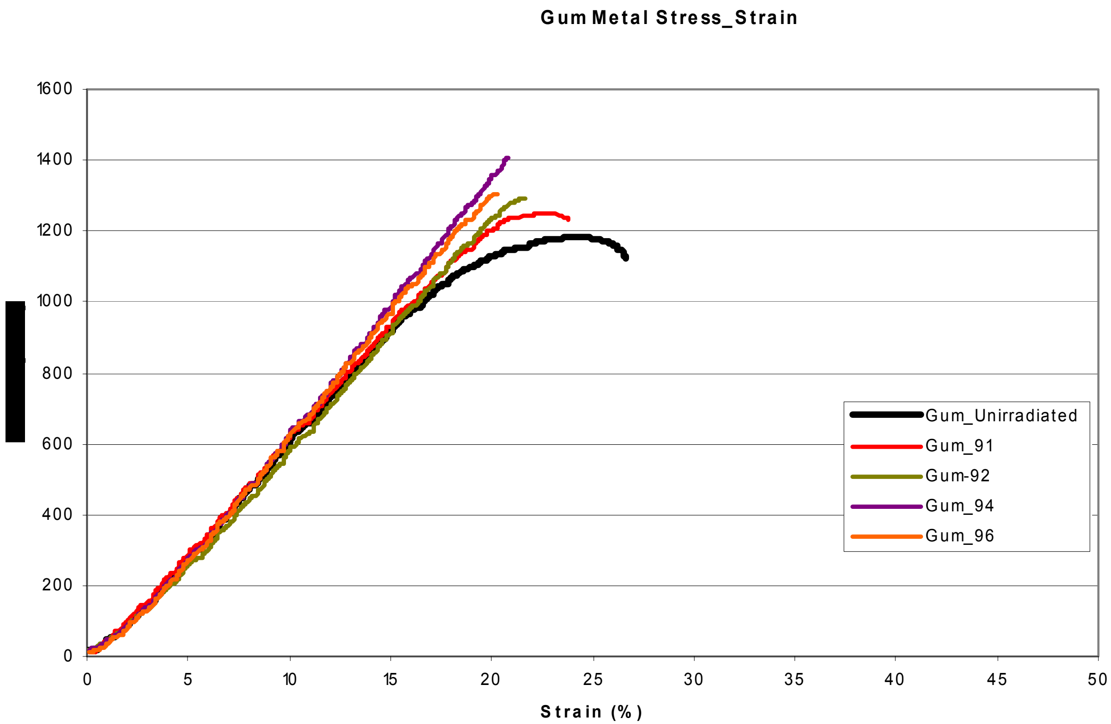

Beryllium Stress-Strain
[redacted]
500
450
400
350
300
250
200
150
100
50
0
0
5
10
15
20
25
30
35
40
% strain (pseudo)
Be_Unirradiated
Be_12
Be_13


AlBeMet Thermal Expansion
Thermal Strain (%)
Temp (C)
AlBeMet - irrad
AlBeMet - unirrad
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
0
100
200
300
400
500
600
700


Stress-Strain Relation in AlBeMet
Yield = 276 MPa
[redacted]
(pseudo) Strain (%)
AlBemet_04
AlBeMet_03
AlBeMet (unirradiated)
400
350
300
250
200
150
100
50
0
0
10
20
30
40


Ti-6Al-4V Stress Strain Relationship
Ti-6Al-4V (unirradiated)
[redacted]
1100
1000
900
800
700
600
500
400
300
200
100
0
0
10
20
30
40
50
(pseudo) STRAIN (%)
Yield Point for Ti-6Al-4V is matched perfectly !

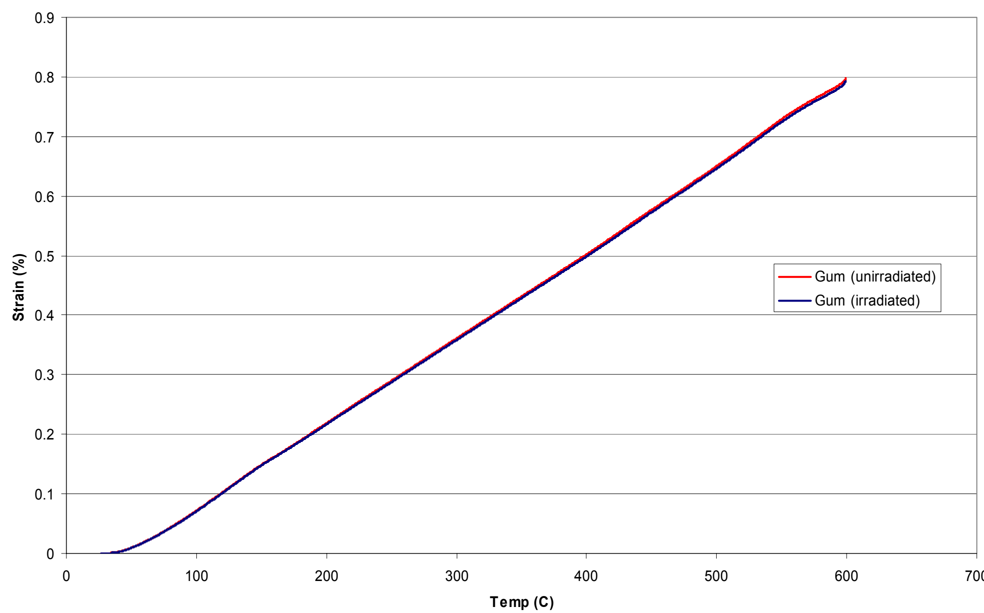

Titanium Alloy (Ti-6Al-4v) Stress-Strain Relationship
[redacted]
1200
1000
800
600
400
200
0
0
10
20
30
40
(pseudo) Strain (%)
Ti_03_unirrad
Ti-04
Ti-08
Ti-06
Ti-05
Ti-04



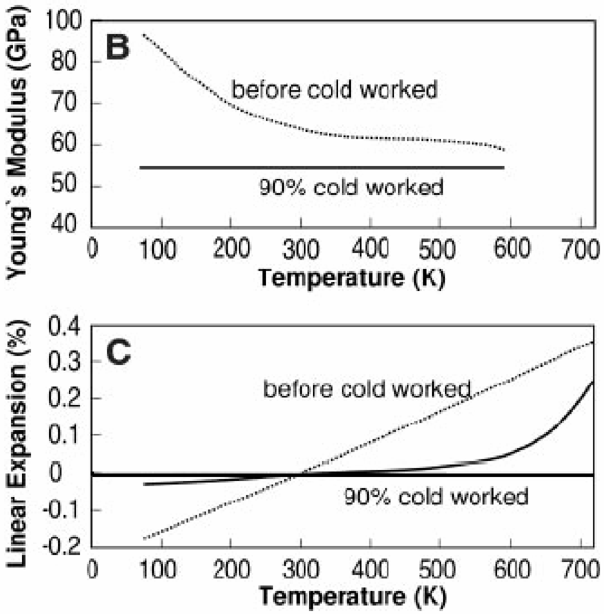
GUM Metal

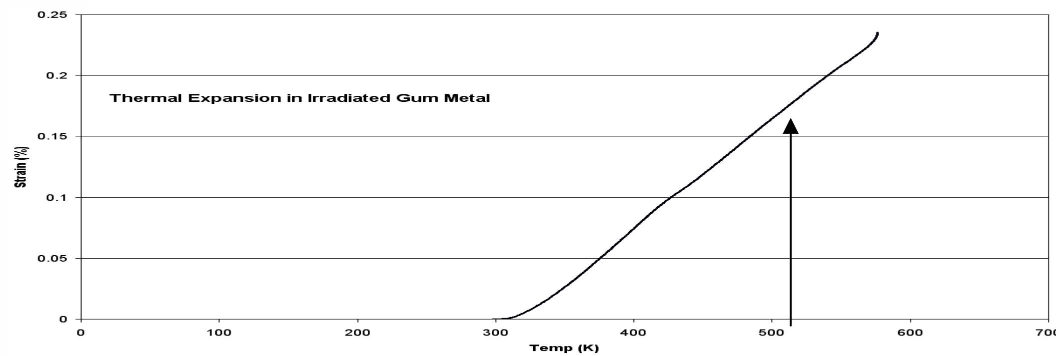
Strengthens but clearly looses the "super-ductility property

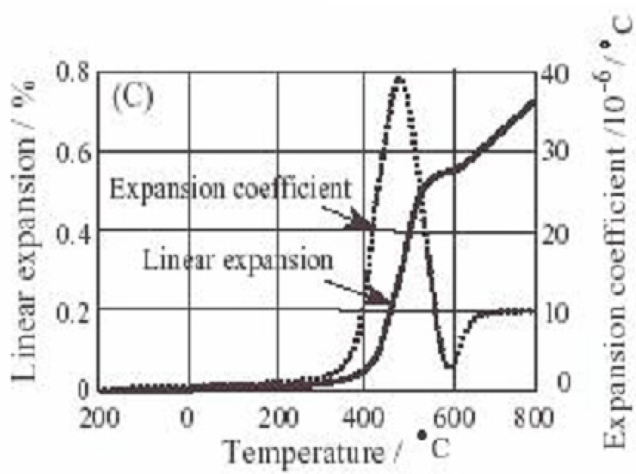
The type of gum metal being tested (between annealed and 90% cold worked) Appears to hold its CTE characteristics

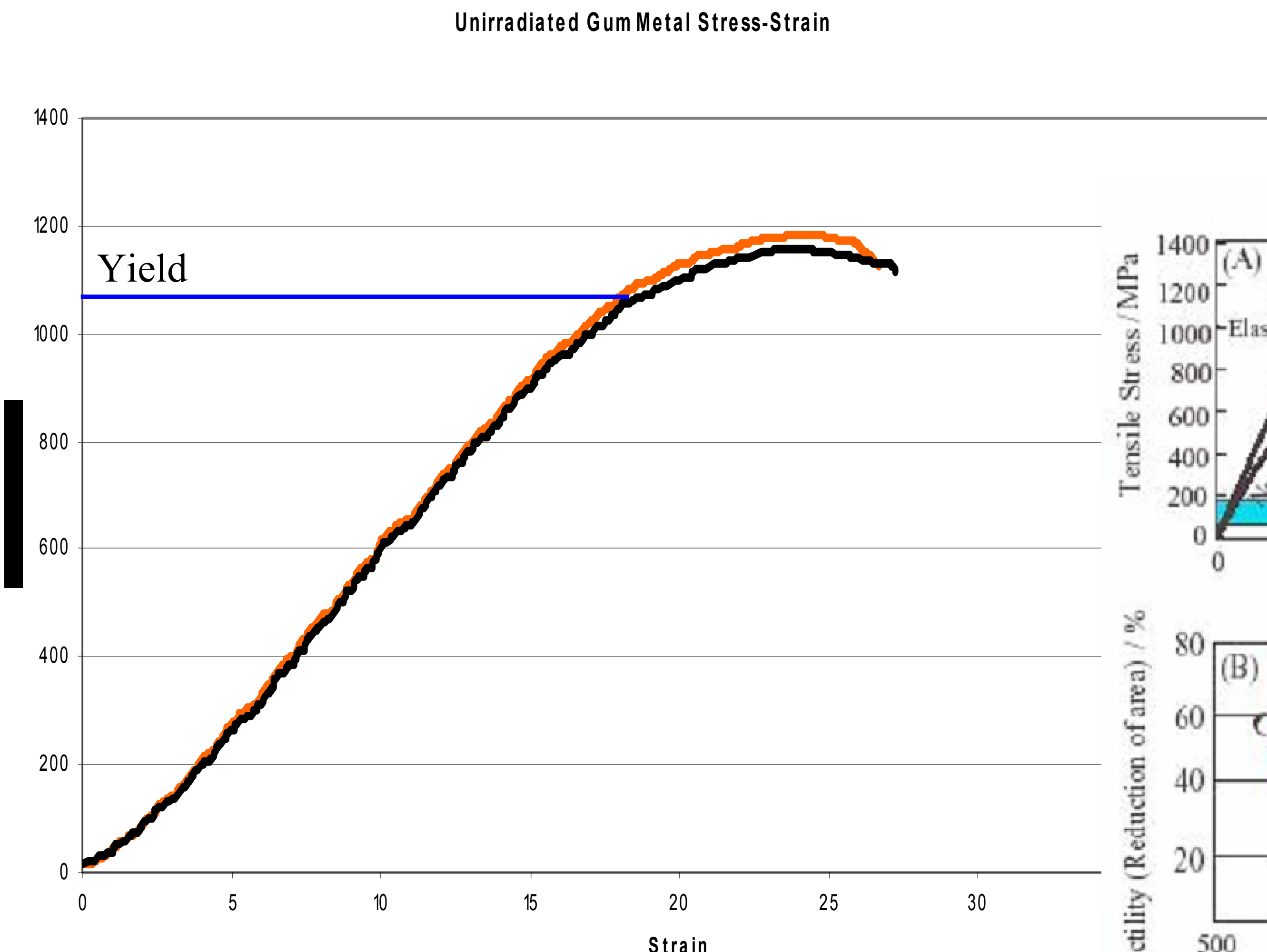


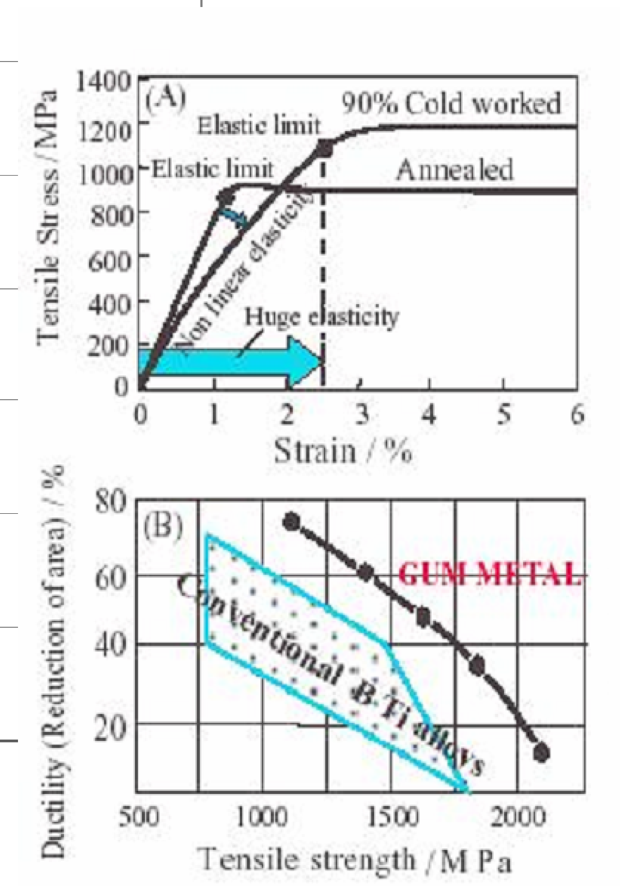
Effects of Irradiation on Gum Thermal Expansion

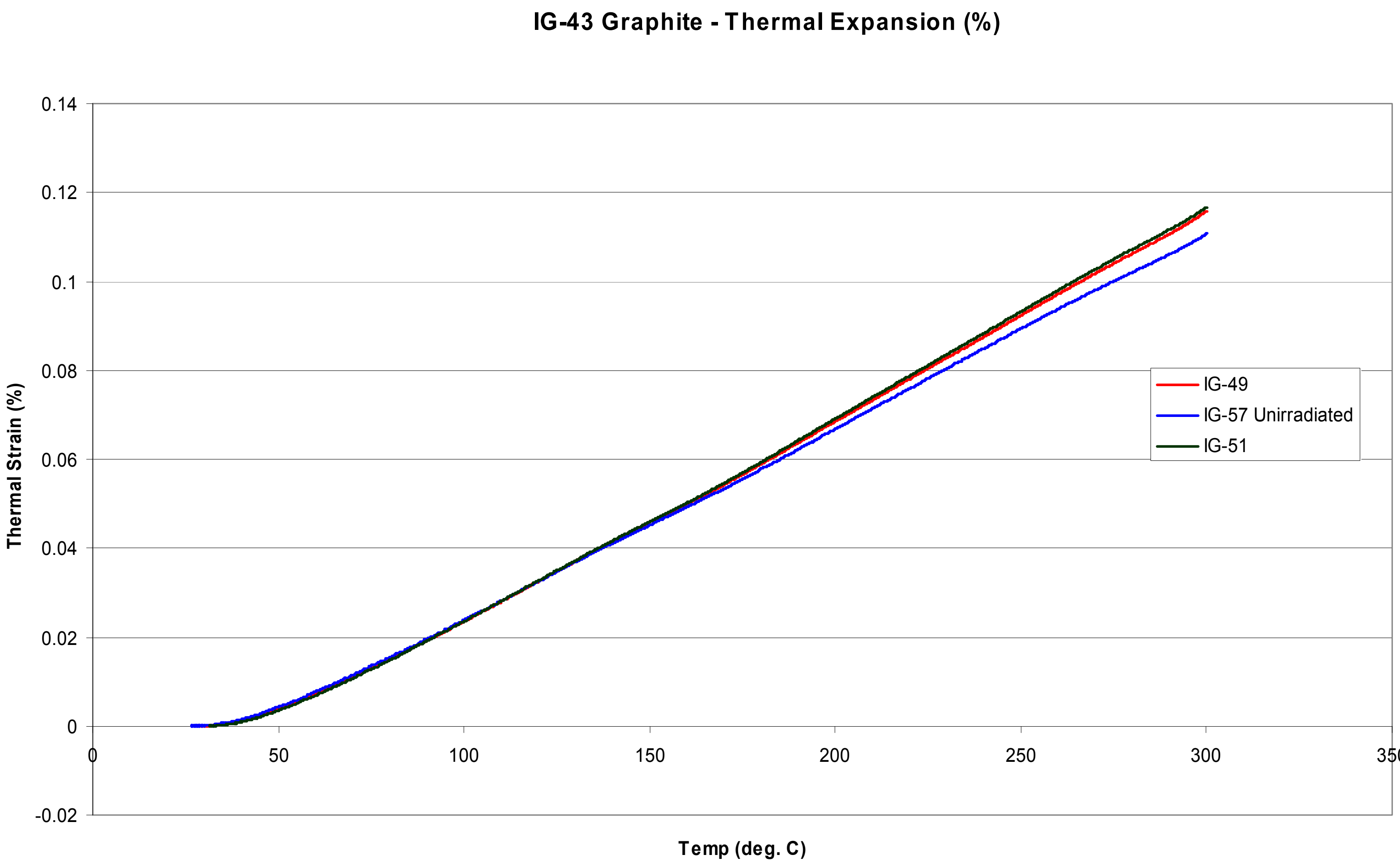


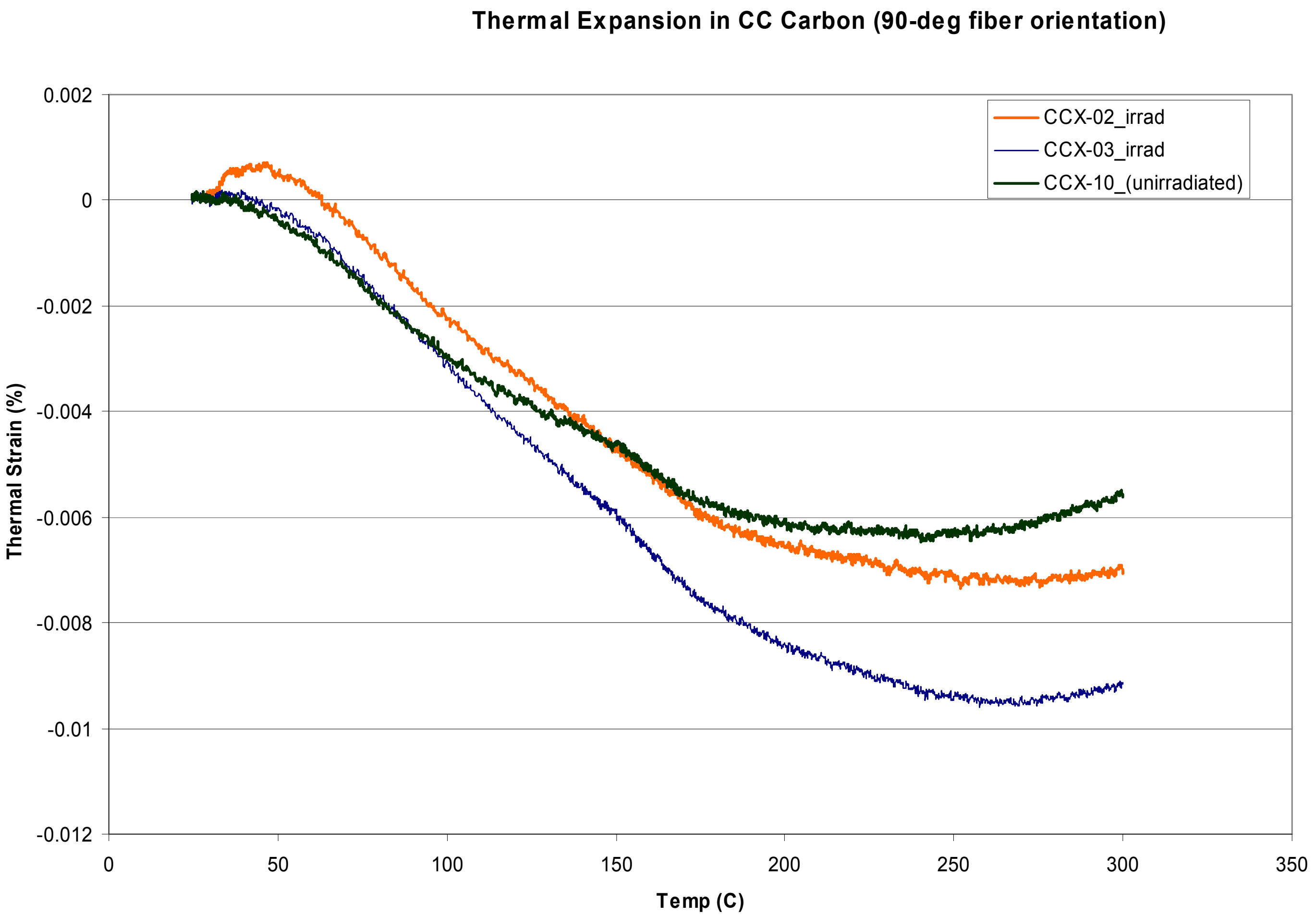


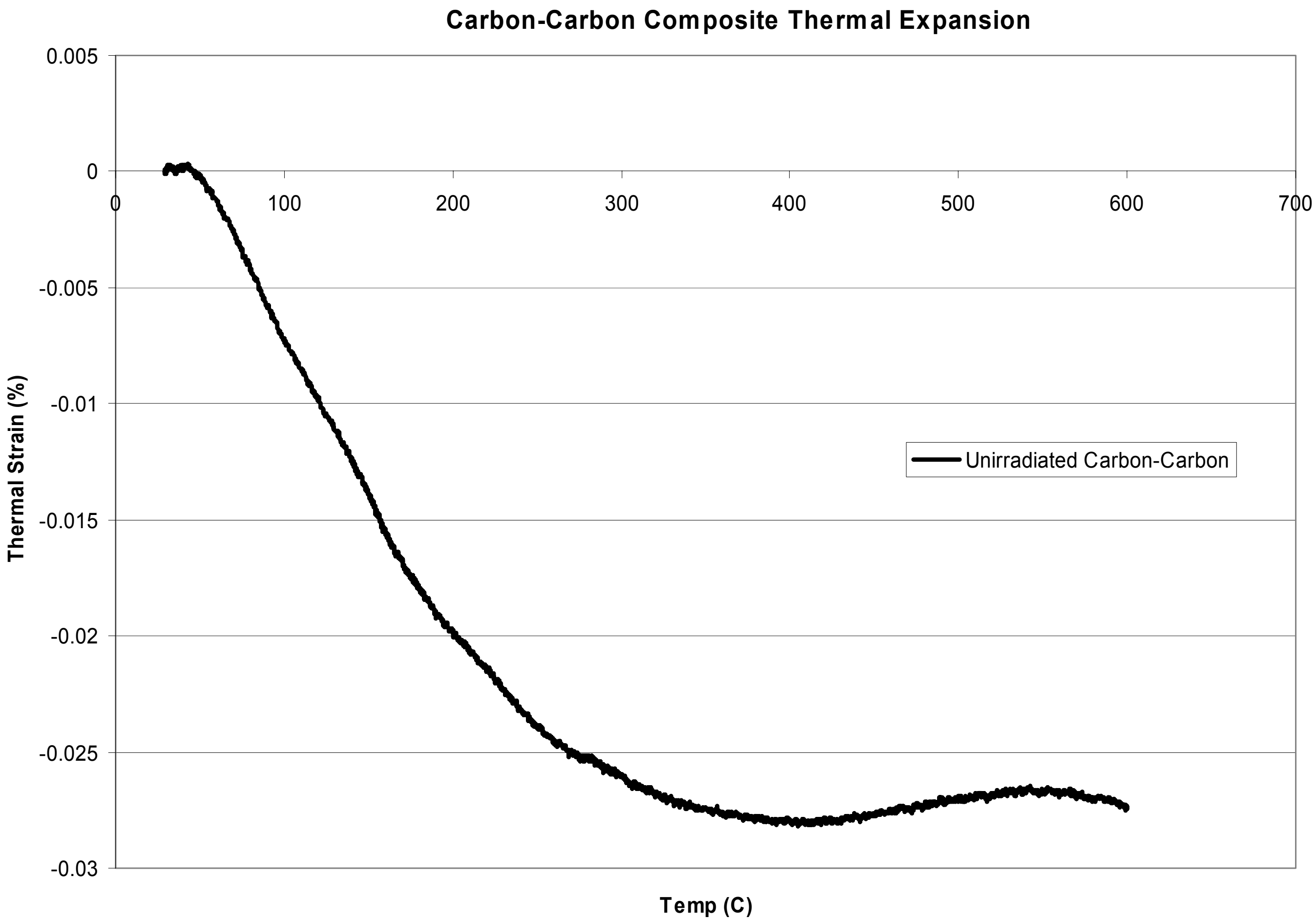



Unirradiated Gum Metal Stress-Strain
1400
1200
1000
800
600
400
200
0
Yield
0
5
10
15
20
25
30
Strain


(A)
90% Cold worked
Elastic limit
Elastic limit
Annealed
Non linear elasticity
Huge elasticity
Tensile Stress / MPa
1400
1200
1000
800
600
400
200
0
0
1
2
3
4
5
6
Strain / %
(B)
GUM METAL
Conventional β-Ti alloys
Ductility (Reduction of area) / %
80
60
40
20
500
1000
1500
2000
Tensile strength / M Pa

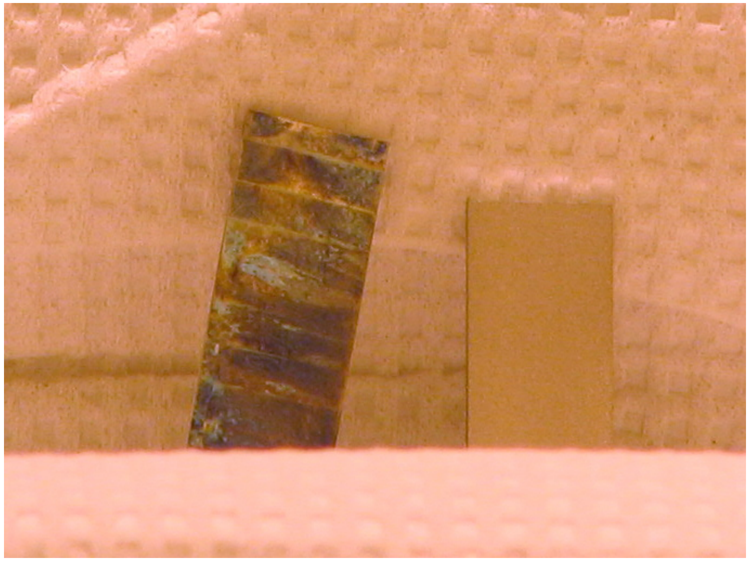

IG-43 Graphite - Thermal Expansion (%)
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
-0.02
Thermal Strain (%)
0
50
100
150
200
250
300
350
Temp (deg. C)
IG-49
IG-57 Unirradiated
IG-51

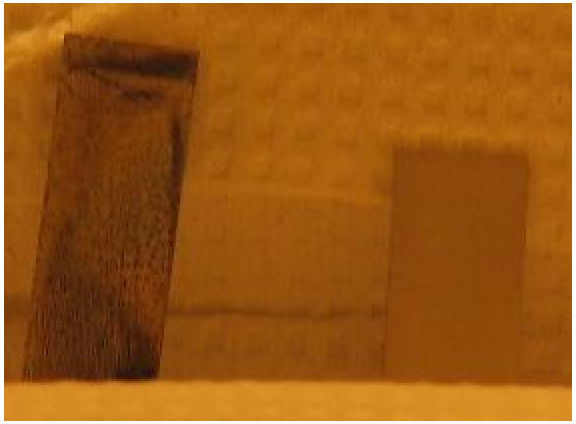

Thermal Expansion in CC Carbon (90-deg fiber orientation)
CCX-02_irrad
CCX-03_irrad
CCX-10_(unirradiated)
Thermal Strain (%)
0.002
0
-0.002
-0.004
-0.006
-0.008
-0.01
-0.012
0
50
100
150
200
250
300
350
Temp (C)

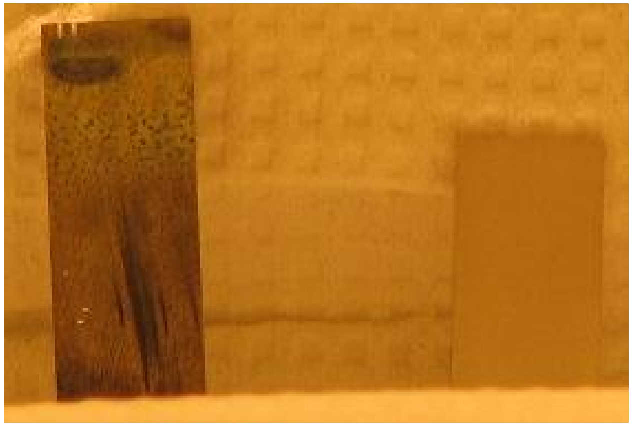


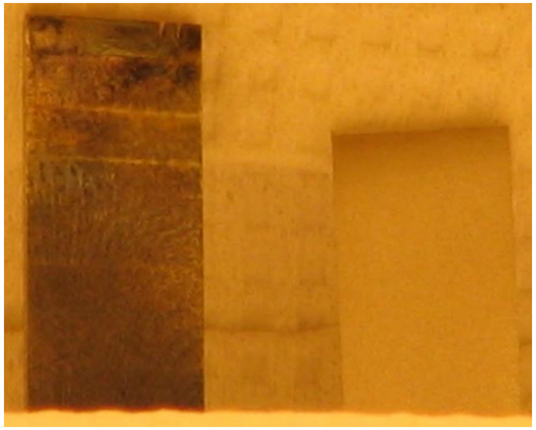
Temp.	% elongation
23 ^{o} C	0%
200 ^{o} C	-0.023%
400^{o} C	-0.028%
600^{o} C	-0.020%
800^{o} C	0%
1000^{o} C	0.040%
1200^{o} C	0.084%
1600^{o} C	0.190%
2000^{o} C	0.310%
2300^{o} C	0.405%

Effects of Irradiation on Nickel-Plated Aluminum (Material of NUMI Horn)









REMAINING "TO DO" LIST

- Graphite and Carbon-Carbon to be tested to cycles up to 1100 C
  - in vacuum
  - with forced helium
  - Dilatometer will be upgraded to allow these two runs

- Thermal diffusivity (or conductivity) will be measured using the dilatometer set-up with an implemented modification that allows for diffusivity measurements in transient mode

- Complete the examination of the nickel-plating on aluminum (NUMI horn material) – Preliminary (visual) examination shows serious surface changes

- Assess damage due defect generation/growth on the irradiated specimens using ultrasonic techniques (more of an issue in graphite & CC) – System is available and ready. Tests to be done after diffusivity measurements

- Material resilience to shock: Use of a high power – focused laser beam to excite the materials of the matrix – Lab is set up and laser system is up and ready. Need to borrow fiber-optic recording system from ORNL