Proton Irradiation Damage Assessment of Carbon Reinforced Composites: 2-D & 3-D Weaved Structures

A love affair going sour !!!

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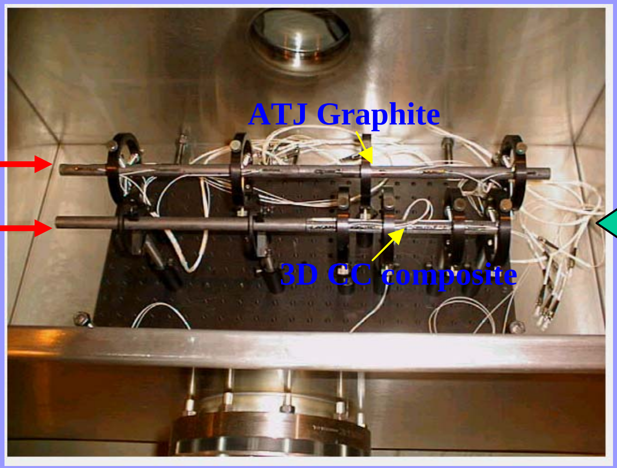
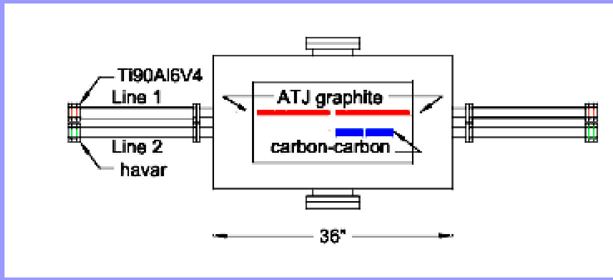
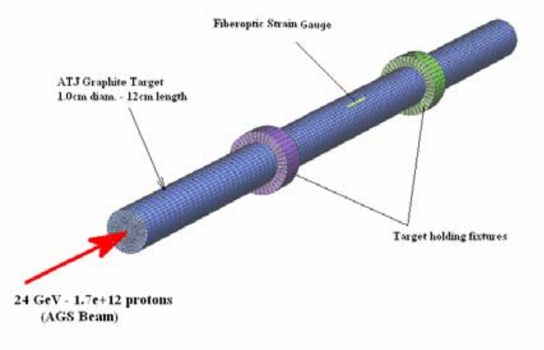
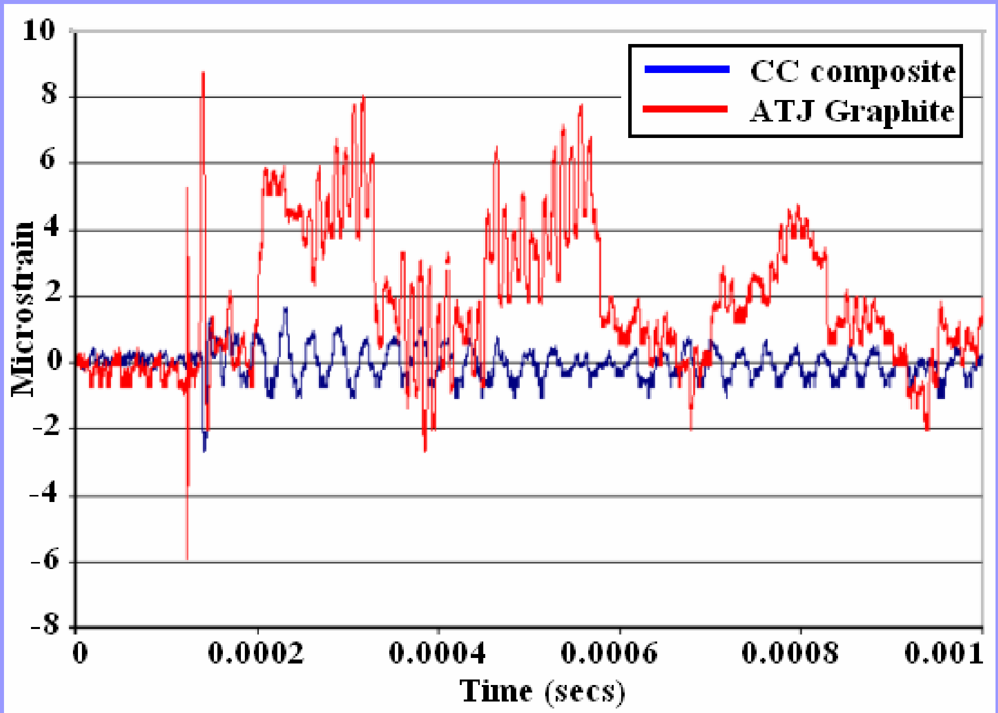
What prompted our love affair with 3D carbon-carbon composite





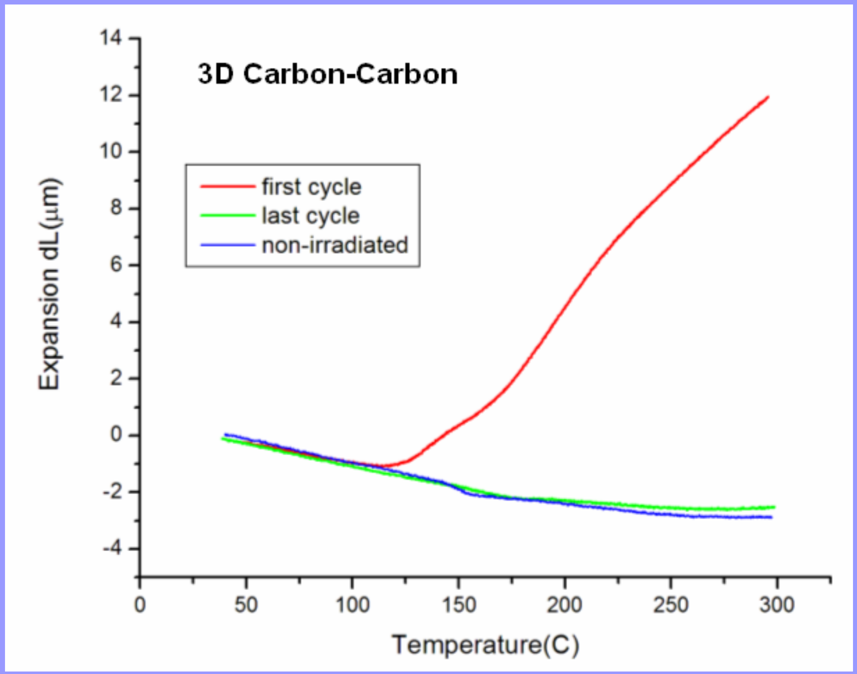


AGS Beam-on-Target tests show clearly that carbon composites are better absorbers of thermo-mechanical shock. This is attributed to the very low coeff. of thermal expansion (CTE).

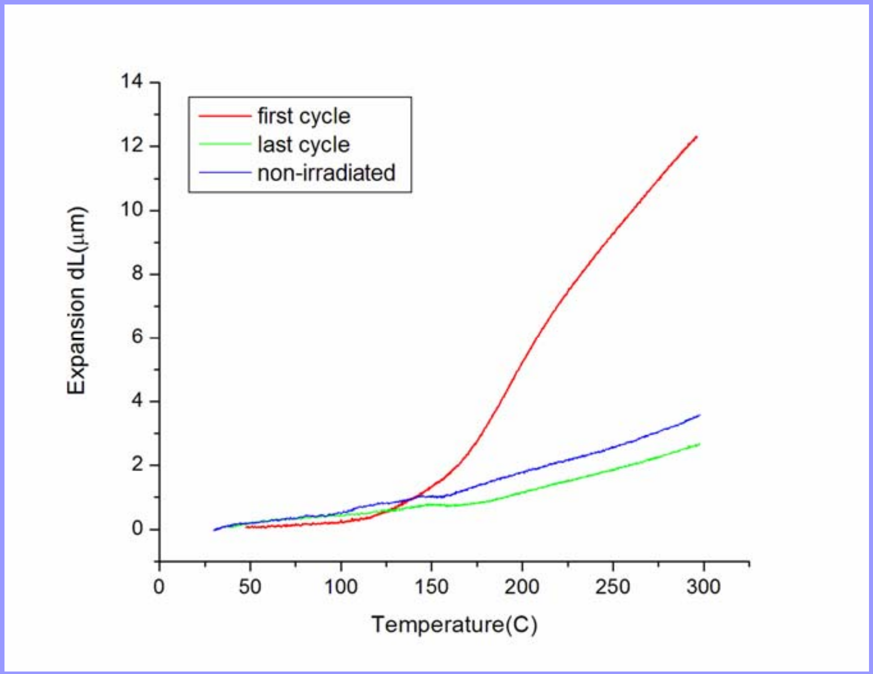


Positive news regarding 3D Carbon composite kept coming !!

Irradiation damage assessment revealed that the composite can undergo self-healing through annealing (even along its 45-degree orientations that form the weak planes)



Fiber orientation



45-degree “weak” orientation

Good news were associated with modest beam exposure (~ 25,000 uA-hrs). More needed to be done to validate that carbon composites can replace graphite.

Embarked into a 2-phase new study

Phase 1 → Assess the 2D carbon-carbon under heavy irradiation

(LHC Phase-I collimator material)

Phase 2 → Expose 2D & 3D carbon-carbon composites under identical experimental conditions

Phase-1: 2D Carbon Composite

In the Spring of 2005 the exact 2-D composite used in the collimator system of LHC was exposed to the BNL BLIP beam.

The 2-D composite has a “strong” and a “weak” orientation. The strong orientation is along the reinforcing meshed fibers which form parallel planes. The weak orientation is along the normal to these planes and as s result does not benefit from the presence of reinforcing fibers. The 3-D composite on the other hand has fibers that run normal to the parallel planes.

The integrated flux of this exposure was approximately ~3x10^21 protons/cm^2

Integrated beam current ~ 108,000 uA-hrs

(at the proton beam 1-sigma ➔ orders of magnitude greater than what the collimator jaw at the LHC is expected to see – nevertheless crucial info for target concepts)

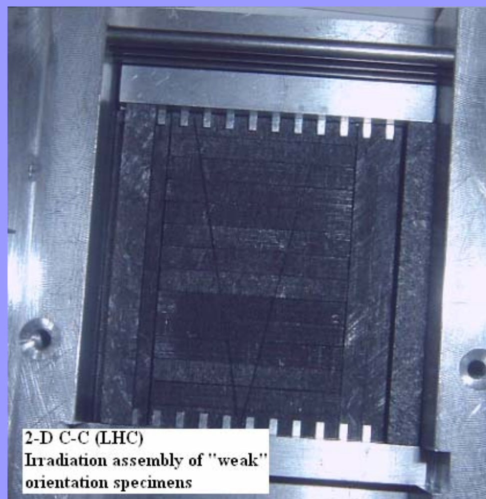
Post-irradiation analysis of the exposed 2-D carbon composite revealed both good and bad news:

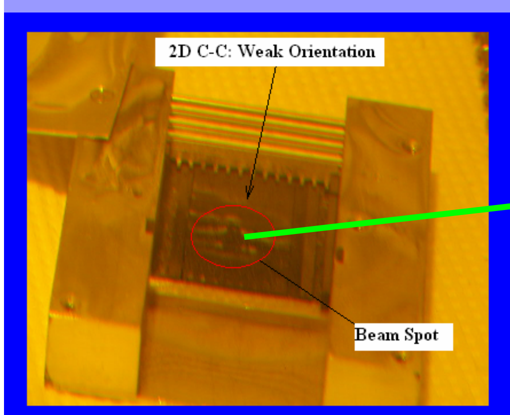
GOOD NEWS: the composite exhibits self-healing behavior
(as in the case of the 3-D counterpart)

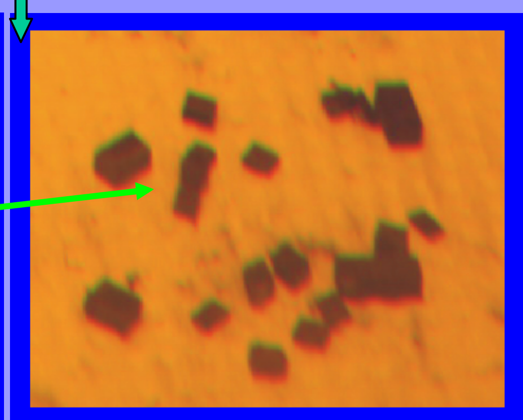
BAD NEWS: Serious structural degradation is observed as a result of high fluences
Damage more pronounced along the “weak” orientation

Bad News First: Shown is structural integrity loss (more pronounced in "weak" orientation)

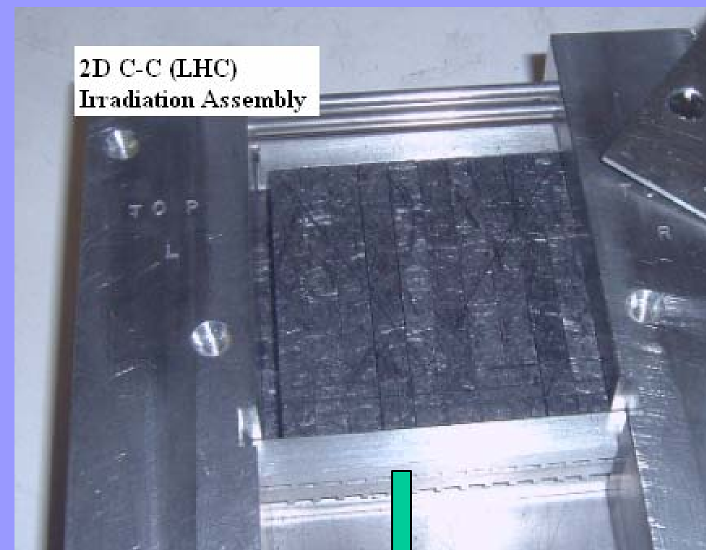
"weak" orientation

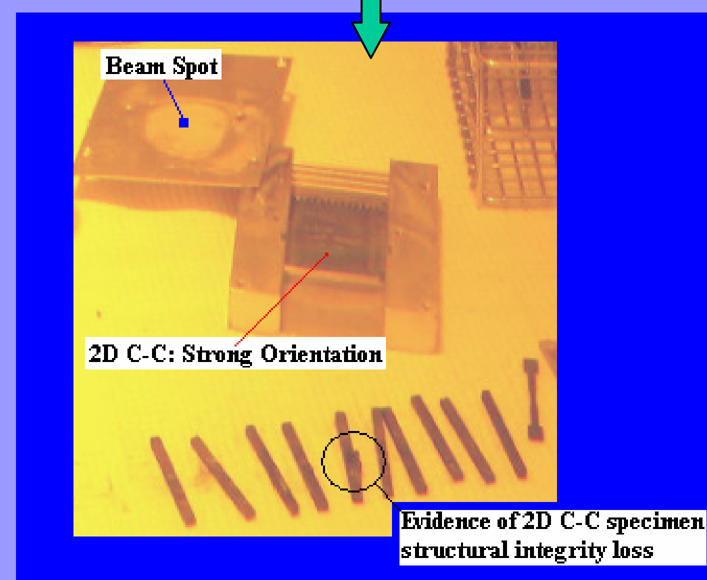




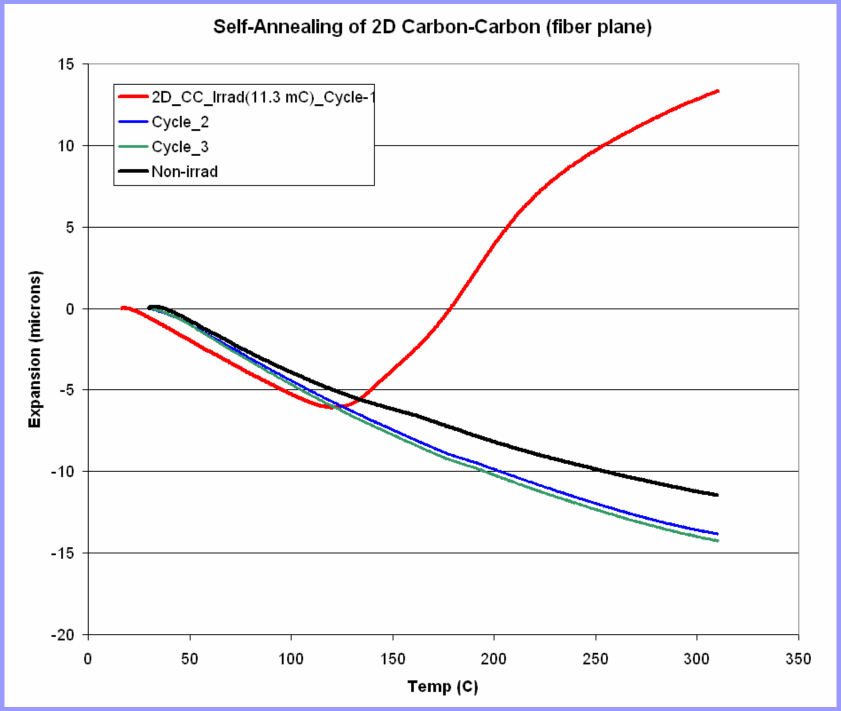


"strong" orientation

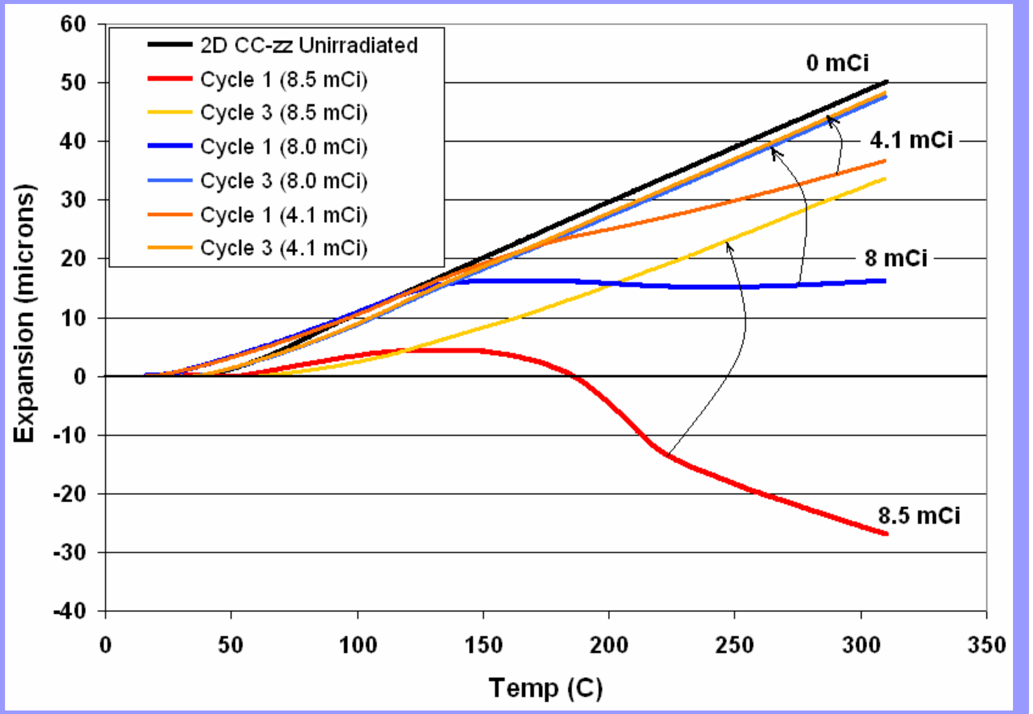




Good News: 2D carbon composite exhibits self-healing through thermal annealing (like 3D counterpart)



“strong” orientation

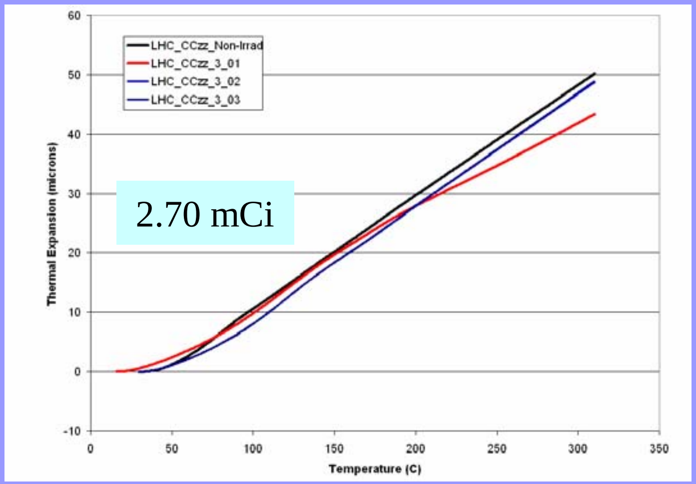


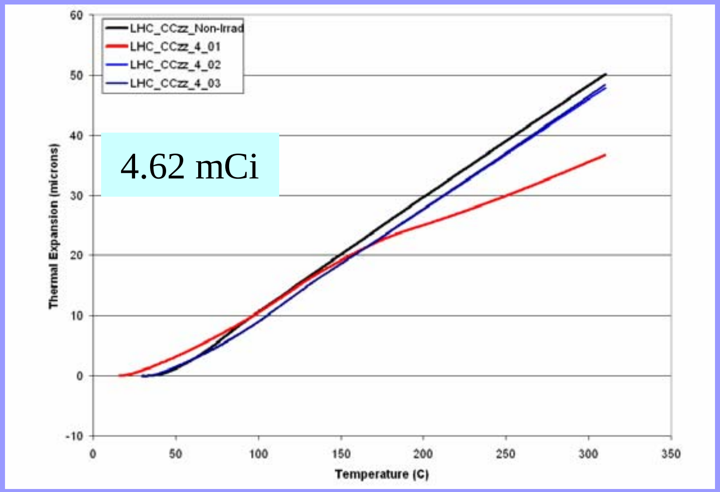
“weak” orientation

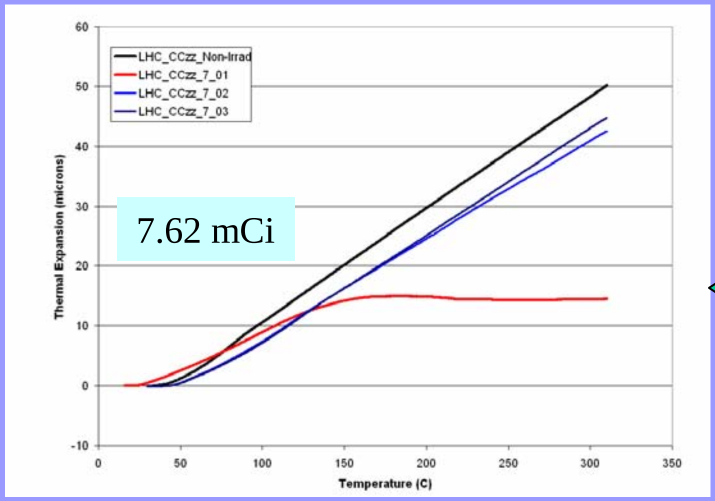
Irradiation exposure of different specimens shown in mCi

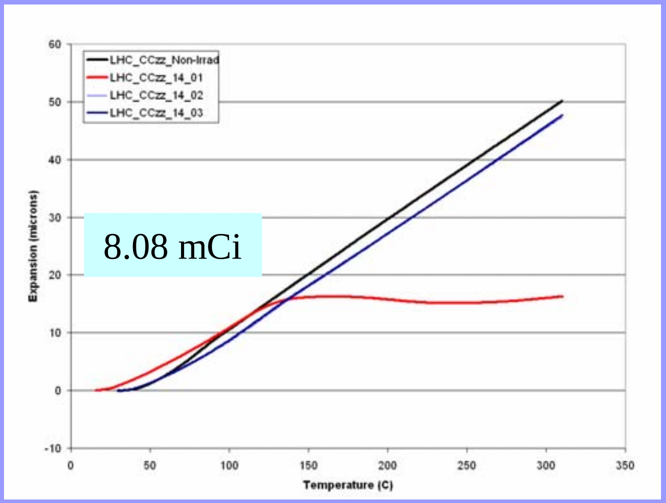
How well is our nanometer-level analysis controlled/stabilized?

Observe the tendency of irradiated 2D carbon (weak orientation) to move away from the expansion trend of the un-irradiated material. Also observe that two specimens at different location within the matrix exposed to similar levels have identical irradiation and post-irradiation (annealing) behavior !!!









DILEMMA

Is it just the 2D carbon composite that is susceptible to high fluences

OR

This holds true will ALL carbon composites (2D & 3D) ?

The mixed-bag of news prompted us to go through another exposure where 2D and 3D carbon composites are irradiated under same conditions

↓

Irradiation of the two carbon composites along with two graphite grades (IG-43 and IG-430) was performed in Spring 2006. Integrated current reached ~ 50,000 uA-hrs (but likely under tighter beam spot!!)

What is the preliminary assessment following irradiation ?

Simply put: **NOT GOOD !!!**

Damage to both C-C type is observed !

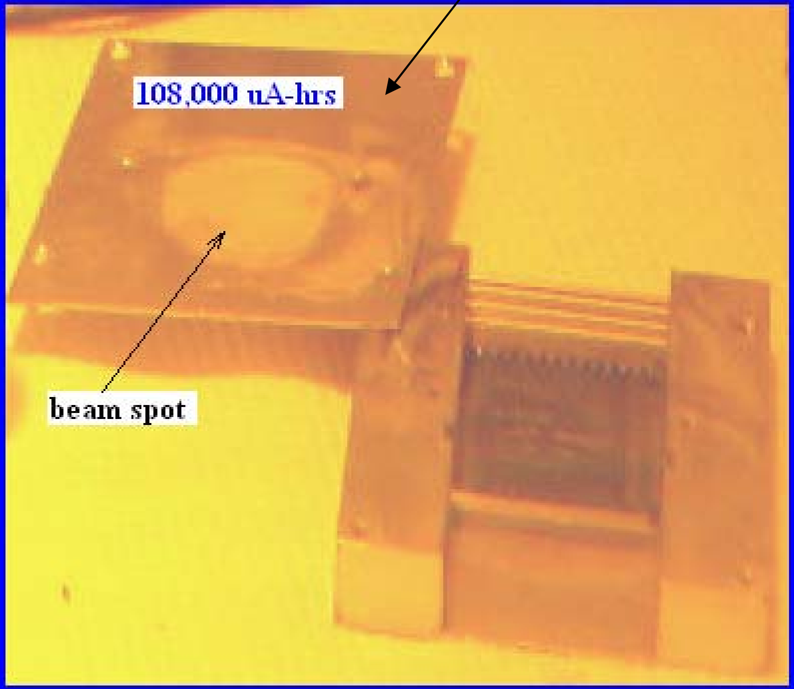
The integrated current is ~ half of the current achieved during the first exposure of the 2-D carbon composite and yet the damage is as serious. Beam spot measurements at the beginning of the latest round of irradiation and post-irradiation examination of the beam window point towards a tighter beam spot. This will imply that, effectively, the affected material was exposed to similar dose levels. This will soon be verified by detailed examination of beam-registering nickel foils placed within the irradiated assembly

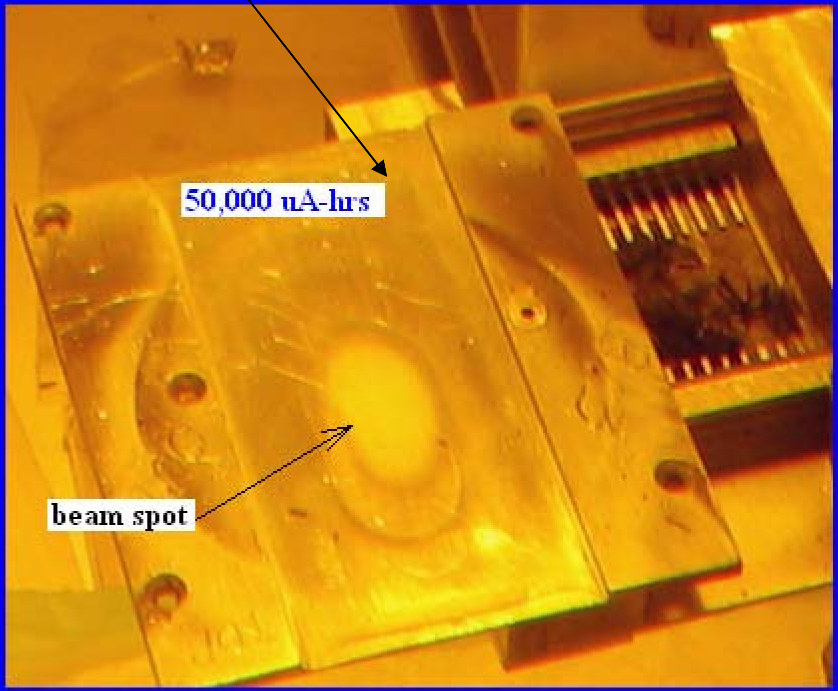
True or not, however, the fact remains that serious damage is observed. Establishing the exact threshold when damage is initiated is of limited value and importance at this point !!!

Irradiating beam footprint

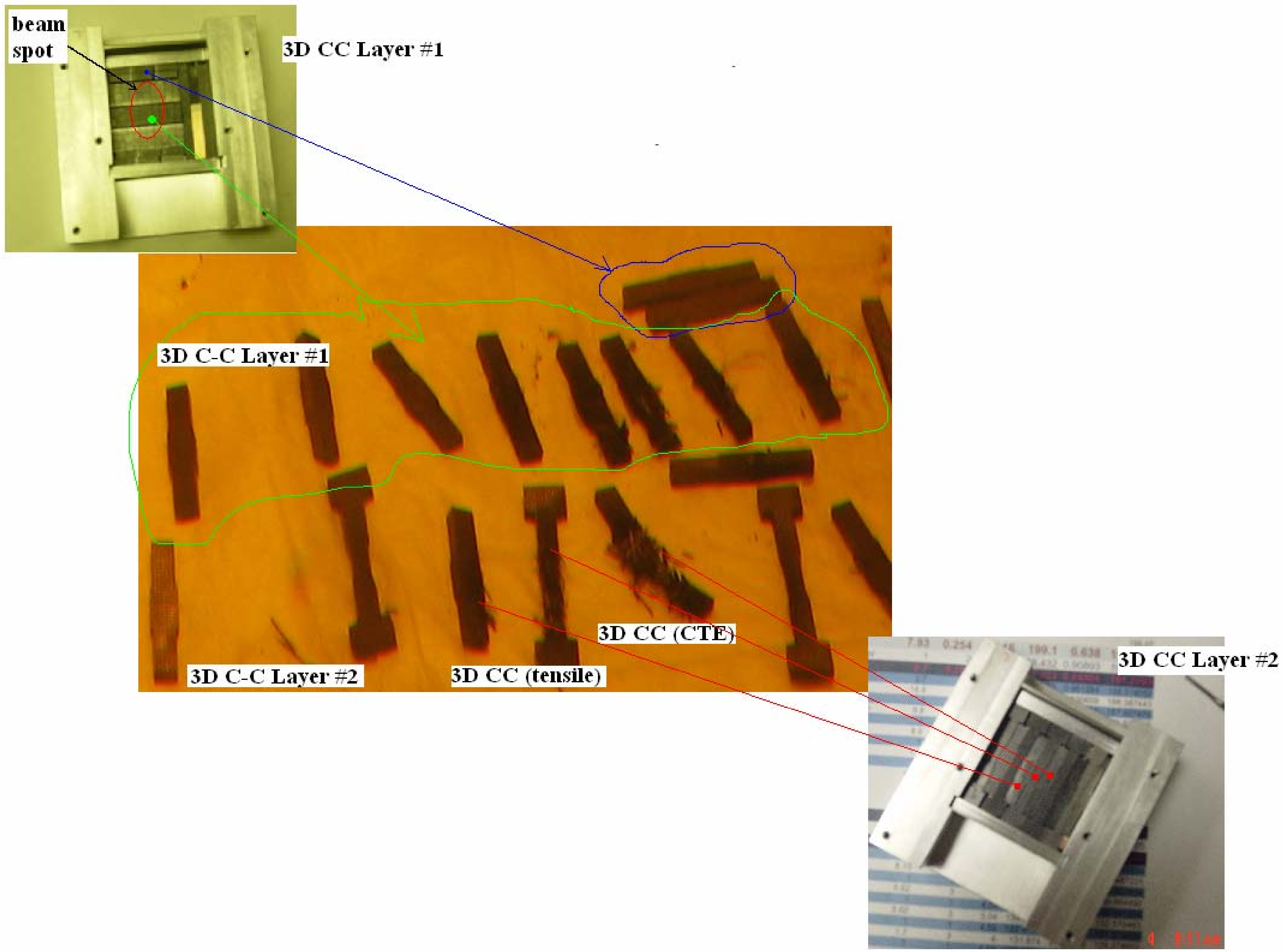
2005 Irradiation

2006 Irradiation

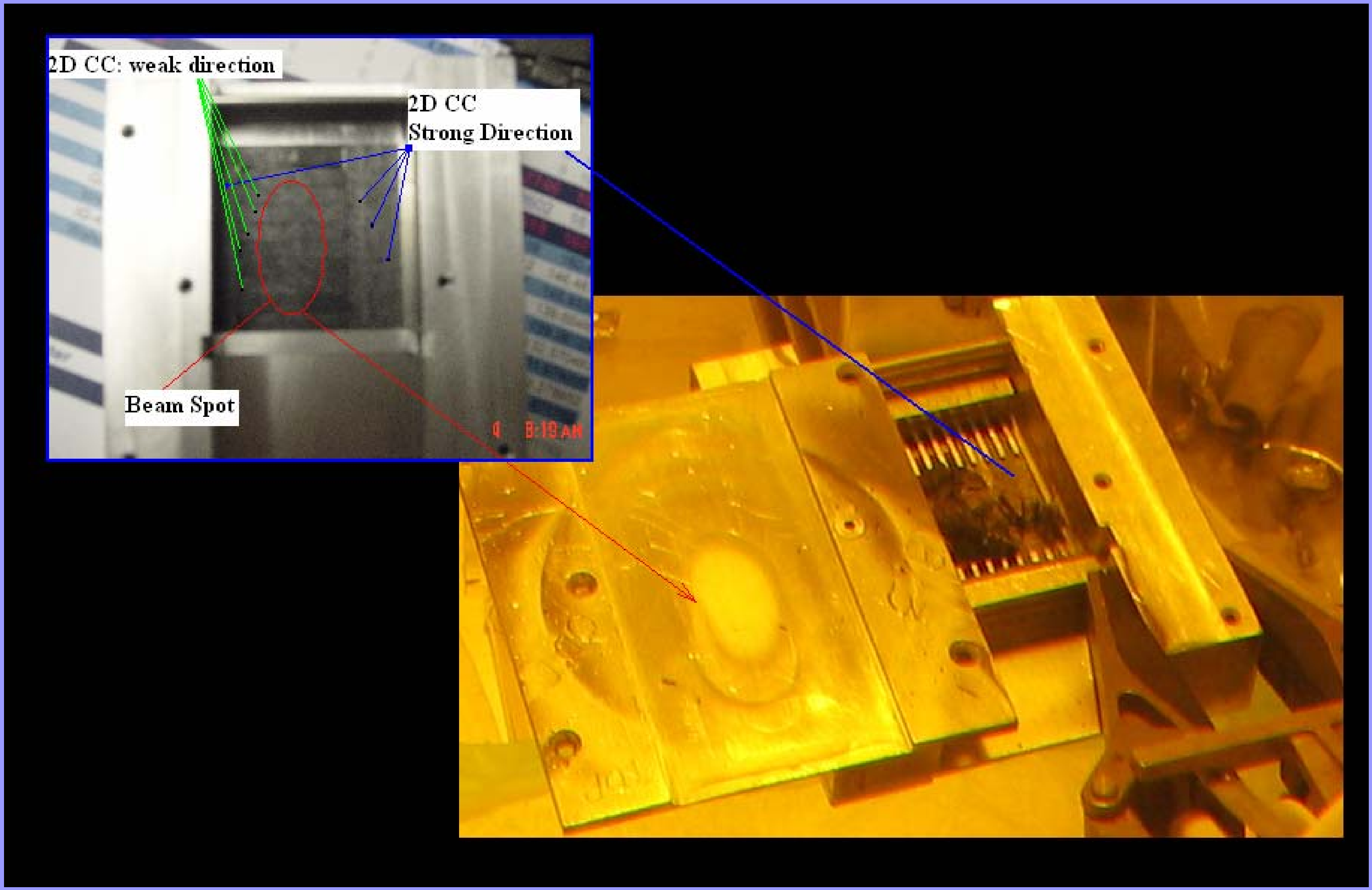




Damage seen in the two layers of 3-D carbon composite. Observe the complete disintegration of irradiated specimens situated within the 1-sigma of the beam



Damage seen in the layer of 2-D carbon composite. Severe disintegration of "weakly-oriented" irradiated specimens situated within the 1-sigma of the beam is observed



Where Do We Go from Here?

- Further experimental scrutiny of 2D or 3D carbon composites for irradiation damage effects is not recommended. These composites clearly CANNOT tolerate the high fluences required by high-power beam targets. These results should prompt a change of course in the search for materials for the multi-MW beam targets.
- For collimator purposes (such as the LHC) with anticipated fluences far smaller than those experienced during BLIP irradiation, these composites can be viable candidates since they can meet the expansion tolerances toward the beam
- FOCUS needs to be shifted toward new graphite grades such as IG-430 that are isotropic in their structure (rather than planes that can move relative to each other)
- Luckily, these graphite grades are part of the latest irradiation phase and their behavior under the same conditions (as those of the carbon composites) will be assessed in the very near term