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Summary of Disposable Debris Shields (DDS) Analysis for Development of Solid Debris Collection at NIF

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Disclaimer

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Summary of Disposable Debris Shields (DDS) Analysis for Development of Solid Debris Collection at NIF

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Collection of solid debris from the National Ignition Facility (NIF) is being developed both as a diagnostic tool and as a means for measuring nuclear reaction cross sections relevant to the Stockpile Stewardship Program and nuclear astrophysics. The concept is straightforward; following a NIF shot, the debris that is produced as a result of the capsule and hohlraum explosion would be collected and subsequently extracted from the chamber. The number of nuclear activations that occurred in the capsule would then be measured through a combination of radiation detection and radiochemical processing followed by mass spectrometry.

Development of the catcher is challenging due to the complex environment of the NIF target chamber. The collector surface is first exposed to a large photon flux, followed by the debris wind that is produced. The material used in the catcher must be mechanically strong in order to withstand the large amount of energy it is exposed to, as well as be chemically compatible with the form and composition of the debris. In addition, the location of the catcher is equally important. If it is positioned too close to the center of the target chamber, it will be significantly ablated, which could interfere with the ability of the debris to reach the surface and stick. If it is too far away, the fraction of the debris cloud collected will be too small to result in a statistically significant measurement. Material, geometric configuration, and location must all be tested in order to design the optimal debris collection system for NIF.

One of the first ideas regarding solid debris collection at NIF was to use the disposable debris shields (DDS), which are fielded over the final optics assemblies (FOA) 7 m away from the center of the target chamber. The DDS are meant to be replaced after a certain number of shots, and if the shields could be subsequently analyzed after removal, it would serve as a mechanism for fielding a relatively large collection area through the use of a part meant to be replaced regularly. The solid angle covered by one of the shields is roughly 10^{-4} of 4π. If several shields were analyzed at once, it would increase the solid angle of the collection area accordingly.

The glass shields consist of ammonia hardened silica with a sol gel coating and kapton tape around the edge. The square sheets are 14” on each side. The original shields were 1 mm thick, but it was determined that a thicker shield (3.3 mm) was more effective in preventing debris from reaching the FOA. The Solid Radchem group received two sets of DDS as part of our evaluation of the potential use of the DDS as solid debris collectors. The first set consisted of two 3.3 mm shields, one each from the top and bottom of the chamber (the "3mm set"). The second set consisted of four 1mm shields, one from the top of the chamber and the other three from the bottom (the "IFSA set"). For each set, the shields were cut into smaller subsamples, which were then imaged using scanning electron microscopy (SEM) followed by chemical leaching and mass spectrometry. The purpose was to evaluate both the quantity and identity of the debris that was present on the DDS surfaces, and to determine if any of the capsule debris was reaching the chamber walls. In addition, potential enhancement due to gravity in the chamber was evaluated by directly comparing shields fielded in the top and bottom of the chamber. Based on the results, the use of the DDS as debris collectors would be evaluated.

The results from both sets were presented to the DDS Working Group. The slides are attached to this document. The 3mm set results are presented first, followed by the results from the IFSA set. In both cases it was determined that a small fraction of the overall debris field was collected on the DDS. This means that the debris that is formed during a NIF shot is condensing out of the plasma and depositing on surfaces closer to the target chamber center, or else it is simply falling to the bottom of the chamber. In either case, it was determined that using the DDS, or fielding a debris collector at the chamber wall, was not feasible for solid debris collection at NIF due to the small amount of debris that had been collected. In addition, since the glass shields suffered quite a bit of damage from particles impacting the surface, glass was ruled out as a collection medium.

Attached to this document are the following presentations made to the DDS Working Group:

1. "Summary of Disposable Debris Shield Analysis" – Results of the 3mm DDS analysis
2. "IFSA Glass Shields Leaching Experiments Experimental Results" – Results of the IFSA set analysis

Summary of Disposable Debris Shield Analysis

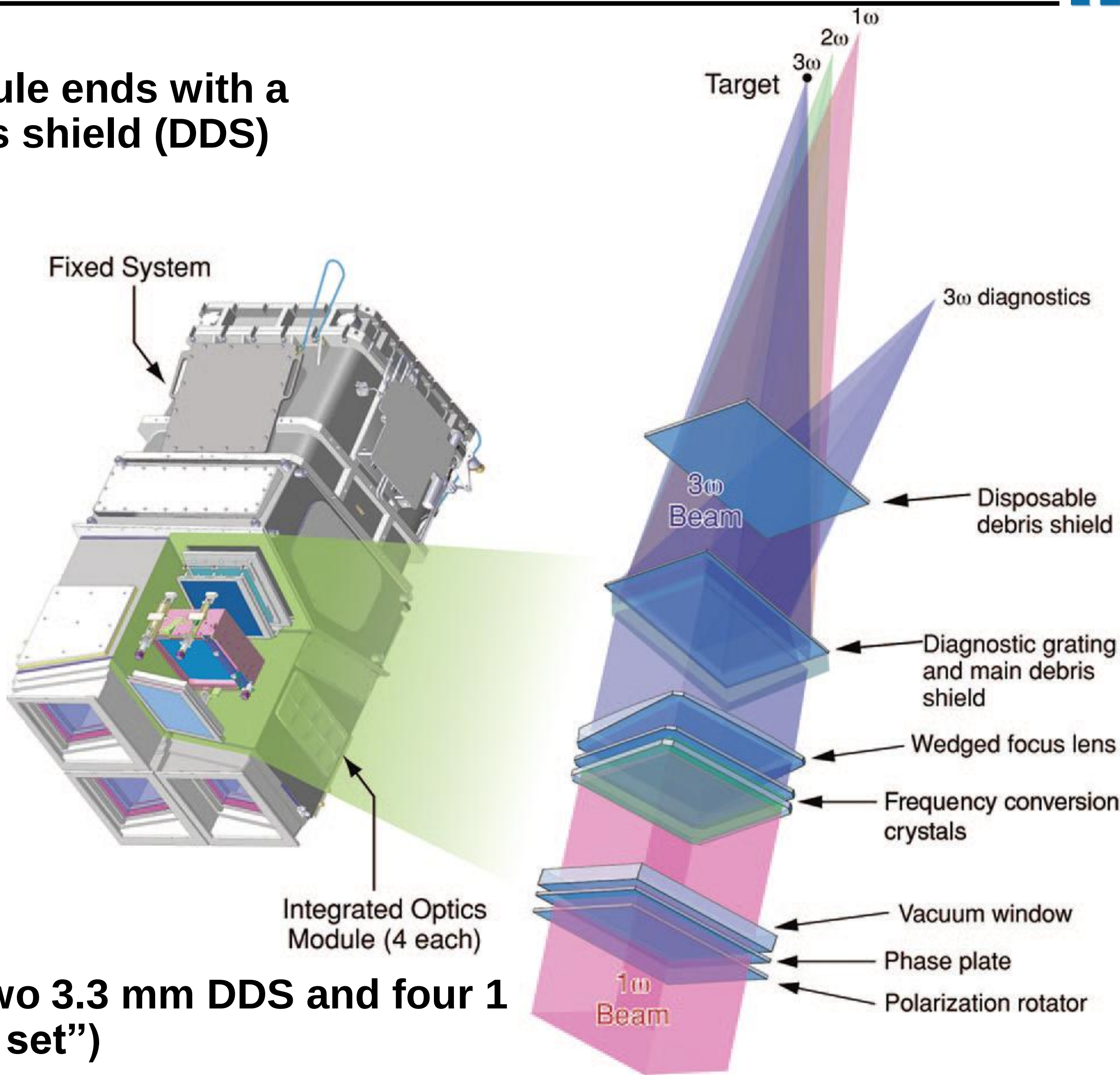
Dawn Shaughnessy, Ken Moody, Pat Grant, Laurence Lewis,
Rachel Lindvall, and Ian Hutcheon

March 15, 2010

This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344

We have received DDS for determination of debris distribution

Each optics module ends with a disposable debris shield (DDS)



We have received two 3.3 mm DDS and four 1 mm DDS (the "IFSA set")

All single DDS are being replaced with casettes

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- DDS are 7 m from TCC
- Once pulled, transmission measurements are made first
- DDS are ammonia hardened silica with a sol gel coating and kapton tape around the edge
  - — Complete digestion is very difficult; surface etching more likely
- 1 mm DDS are all being replaced with 3.3 mm DDS
- We want to evaluate the (1) elemental composition, (2) physical morphology of the debris, and (3) determine debris composition quantitatively
  - — We are trying to evaluate if there is a preferential debris distribution (i.e. does gravity make a noticeable difference)

Two 3.3 mm DDS were received from the bottom quads with varying shot histories

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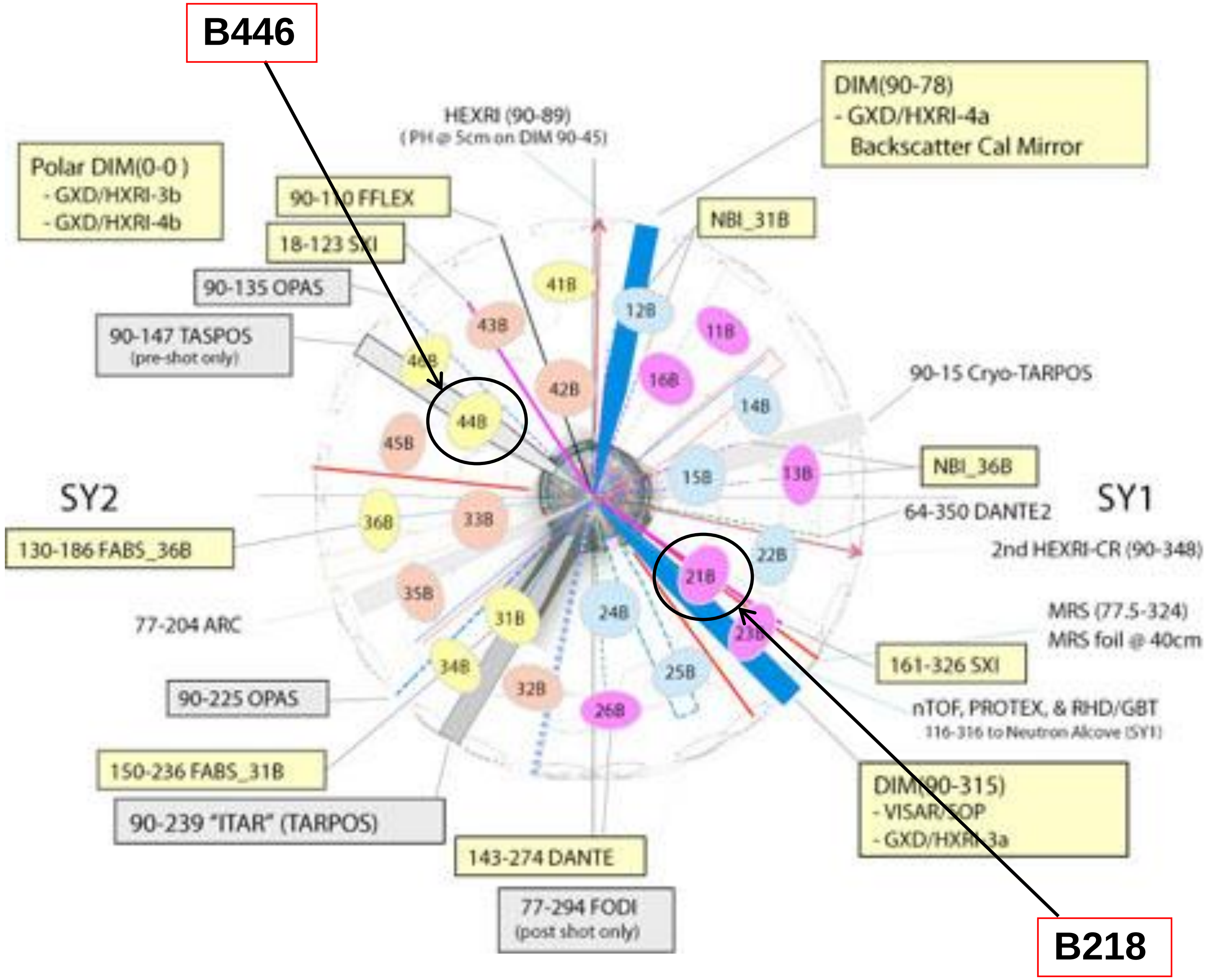

21B photos (all 3.3mm DDS)

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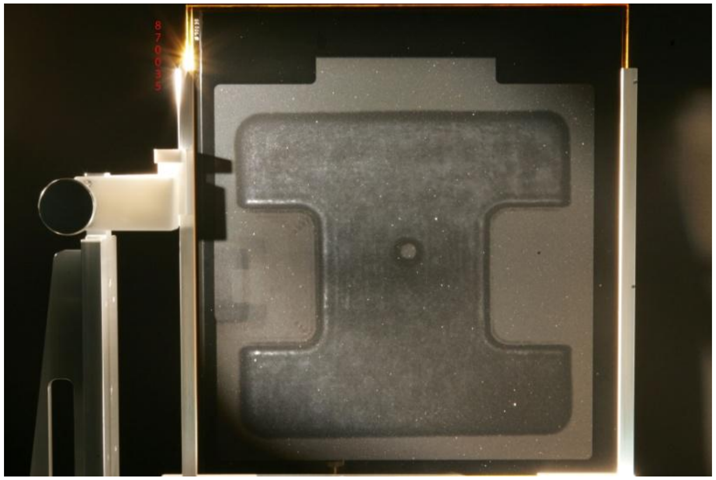
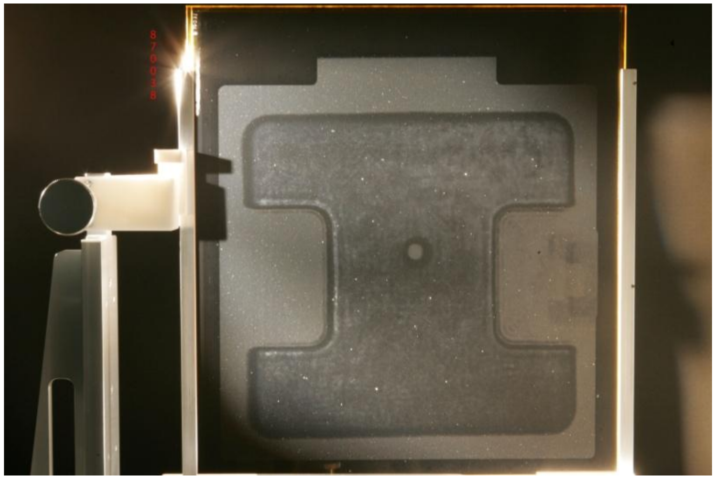
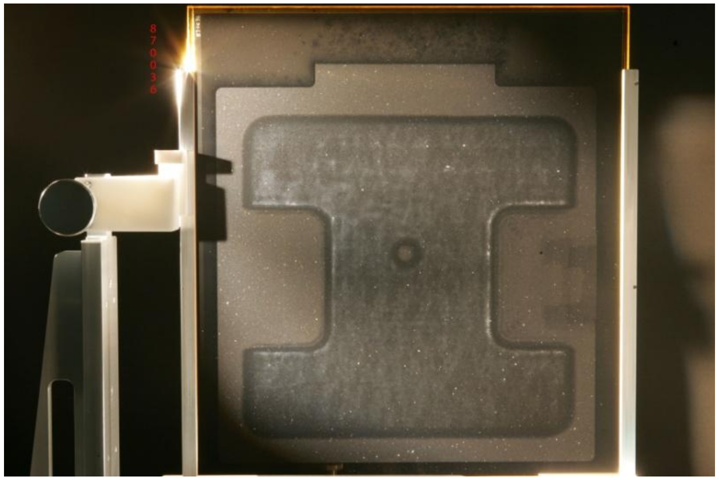
B217 (Q2) – 870035, 86.3 %T; clean patch for contamination; need previous



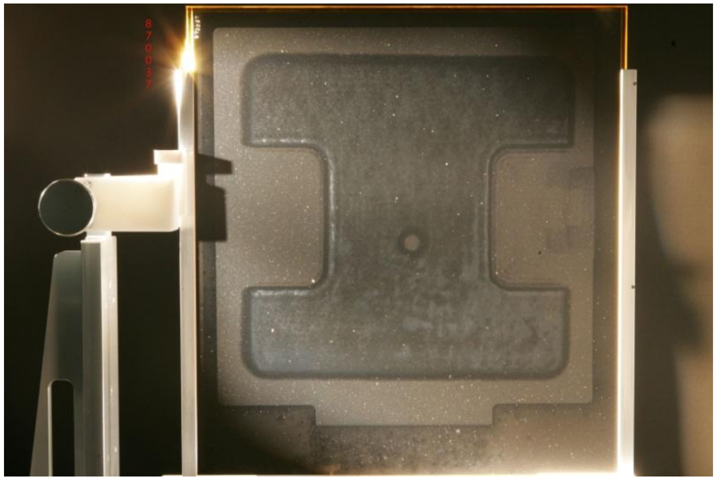
B215 (Q1) – 870038, 87.6 %T



SL B218 (Q3) – 870036, 86.0 %T DAWN



SL B216 (Q4) – 870037, 87.2 %T



44B photos (all 3.3mm DDS)

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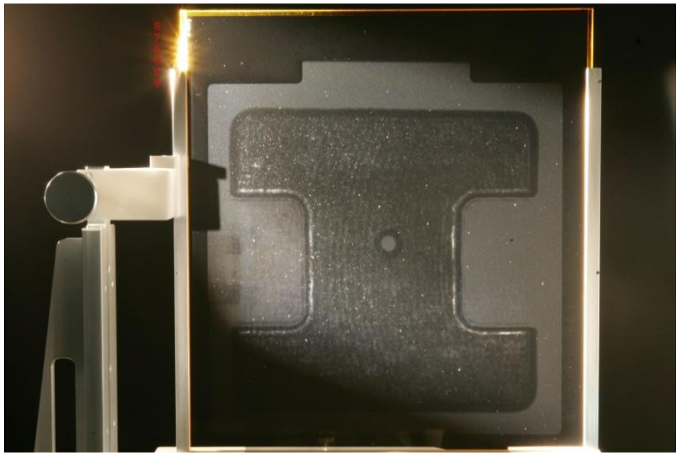
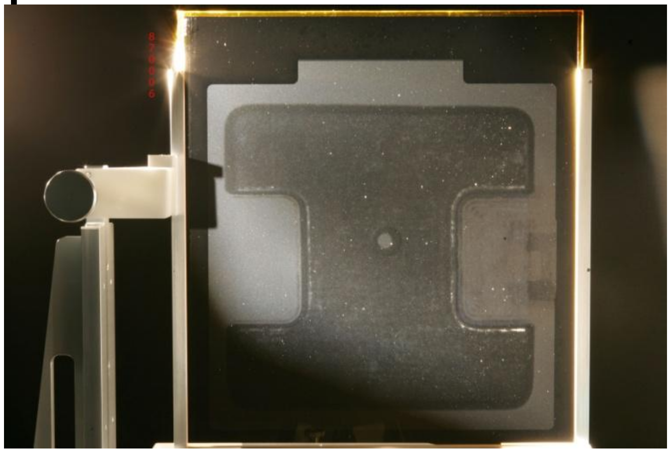
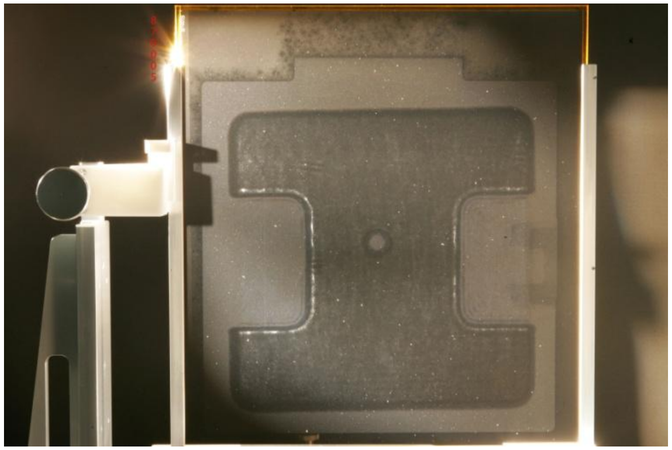
B446 (Q2) – 870009, 86.0 %T DAWN



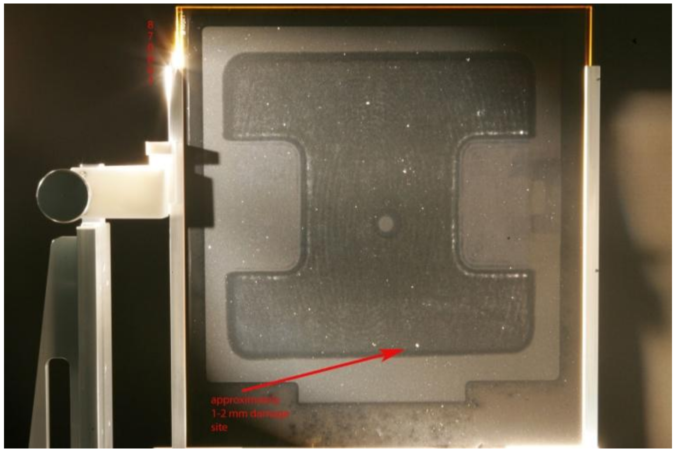
B448 (Q1) – 870006, 85.9 %T; clean patch for contamination; need previous DDS



SL 445 (Q3) – 870005, 86.4 %T



SL B447 (Q4) – 870007, 86.7 %T



Choate 10/20/09

There are three regions of interest on each DDS

Procedure for 3.3 mm DDS analysis

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1. Small pieces cut from each of the three regions with a diamond tip cutting tool (1” square)

2. Lana Wang performed microscopy on the small pieces

3. Ian Hutcheon/Laurence Lewis performed SEM to determine elemental composition, debris morphology, and uniformity of debris

4. Samples were leached in aqua regia (HNO_3 + HCl) with a touch of HF at 50° C for 30 min; solutions then converted to 0.5 M HNO_3 for mass spectrometry

5. Rachel Lindvall performed ICP-MS on solutions to quantitatively determine elemental composition

6. Still need to acquire complete shot histories for both of these DDS

Results and observations from SEM and mass spectrometry of 3.3 mm DDS

- SEM images are from DDS 870009 (see separate files)
- DDS 870036 was not imaged
- Mass spectrometry has been run in regions 1-3 on both DDS
- The process blank had high levels of most analytes due to vigorous leaching that dissolved too much of the surface
- Gold and indium were observed at concentrations at least ten times higher than the process blank
- Most elements observed (other than gold) are from first wall components and not from TCC
- Region 1 had few splats but more cratering due to beam cleaning and laser damage
- Region 2 had a high density of both splats and craters

NIF Debris Shield Element Compilation (from Al and glass shields)

Abundance	Element	Splats	Particles	Seen With
Most Abundant	Al	X	X	
	Si	X		
	Cu	X	X	
	Au	X	X	
Fairly Abundant	In	X	X	
	Fe	X	X	
	Cr	X	X	Fe
	Ni	X	X	Fe, Cr
Least Abundant	Zn		X	Cu
	C	X	X	
	Ti		X	
	Ag		X	
	Mn		X	
	Ca		X	
	S	X		Cu
	Cl	X		Cu
	Ba		X	Mo
	Mo		X	Ba
	Pb		X	
	F	X		
	B	X		

Origin of materials on DDS and Al blast shields (from B. Gourdin)

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- **1.** ***Most abundant elements:***

  ---*Al*: Structural parts.

  --- *Si*: Target support arms.

  --- *Cu*: Wires.

  --- *Au*: Holhraums.

  2. ***Fairly abundant elements:***

  ---*In*: Low-melting point solders.

  ---*(Fe, Cr, Ni)*: Austenitic stainless steel, ferritic stainless steel structural parts.

  3. ***Least abundant elements:***

  ---*(Zn, Cu)*: Brass structural parts, of which there are relatively few.

  ---*C* : Pyrolyzed polymers.

  --- *Ti*: Alloying element in 5356 aluminum weld alloy.

  --- *Ag*: Silver plating on stainless steel screws.

  --- *Mn*: Alloying element in stainless steels and 6000-series aluminum alloys used for structural parts.

  --- *Pb*: Solder.

  ---*F* : Fluoropolymers, PFPE oils and greases used as lubricants.

  ---*B* : Targets?

  ---*Ca, S Cl, Ba, Mo*: I have no suggestions.

Conclusions from 3.3 mm DDS

- **Leaching was too aggressive – procedure has been modified for 1 mm DDS samples**
- **Elements observed are mostly from nearby structural materials and not from TCC (except for gold)**
- **Amount of gold measured via mass spec was too small to make collection at the chamber walls a viable option for solid debris collection**

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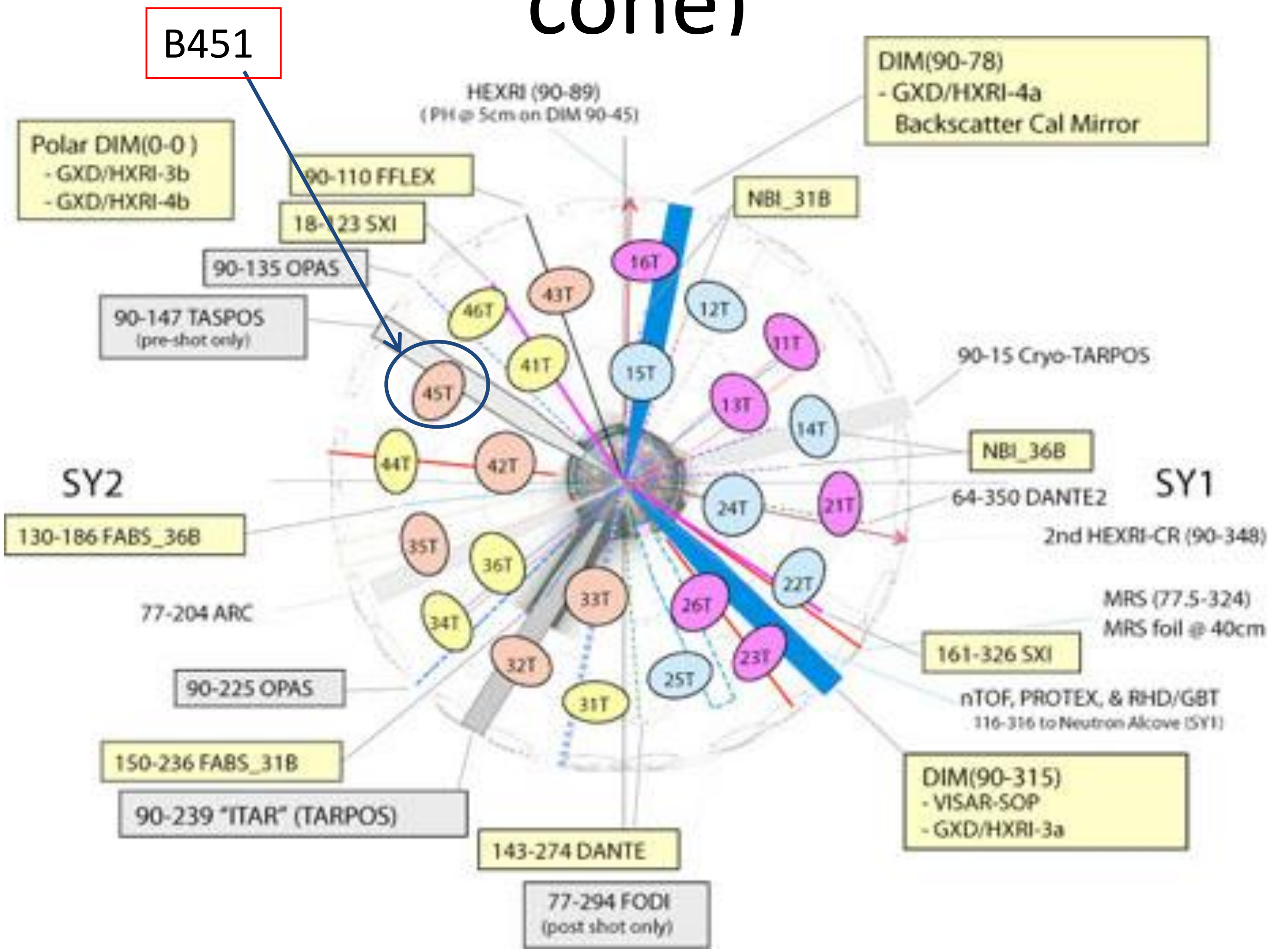
IFSA Glass Shields
Leaching Expers.-Elemental Results

Solid Debris Collection Group

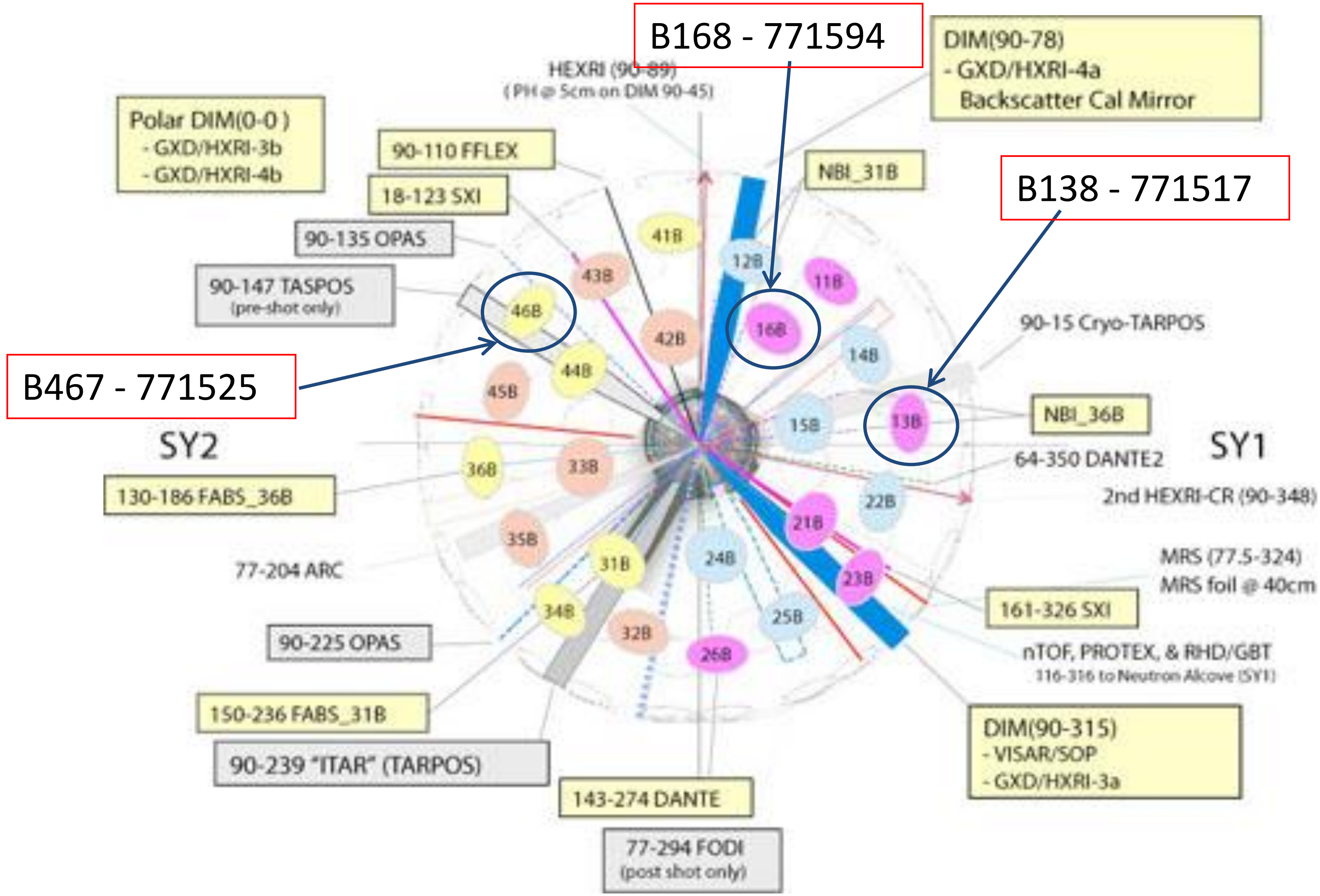
Chemical Sciences Division

July 2010

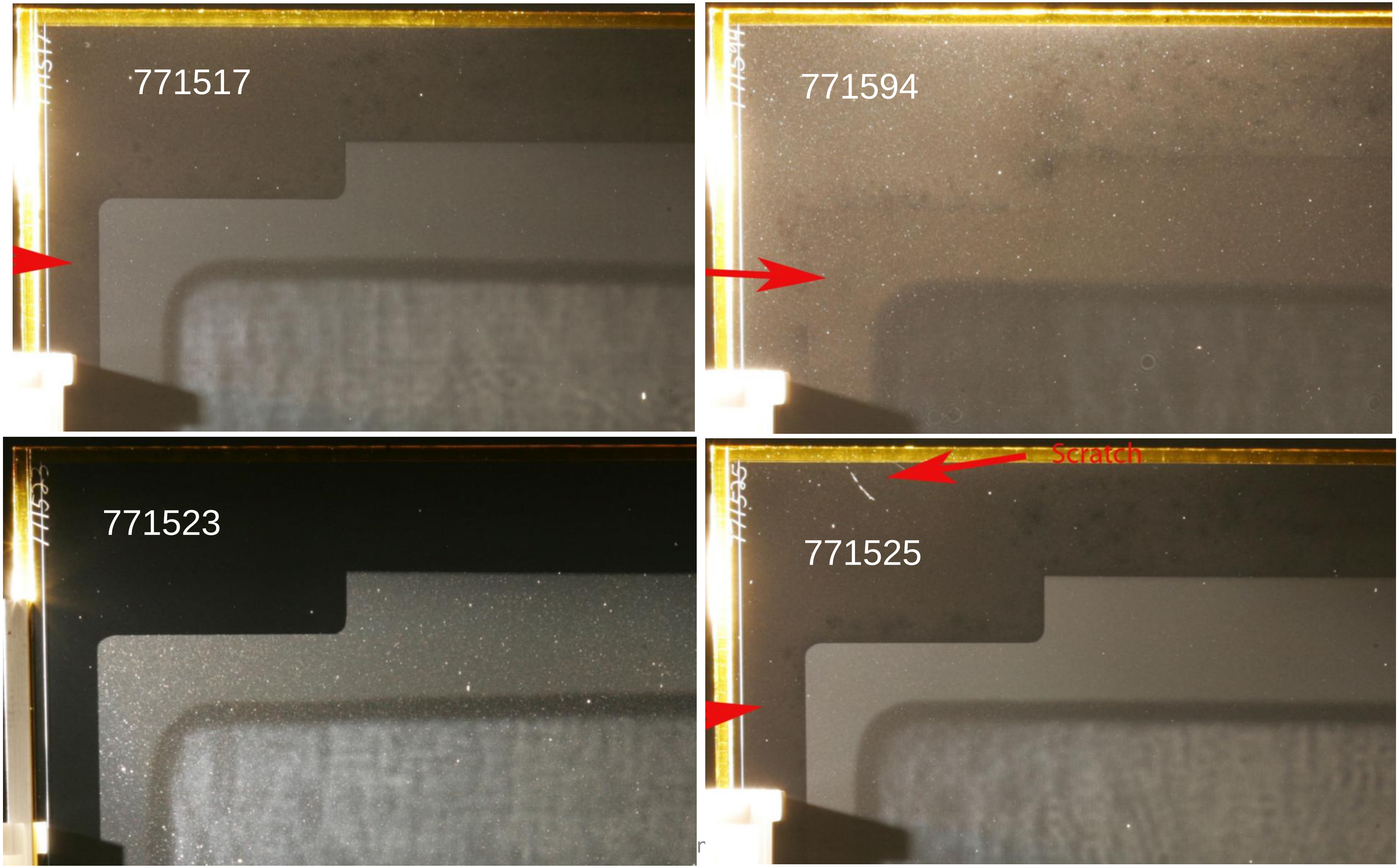
771523 is from BL 451 (top, outer cone)



Other 3 IFSA DDS are from bottom



ICP-MS analyses of four 1-mm DDS that had the same shot history (IFSA set)



Boundary Conditions

- Only HF-protocol experimental data
- Samples = 1 upper + 3 lower DDS
- Process blanks effectively superfluous
  - Operational blanks = DDS border regions (n=9)
  - Only analytic samples = DDS intermediate & central regions (n=12 each)
- Total elements = 48 (Be-U)
- Intermediate & central regions assessed independently

Results

- Major analytes = Na, Al, K, Ti, Fe, Zr, Sn, Au
- Diagnostic analytes at ppb
- All errors 1s
- Assessed overall uncertainties typically up to 50% & greater
- Arbitrary threshold for + result:

$$([\ Z(\boldsymbol{I})_i\ ] \text{ or } [\ Z(\boldsymbol{M})_i\ ])\ /\ [\ Z(\boldsymbol{B})_i\ ] = \times \text{ several}$$

Results - 2

- Only + results: Intermediate Region
  - Co = × 3.8
  - Au = × 3.2

Co = × 3.8 ± 5

Au = × 3.2 ± 4

(Central Region = × 50-60 %)

Results - 3

- Inhomogeneous Distributions
  - [Au] ***B*** = 2, 410 / 380, 27, 2, 2, 4, 23 ppb; <Au> ≈ 11
  - [Au] ***I*** = 9, 490, 6 / 26, 22, 14, 44, 57, 15, 49, 61, 49
  - [Au] ***M*** = 7, 440, 9 / 8, 18, 18, 33, 11, 25, 20, 12, 54
- Apparent Systematic Bias for Gravity Effect

$[\ Z(lo)_i\ (n=2,3)]\ /\ [\ Z(hi)_i\ (n=6\text{-}9)]$

over all accepted *B, I, M* data

$<[\ Z(lo)_i]\ /\ [\ Z(hi)_i]> = 1.5 \pm 1.2\ (75\%)$ n = 110

Conclusions

- Experiments not in effective control
  - Limited data / element
  - Hypersensitive instrument
  - Non-optimum experimental design
- NIF target debris can be quite anisotropic
  - Better solid-angle collection
  - (μ-bomb-fraction tracer in hohlraum)