Post-shot Report: Dynamic materials experiments at Trident laser facility, April 25–May 13, 2005*

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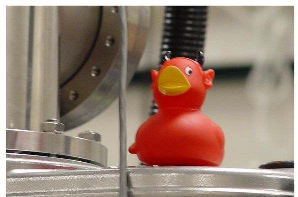

"Devil Duck" April 25 - May 13, 2005

Abstract. We have conducted laser-driven shock wave experiments to investigate dynamic properties of condensed matter including plasticity, phase transitions, equations of state and optical properties, using line-imaging Doppler interferometry, transient x-ray diffraction and spectroscopy. The starting materials investigated include sputtered Cu-doped Be ($Be_{0.991}Cu_{0.009}$), single crystal Be ($\langle\bar{2}110\rangle$), Be- and Zr-based metallic glasses, Ti, Zr, Si, NiAl, PTFE (Teflon®) and scintillator LSO. We have obtained quality data on the flow stress of Be under ablative laser loading, the key objective of the present laser experiment campaign at Trident.

1. Objectives

- **Primary – flow stress of Be:** Given the potentially severe effects of the dynamic response Be-capsule on the implosion characteristics for the ICF, the orientation-dependence (anisotropy) of plasticity of single-crystal Be as well as its bulk behavior under ultrahigh strain-rate is one of the key material factors to be considered. The main technique is VISAR with complement by TXD.
- **Opportunistic:** Scoping and continuing investigations of dynamic responses of Be- and Zr-based metallic glasses, NiAl, Teflon® PTFE resin, LSO scintillators, Ti and Zr under laser-driven stress wave loading, and technical development of quadrature and areal VISARs.

* ICF-related experiment report, `LA-UR-05-5643`.

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2. Schedule

- **Start of access and set-up:** April 25–26.
- **First shot:** April 27.
- **Last shot:** May 13.

3. Materials

- **Sputtered $Be_{0.991}Cu_{0.009}$:** Two samples (A and B, about 1 mm×1 mm ×50 μm) were supplied by LLNL with one side polished.
- **Single Be crystals:** 3–5 mm wide and 60–150 μm thick, cut in $\langle\bar{2}110\rangle$ direction and (one-side) polished by MST-6 and 7. Among 4 pieces supplied, Be#1, #2 and #4 were either wrinkled or with holes or cracks. The speed of the elastic precursor is estimated as about 13 km/s. Note: There is a confusion about the orientation which was recorded originally as $\langle\bar{2}\bar{1}10\rangle$, however, it seems that it be $\langle\bar{2}110\rangle$.
- **NiAl:** single- and bi-crystals from Koskelo's LDRD-DR. The speed of the elastic precursor is about 7.2 km/s (in [111]).
- **Zr:** foil from Goodfellow. The speed of the elastic precursor is about 4.6 km/s.
- **Ti:** foil from Goodfellow. The speed of the elastic precursor is about 6.1 km/s.
- **Si:** Goodfellow - scoping shot material for Be-Cu shots.
- **Teflon® PTFE resin:** a polymer consisting of recurring tetrafluoroethylene monomer units. Sample thickness is about 102 μm with Al-coating on one side (fabricated by DX-2). We estimate the wave speed as 1.7–2.0 km/s.
- **LSO scintillator:** from McClellan at MST-8 (about 60 μm thick).
- **Metallic glass Vitreloy 1:** $Zr_{41.2}Ti_{13.8}Ni_{10}Be_{22.5}$ (various thicknesses, from Caltech).
- **Metallic glass Vitreloy 106:** ribbon, $Zr_{57}Nb_5Al_{10}Cu_{15.4}Ni_{12.6}$ (24 μm, from Singapore and Caltech).

4. Experimental

The basic experimental aspects are essentially the same as previous dynamic materials campaigns at Trident. Some details omitted here can be found in our previous post-shot reports (e.g. LA-UR-04-2603, LA-UR-04-1508 and LA-UR-04-1475).

- **Schematic layout:** see Figs. 1 and 2.
- **Laser drive conditions**
  - **Trident laser:** Nd:YLF with a fundamental wavelength of 1054 nm.
  - **A-beam**: 2.4-ns duration, 527 nm, 100–200 J for transient x-ray diffraction. A-beam drives the x-ray backlighter (e.g. 6-μm Ti foil at the tip of the gold cone) from nearly due west.
  - **B-beam:** 2.4-ns duration, 527 nm, 1–250 J for shock wave loading. B-beam irradiates the sample from the northeast port (nominally, 35° from east and 6° from sample normal, as defined by the axis set up for the VISAR: 41° south of west). In practice, we set the VISAR probe laser beam and drive

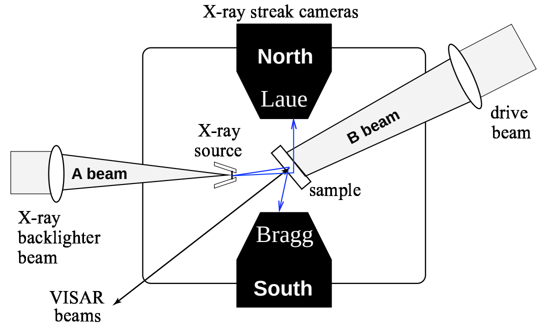

Figure 1. Schematic experimental setup for VISAR and TXD measurements at Trident.

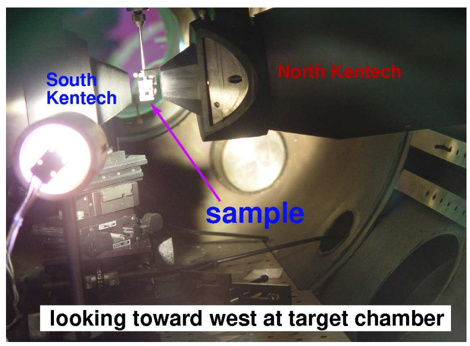

Figure 2. A representative experiment setup inside the south target chamber at Trident.

Table 1. Driving laser spot on the sample.

Spot dia. (mm)	Phase plate	Defocus (in)	Comments
5.0	Fresnel zone	0.600	4-mm design spot defocused to remove central hotspot
1.5	2-mm hexagonal	0.339	0.6-mm design spot defocused for better power control and easier alignment

laser beam collinear, and we made use of the drive beam entering the VISAR recording camera for timing of the time fiducial against the drive beam.

– **Laser spot:** 5 mm in diameter (Table 1). Diffractive optical elements were used where possible to smooth large-scale spatial variations in beam intensity. Generally these phase plates were not ideal for the desired uniformity or spot size, so the drive beam was defocused slightly.

Table 2. Timing of Hamamatsu streak camera for recording VISAR signals using DG525 relative to B-beam. t denotes the instant on streak record.

	Streak sweep time (ns)		
	50	20	10
$t = 0$ ns	**2978**	**3017.5**	**3027.5**
↓	2968	3012.5	3025.5
	2958	3007.5	3023.5
	2948	3002.5	3021.5
	2938	2997.5	3019.5
	–	–	3017.5

- **VISAR**
  - **Line-imaging VISAR:** Forsman type. Two VPF's (velocity per fringe) of 4.95 and 0.8 km/s are available using two SF6 etalons of different lengths for the 660-nm probe laser. Probe laser was timed using DG535 at 546,330 ns for VISAR streak camera at 2988 ns for the 50-ns sweep.
  - **Timing of Hamamatsu streak camera:** Table 2.
  - **Spatial calibration of Hamamatsu streak camera:** using calibration grids by DRC Metrigraphics' 201-μm grid (file `spat0427.ipl`).
  - **Temporal calibration of Hamamatsu streak camera:** using fiducial pulses at 1.71-ns separation with mirror spacing of 10.09″. (It was 1.69-ns for last campaign.)
- **TXD**
  - **Setup:** (Fig. 1) The normal of the Ti-backlighter-foil at 45° to the sample normal (i.e. 4° north of west), and 8-mm away from target center. X-ray wavelength is 2.61 Å.
  - **Timing of A-beam relative to B-beam:** 0±50 ps.
  - **Timing of TXD Kentech cameras:** using elements 1, 7, 10, 13 of the pulse stacker, at 3007 ns for South and 2998 ns for North Kentech camera.
- **Spectroscopy:** Intended for preliminary measurements of light emission of shocked LSO scintillator, and recorded with a PDC photodiode split from the VISAR return beam. The incoming light was filtered by a green and a red filter (possibly the real emission was filtered, too).

5. Shot log and statistics

See Tables 3–7 for shot log. The shot statistical results are:

- **total:** 49
- **Be-Cu, VISAR:** 2
- **Be single crystal, VISAR:** 2
- **Be single crystal, VISAR + TXD:** 2
- **Be, static TXD:** 6
- **NiAl single crystals, VISAR:** 5
- **NiAl bi-crystals, VISAR + recovery:** 1
- **Ti, VISAR** (also intended for diagnostics testing): 14
- **Zr, VISAR** (also intended for diagnostics testing): 1

- **Si, VISAR** (intended for diagnostics testing): 2
- **LSO scintillator, VISAR:** 2
- **Vitreloy 1, VISAR:** 1
- **Vitreloy 106, VISAR:** 1
- **PTFE, VISAR:** 10.

The average shot rate is 4.5 shots/day (49 shots for 11 shooting days). We also encountered Trident laser problem, and distractions from other commitments.

6. Preliminary evaluation

- **VISAR timing offset and scales**: To relate VISAR camera timing to the drive pulse, the target was omitted and a low-energy pulse was fed through the VISAR collection optics to the streak camera. The last element of the drive pulse was used, giving a roughly Gaussian pulse 180 ps wide. The streak record showed the pulse, giving a direct measurement of the arrival of the drive pulse at the target for a given camera delay. If the delaying leg of the VISAR was not blocked, a second, delayed pulse was also recorded. In most cases here, the filtering was too low and the record was saturated during the pulse. The time center of the pulse was estimated as the center of the saturated region. As this was the last of 13 elements, the start of a standard 13-element drive pulse was 2.4 ns earlier.

  Several records were taken for each sweep setting on the streak camera, varying the camera delay using a Stanford Instruments DG535 delay generator. Polynomial fitting (linear or quadratic) was used to determine the relation between delay time t_d and pixel p (Table 3 and Figs 3 to 5) – note that the correction to a time for element 1 has *not* been applied to the graphs, but it was applied to the reference time in the table. Fitting was performed using the 'Gnuplot' program, version 3.8j. The quadratic term was small but finite; this reflects nonlinearity in the sweep. Thus, assuming the DG535 was accurate and linear, the time corresponding to a given pixel can be obtained for an arbitrary delay setting t'_d, with respect to the start of the drive pulse:

  $$t(p) = t'_d - t_d(p). \tag{1}$$

  Based on the delay data, the linear fit is adequate for the '50 ns' sweep, and the quadratic fits should be used for the '20 ns' and '10 ns' settings.

- **Be flow stress measurement**: decent VISAR recordings obtained for Be single crystal ($\langle\bar{2}110\rangle$) and sputtered $Be_{0.991}Cu_{0.009}$. Weak but recognizable TXD lines were also recorded. These data and previous shots on single- and poly-crystal Be could allow us to calibrate empirical plasticity models.
- **Teflon® PTFE resin**: two-wave structure was observed in some shots, indicating the potential of laser shock wave experiments for improved investigation of its mechanical properties and phase transitions under higher strain-rate loading. Both sides need to be coated as the uncoated side still transmits the driving laser that would complicate VISAR recordings.
- **NiAl**: Single crystals and a bi-crystal were shot for plasticity properties. Successful recovery of the bi-crystal for detailed metallurgical examinations at ASU.

Table 3. Functional fits to sweep/timing data for VISAR streak camera. Functional fits: $t_d = t_0 + \alpha p$ and $t_d = t_0 + \alpha p + \beta p^2$, where t_d is the delay time and p the pixel position of the reference pulse. The correction from the measurement of element 13 to the reference time for element 1 has been applied to t_0.

nominal sweep (ns)	t_0 (ns)	α (ps/pixel)	β (ps/pixel)^2
50	2975.6 ± 0.3	-48.42 ± 0.67	
	2975.4 ± 0.4	-46.56 ± 2.61	-2.28 ± 3.07
20	3015.4 ± 0.3	-20.86 ± 0.50	
	3015.1 ± 0.1	-18.0 ± 0.6	-3.0 ± 0.6
10	3025.42 ± 0.14	-10.88 ± 0.24	
	3025.20 ± 0.08	-9.25 ± 0.39	-1.73 ± 0.40

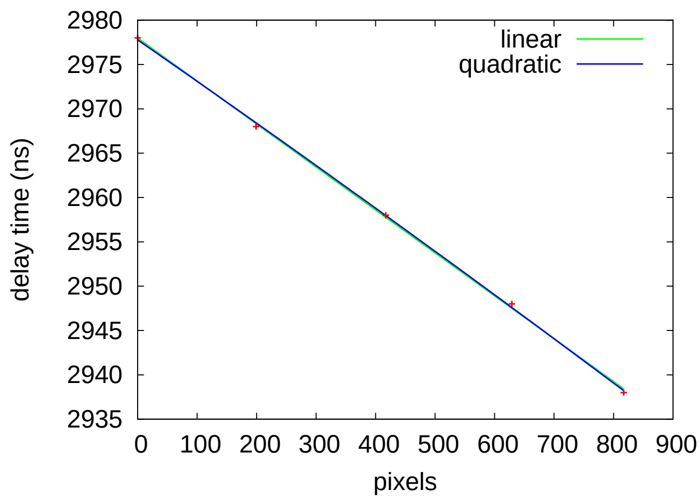

Figure 3. Delay time as a function of pixel position for nominal 50 ns sweep, with linear and quadratic fits.

- **Zr and Ti**: Decent VISAR recordings obtained at two different VPF's complement our database on these hexagonal metals, and may illuminate our understanding of hex materials in general and Be in particular.
- **Be-(Zr)-based metallic glass**: Although the probe laser multi-moded, the clear shock breakout indicates that laser experiments may be appropriate for investigating dynamic properties of metallic glasses at high strain rates.
- **LSO scintillator**: No useful data was recorded – a spectrometer and more sophisticated separation of the drive and VISAR probe lasers are necessary.

7. Acknowledgments

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- Trident laser facility and staff, R Johnson, T Hurry, N Okamoto, T Ortiz, R

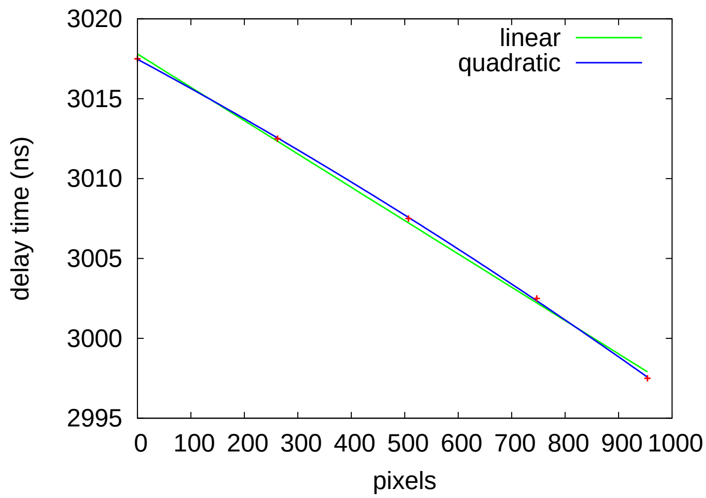

Figure 4. Delay time as a function of pixel position for nominal 20 ns sweep, with linear and quadratic fits.

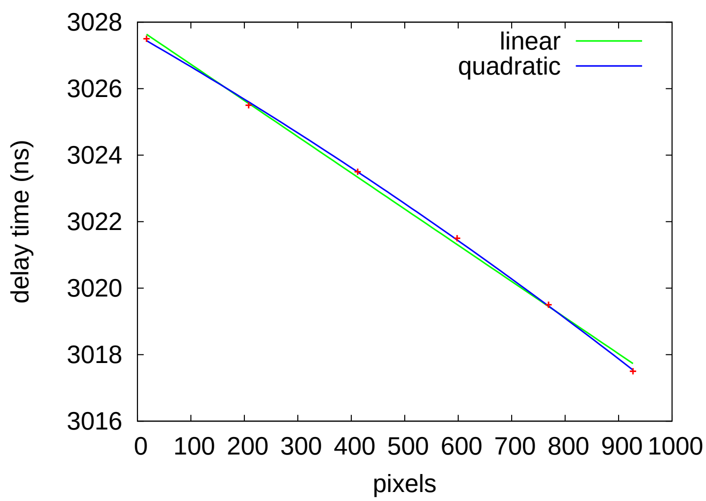

Figure 5. Delay time as a function of pixel position for nominal 10 ns sweep, with linear and quadratic fits.

Gonzales, T Shimada, F Archuleta, D Pacheco and S. Reid, for target area and laser support.

- J. Cowan for photographic support.
- MST-6 and 7 for Be single crystal fabrication and characterization.
- LLNL for sputtered Be with Cu doping.

Table 4: Shot log. VISAR≡V; TXD≡T; V-laser≡VISAR probe laser. The drive laser spot is 5 mm (diameter) only. VPF of 4950 m/s was adopted for shots #17496–17561, and changed to 800 m/s on May 13, 2005 for #17565–17571.

Shot	**Sample**	**A**	**B**	**Sweep**	**Camera**	**V-laser**	**Diag.**
VPF of 4950 m/s for shots 17496 – 17561.							
April 27, 2005, Wednesday							
17496	Zr	—	27	50	2,968(-10)	546,310	V
	Comm.	laser multimode, sample thickness unknown ∼25 μm.					
17497	Ti, 29	—	26	50	2,968(-10)	546,310	V
	Comm.	probe laser OK, 1/4 VPF					
April 28, 2005, Thursday							
17499	Ti, 27	—	28	20	3012.5(-5)	546,300	V
	Comm.	weak, 1/4F; file saving problem, restart computer					
17500	Ti, 28	—	31	20	3012.5(-5)	546,300	V
	Comm.	uniform breakout, 1/4F					
17501	Ti, 28	—	62	20	3012.5(-5)	546,300	V
	Comm.	one VISAR-beam blocked, no fringes					
17502	Ti, 28	—	74	20	3012.5(-5)	546,300	V
	Comm.	repeat #17501, two-wave structure					
17503	Ti, 28	—	126	20	3012.5(-5)	546,300	V
	Comm.	two-wave structure					
17504	Si, 20	—	49	20	3012.5(-5)	546,300	V
	Comm.	1×1 mm^2, Fe foil punch 0.6 mm hole					
17505	**Be-Cu A**, 50	—	45	20	3012.5(-5)	546,300	V
	Comm.	sputtered, on 67-μm Zr base with a 0.7mm hole. sample one side polished, from GA or LLNL. sample on drive-laser side. clear breakout of elastic precursor, but reflectivity disappeared later.					
April 29, 2005, Friday							
17507	Ti, 27	—	63	20	3012.5(-5)	546,300	V
	Comm.	1×1.5 mm^2 Ti on 1-mm LiF, intended for scoping shot for sputtered Be-Cu with a window. breakout occurred 5 ns earlier.					
17508	Si, 20	—	55	20	3012.5(-5)	546,300	V

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Shot	Sample	A	B	Sweep	Camera	V-laser	Diag.
	Comm.	1×1.5 mm^2 Si on Ti with a hole of 0.6 mm.					
		Si near VISAR side.					
		shock breakout near 20 ns, no time fiducial.					
17509	**Be-Cu**	—	31	20	3012.5(-5)	546,300	V
	B, 50						
	Comm.	sputtered, on a 67-μm Zr base with a 0.7mm hole.					
		sample on drive-laser side.					
		sample B one side polished, from GA or LLNL.					
		breakout near the end of record, misalignment?					
17510	**Be**	—	74	20	3022.5(5)	546,310	V
	#1, 125						
	Comm.	single crystal $\langle\bar{2}110\rangle$.					
		transit time 12 ns, shock breakout 7 ns.					
		slow rise in precursor; plastic wave seen.					
17511	Ti, 28	—	153	20	3012.5(-5)	546,300	V
	Comm.	Ti foil. two-wave structure.					
		May 03, 2005, Tuesday					
17513	Ti, 28	—	∼0	20	3012.5(-5)	546,300	V
	Comm.	frequency-doubling laser crystals not aligned,					
		very low energy in B-beam.					
17514	Ti, 28	—	∼190	20	3012.5(-5)	546,300	V
	Comm.	decent shock breakout, possibly near over-drive					
17515	**Be**	—	90	20	3022.5 (5)	546,310	V
	#2, 112						
	Comm.	single crystal $\langle\bar{2}110\rangle$, cracked, rough surfaces.					
		transit time 12 ns, shock breakout @ 7 ns.					
		slow ramping; possible plasma interfering					
		through the cracks.					
		May 04, 2005, Wednesday					
17529	Ti, 28	—	111	20	3012.5(-5)	546,300	V
	Comm.	pilot shot for Be next shot					
		the record is weak, but nice if normalized					
17530	**Be**, 112	—	122	20	3022.5 (5)	546,310	V
	#3						
	Comm.	single crystal $\langle\bar{2}110\rangle$, shining surface.					
		(transit time 12 ns, shock breakout @ 7 ns).					
		there is one small DOT on one side of the sample					

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Shot	Sample	A	B	Sweep	Camera	V-laser	Diag.
		for relative orientation upon cutting					
		–facing VISAR for the sake of TXD.					
		nice and clean record, possibly over-drive.					
		May 05, 2005, Thursday					
	Comm.	TXD, Kentech cameras static timing to A and B.					
		B-to-A was done (0).					
17532	Au	7	9	—	3022.5(5)	546,310	T
	Comm.	Au foil for timing Kentech cameras, elements 1, 7, 10, 13.					
		South sees A, delay 3009.6 ns, 17 mils Be, CsI.					
		North sees B, delay 3009.3 ns, 17 mils Be, CsI.					
17539	Ti	172		—	3022.5(5)	546,310	T
	Comm.	x-rays from Ti-foil on time-integrated tubby					
		no real target; tubby looks good					
		South sees A, delay 3009.6 ns, 17 mils Be, CsI.					
		North sees B, delay 3009.3 ns, 17 mils Be, CsI.					
		May 06, 2005, Friday					
17541	PTFE,102	103	21	50	3012.5(34.5)	546,360	V, T
	Comm.	aluminized Teflon. Ti backlighter, tubby only.					
		49.8 to 60.7 ns transit?					
		no shock observed; weak or camera timing too late					
17542	PTFE,102	179	96	50	2967.5(-10.5)	546,320	V, T
	Comm.	aluminized Teflon. Ti backlighter, tubby only.					
		49.8 to 60.7 ns transit might be wrong.					
		probe laser multimoding.					
17543	NiAl, 58	—	108	20	3012.5(-5)	546,530	V
	Comm.	NiAl-[111]-04-1					
		late breakout.					
		May 06, 2005, Friday					
17544	NiAl, 180	—	98	20	3037.5(20)	546,350	V
	Comm.	NiAl-[110]					
		confusing record.					
17545	PTFE,102	146	88	50	3012.5(34.5)	546,360	V, T
	Comm.	aluminized Teflon. Al driver.Ti backlighter, tubby only					
		49.8 to 60.7 ns transit?					
		timing is right.					
17546	PTFE,102	—	167	50	3012.5(34.5)	546,360	V
	Comm.	aluminized Teflon. Al driver.Ti backlighter, tubby only					

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Shot	Sample	A	B	Sweep	Camera	V-laser	Diag.
		49.8 to 60.7 ns transit?					
		no shock. timing?					
17547	PTFE,102	—	167	50	3012.5(34.5)	546,360	V
	Comm.	aluminized Teflon. Al driver.Ti backlighter, tubby only					
		49.8 to 60.7 ns transit?					
		tilted shock breakout.					
		May 10, 2005, Tuesday					
17549	NiAl,120	—	30	20	3027.5(10)	546,320	V
	Comm.	⟨111⟩, 16.7 ns transit.					
		weak shock, clear breakout.					
		no recovery.					
17550	PTFE,102	—	139	50	3012.5(34.5)	546,360	V
	Comm.	aluminized Teflon. Al driver.					
		49.8 to 60.7 ns transit?					
		tilted shock breakout, possibly 2-wave structure.					
17551	PTFE,102	—	120	50	3012.5(34.5)	546,360	V
	Comm.	aluminized Teflon. Al driver.					
		49.8 to 60.7 ns transit?					
		tilted shock breakout, possibly 2-wave structure.					
17552	PTFE,102	—	99	50	3012.5(34.5)	546,360	V
	Comm.	aluminized Teflon. Al driver.					
		49.8 to 60.7 ns transit?					
		no shock breakout, possibly due to glue.					
17553	NiAl,160	—	18	20	3032.5(15)	546,320	V
	Comm.	⟨111⟩, with LiF window, 22.3ns					
		nice and clean record with wiggles. Recovered.					
17554	**Be#3**, 60	168	—	20	3022.5 (5)	546,310	T
	Comm.	single crystal ⟨$\bar{2}$110⟩, cracked, rough surfaces					
		static TXD, A-beam only, 45 degree, 8 mm.					
		S Kentech, delay 3007.0 ns, 17mils Be + 12μm Fe CsI.					
		N Kentech, delay 2998.0 ns, 17mils Be + 6μm Ni CsI.					
		small signal on PCD.					
		time-integrated x-ray films saturated,					
		Kentechs noisy, more filtering.					
17555	Vit1,158	—	65	20	3037.5(20)	546,320	V
	Comm.	30.5ns transit					
		shock breakout @ 10 ns, laser multimode.					

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Shot	Sample	A	B	Sweep	Camera	V-laser	Diag.
			May 11, 2005, Wednesday				
17557	**Be**, 60 **#3**	168	—	20	3022.5 (5)	546,310	T
	Comm.	single crystal ⟨$\bar{2}$110⟩, cracked, rough surfaces. static XRD, A-beam only, 45 degree, 8mm S Kentech, delay 3007.0 ns, 17mils Be + 12μm Fe CsI. N Kentech, delay 2998.0 ns, 17mils Be + 6μm Ni CsI. different, need more tests. time-integrated x-ray films saturated, Kentechs noisy, more filtering.					
17558	NiAl,140	—	22	20	3027.5(10)	546,320	V, R
	Comm.	⟨110⟩, with LiF window, 20ns drive at window side, no shock, no recovery					
17559	**Be**, 60 **#3**	152	—	20	3022.5 (5)	546,310	T
	Comm.	single crystal ⟨$\bar{2}$110⟩, cracked, rough surfaces static XRD, A-beam only, 45 degree, 8mm S Kentech, delay 3007.0 ns, 17mils Be + 12um Fe CsI N Kentech, delay 2998.0 ns, 17mils Be + 6um Ni CsI different, need more tests.					
17560	PTFE,102	—	99	50	3012.5(34.5)	546,360	V
	Comm.	aluminized Teflon. Al driver. 49.8 to 60.7 ns transit?					
17561	**Be**, 60 **#3**	136	149	20	3022.5 (5)	546,310	V, T
	Comm.	single crystal ⟨$\bar{2}$110⟩, cracked, rough surfaces. TXD, 45 degree, 8mm. S Kentech, delay 3007.0 ns, 17mils Be + 12um Fe CsI. N Kentech, delay 2998.0 ns, 17mils Be + 6um Ni CsI. *nice VISAR record.* S x-ray film some lines, N x-ray film saturated. time-integrated x-ray films saturated, Kentechs noisy.					
			May 12, 2005, Thursday				
17563	**Be**, 149 **#4**	136	—	20	3022.5(5)	546,310	T
	Comm.	single crystal ⟨$\bar{2}$110⟩, shining surface, big wrinkle. transit time 12 ns, shock breakout @ 7 ns. S Kentech lines.					

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Shot	Sample	A	B	Sweep	Camera	V-laser	Diag.
VPF of 800 m/s for shots 17565 – 17571.							
			May 13, 2005, Friday				
17565	Ti, 28	—	105	20	3012.5(-5)	546,310	V
	Comm.	Ti foil. nice shock breakout, two-wave structure.					
17566	**Be**, 149 **#4**	139	62	20	3022.5(5)	546,310	V, T
	Comm.	single crystal $\langle\bar{2}110\rangle$, shining surface, big wrinkle. transit time 12 ns, shock breakout @ 7 ns. S Kentech lines. *beautiful breakout, two-wave structure.*					
17567	PTFE,102	—	23	50	3012.5(34.5)	546,360	V
	Comm.	aluminized Teflon. Al driver. 49.8 to 60.7 ns transit? non-uniform breakout					
17568	NiAl,175	—	65	20	3037.5(20)	546,330	V
	Comm.	$\langle 111\rangle - \langle 100\rangle - 04 - 32$ with LiF. bicrystal, window-complicated recoved.					
17569	Vit106,24	—	34	20	3012.5(-5)	546,330	V
	Comm.	Vitreloy 106 (40 m/s) on LiF, Caltech, Singapore, Yi Li. no clear record.					
17570	LSO, 60	—	58	20	3012.5(-5)	546,310	V
	Comm.	on 28-μm Ti, with photodiode to scopes. nice shock breakout; small LSO signal.					
17571	LSO, 60	—	75	20	3012.5(-5)	546,310	V
	Comm.	on 28-μm Ti, with LSO photodiode to scopes. nice shock breakout; small LSO signal.					