LA-UR- 98-3754

Proton Radiography of the Detonation Front in HE systems

John D. Zumbro

P-25

Los Alamos National Laboratory

reporting on the work of many people

11th International Detonation Symposium

31 August 1998

Proton Radiography

Science Based Stockpile Stewardship

Bechtel Nevada

University of California Lawrence Livermore National Laboratory

Los Alamos NATIONAL LABORATORY

... reporting on the work of many people

P-21	DX-1	ESH-1
P-23	DX-2	ESH-5
P-25	**DX-3**	
P-DO	DX-4	
LANSCE-1	DX-5	
LANSCE-2	DX-6	
LANSCE-3	DX-DO	**Bechtel Nevada**
LANSCE-5	**X-NH**	**LLNL**
LANSCE-6	X-TM	SNL
LANSCE-7	X-CI	UK / AWE
LANSCE-DO	ESA-WMM	

Outline of talk

- Comparison of proton and x-ray radiography
- describe the 800-MeV proton radiography area at LANSCE
- will describe the onionskin data
- other capabilities
- summary

X-ray radiography

- Source size (dose)
- Detector blur
- Scattered background
- Hardening

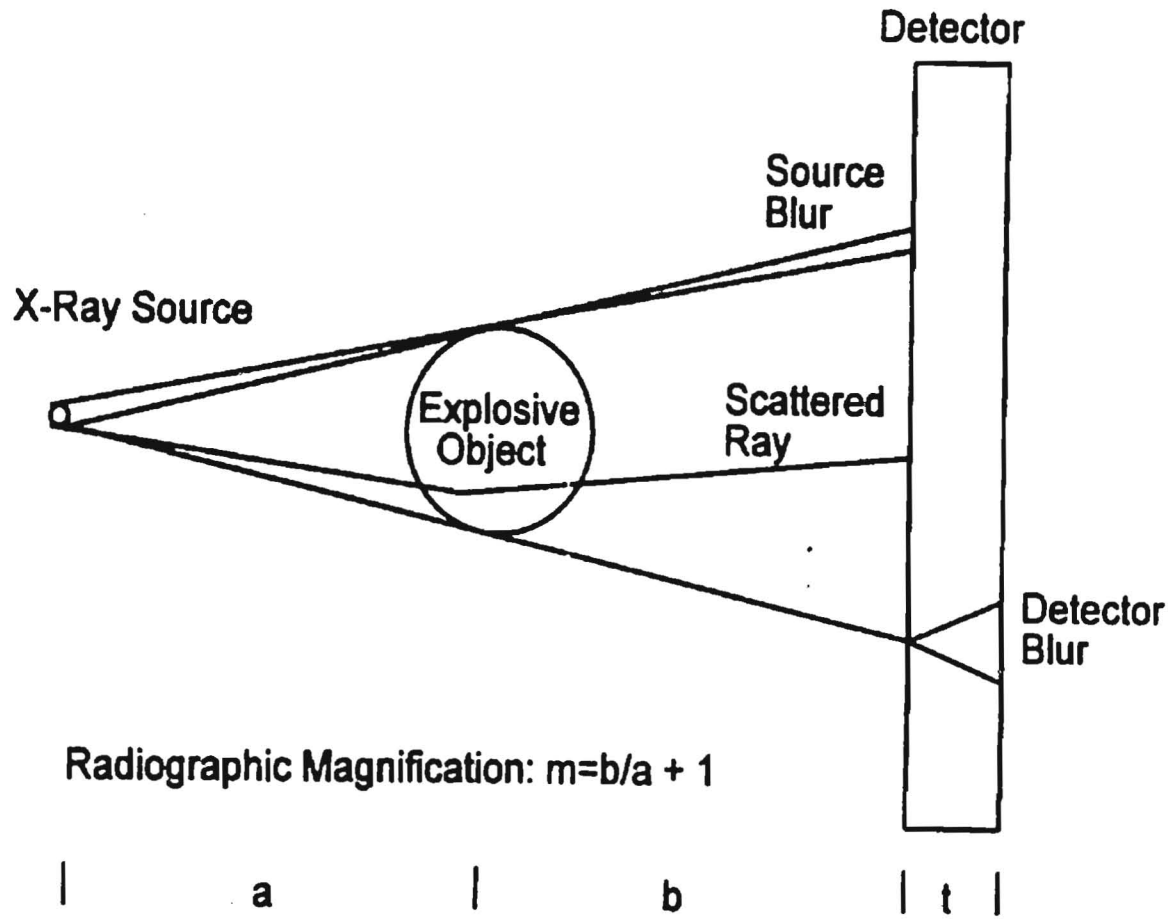
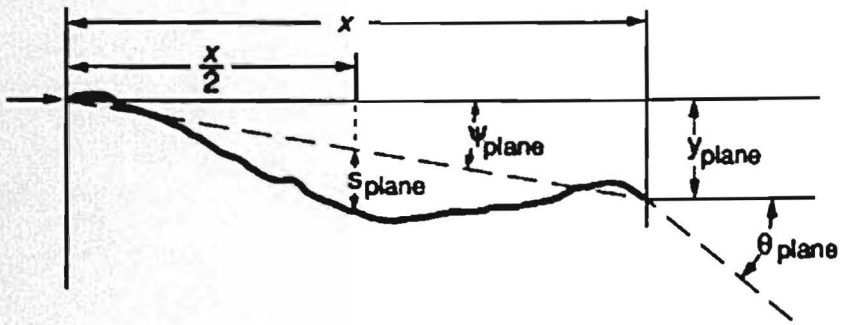


Figure 1 - Typical Radiographic System

Proton radiography

- Attenuation
- Multiple scattering
- Energy loss

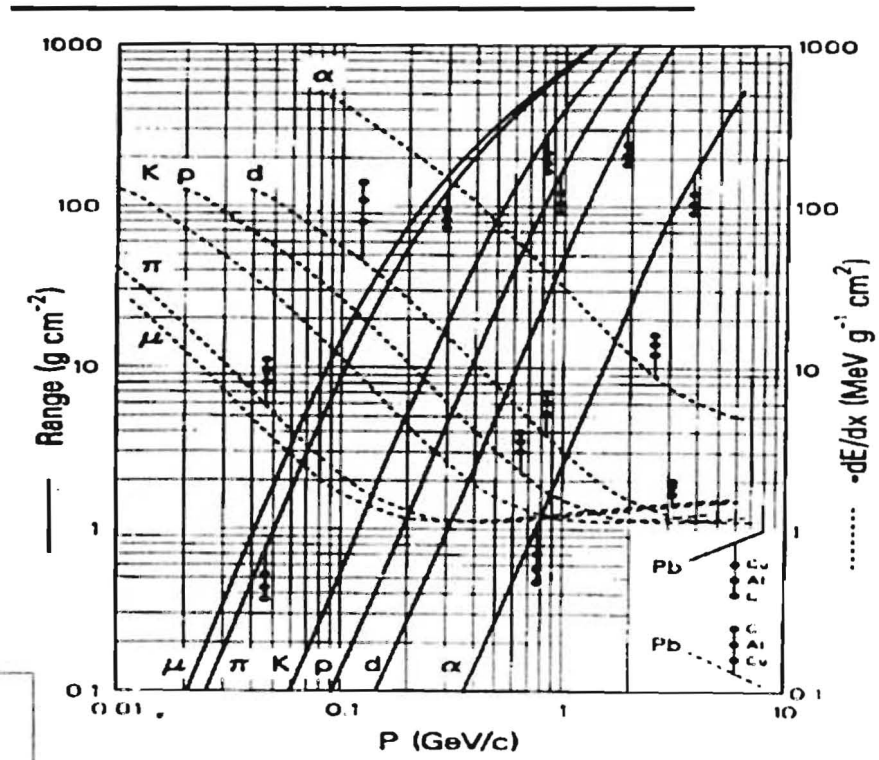
Material	λ_γ (gm/cm^2)	λ_n (gm/cm^2)
Li	25	73
U	25	199



$$y_{\text{plane}} = z_1\, x\, \theta_0 (1-\rho_{y\theta}^2)^{1/2}/\sqrt{3} + z_2\, \rho_{y\theta} x\, \theta_0/\sqrt{3}$$

$$= z_1\, x\, \theta_0/\sqrt{12} + z_2\, x\, \theta_0/2\ ;$$

$$\theta_{\text{plane}} = z_2\, \theta_0\ .$$



Proton radiography - the effects

$$N_{out}=N_{in}\, e^{-\Sigma(l_i/\lambda_i)}\, e^{-2\theta_o^2/\theta_{cut}^2}$$

Transmission	Multiple scattering	Energy loss
$\frac{N_1}{N_0}=e^{-\sum\frac{l_i}{\lambda_i}}$ so, $\sum\frac{l_i}{\lambda_i}=-\ln\left(\frac{N_1}{N_0}\right)$	$\frac{N_2}{N_1}=\frac{1}{2\pi\theta_0^2}\int_0^{\theta_m} e^{-\frac{\theta^2}{2\theta_0^2}}d\Omega \cong \left[1-e^{-\frac{\theta_m^2}{2\theta_0^2}}\right]$ where, $\theta_0\approx\frac{14.1}{p\beta}\sqrt{\sum\frac{l_i}{L_{Ri}}}$ so, $\sum\frac{l_i}{L_{Ri}}=-\frac{(p\beta\theta_m)^2}{2(14.1)^2\ln\left(1-\frac{N_2}{N_1}\right)}$	$E=E_0-\sum\frac{dE}{dx_i}l_i$ $\sum\frac{dE}{dx_i}l_i=E-E_0$

Proton radiography - angle matching

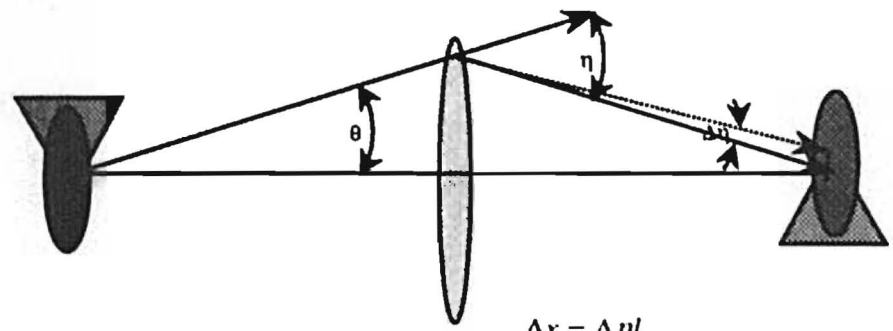
The leading aberations are chromatic:

$x_{image} = x_{object} + (x|\theta\delta)\theta\delta + (x|x\delta)x\delta + \cdots$

Setting:

$(x|\theta\delta)\theta\delta = -(x|x\delta)x\delta$ gives:

$$\theta = \frac{-(x|x\delta)}{(x|\theta\delta)}x$$



$\Delta x = \Delta\eta l$

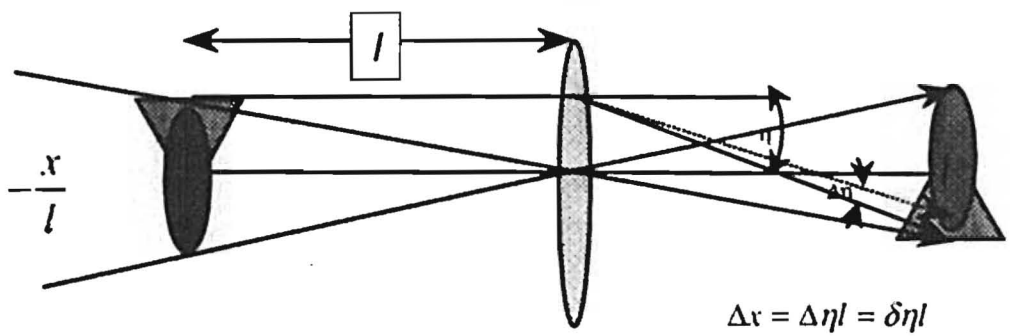
$\delta = \frac{p - p_0}{p_0}$, $\eta = 2\theta$, $\Delta\eta = \delta 2\theta$, so

$\Delta x = \delta 2\theta l$

$(x|\theta\delta) = 2l$

- **Uniform acceptance**
  - **analysis simple**
- **Reduced aberrations**
  - **pin hole camera**

$$\theta = -\frac{x}{l}$$

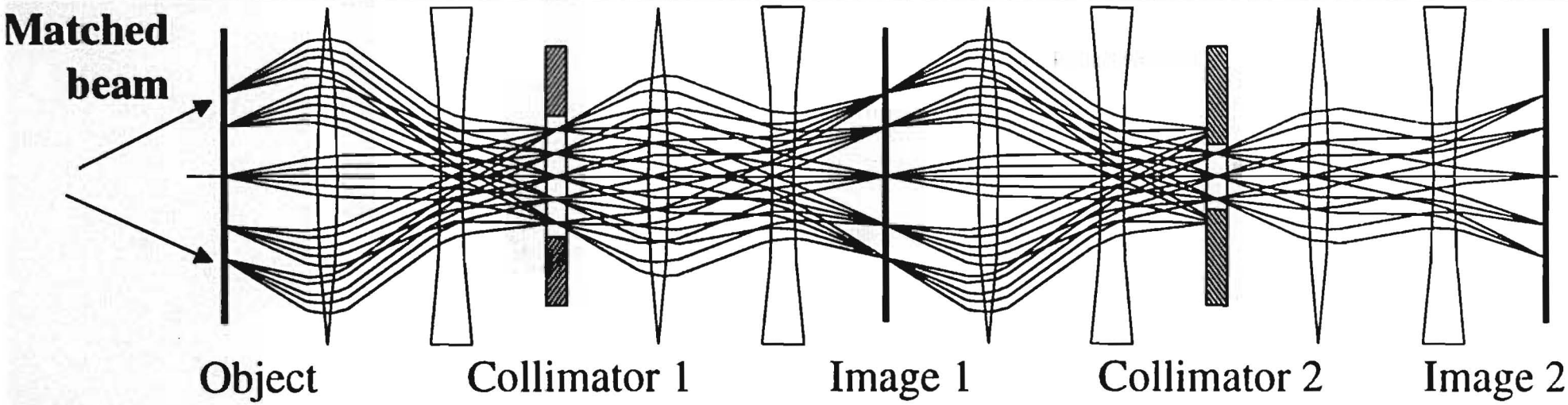


$\Delta x = \Delta\eta l = \delta\eta l$

$\eta = \frac{2x}{l}$, so

$(x|x\delta) = 2$

Material differentiation



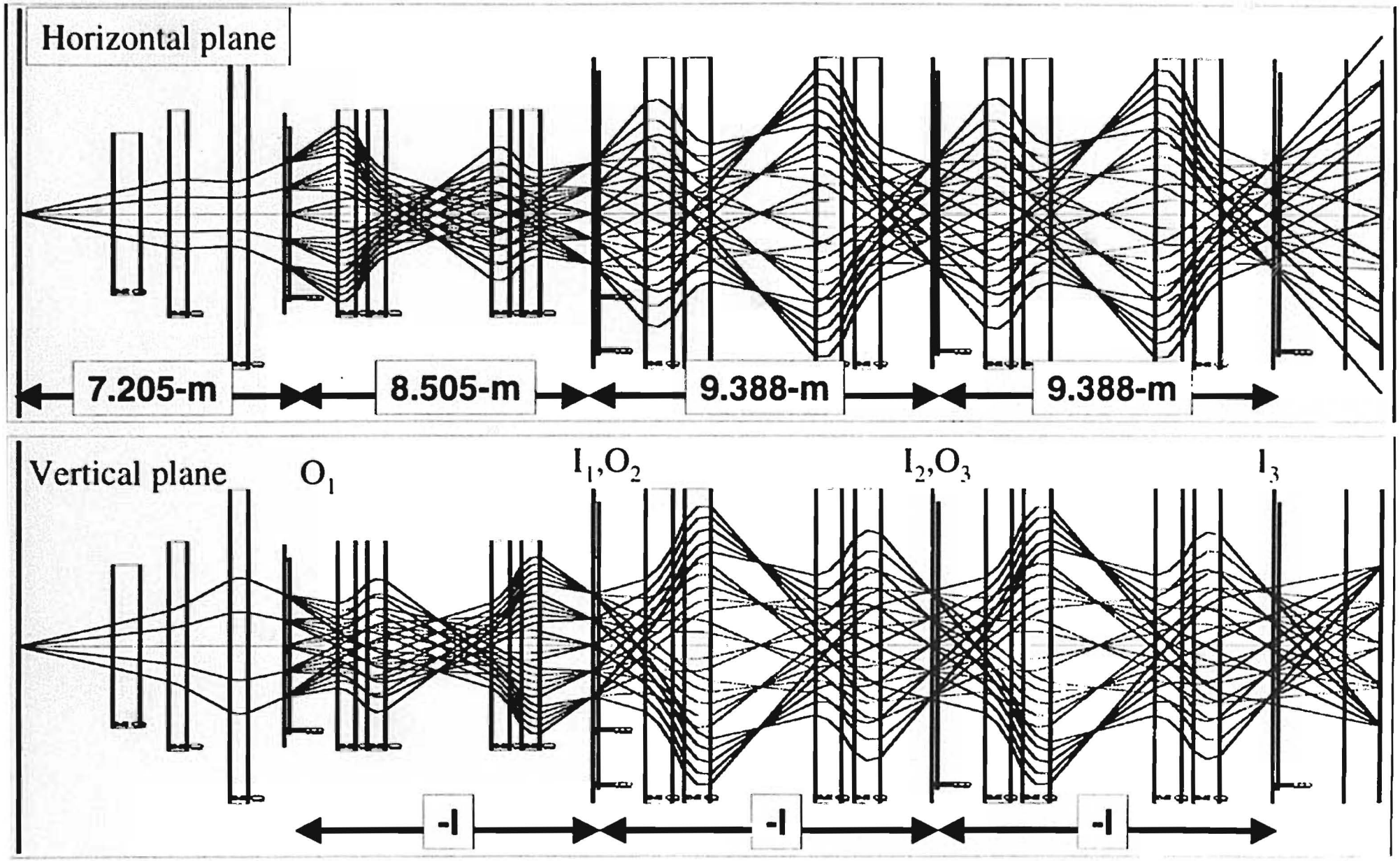
$$\frac{N_1}{N_0} = e^{-\sum \frac{l_i}{\lambda_i}} \left(1 - e^{-\frac{\theta_1^2}{2\theta_0^2}}\right)$$

$$\frac{N_2}{N_0} = e^{-\sum \frac{l_i}{\lambda_i}} \left(1 - e^{-\frac{\theta_2^2}{2\theta_0^2}}\right) \text{ where}$$

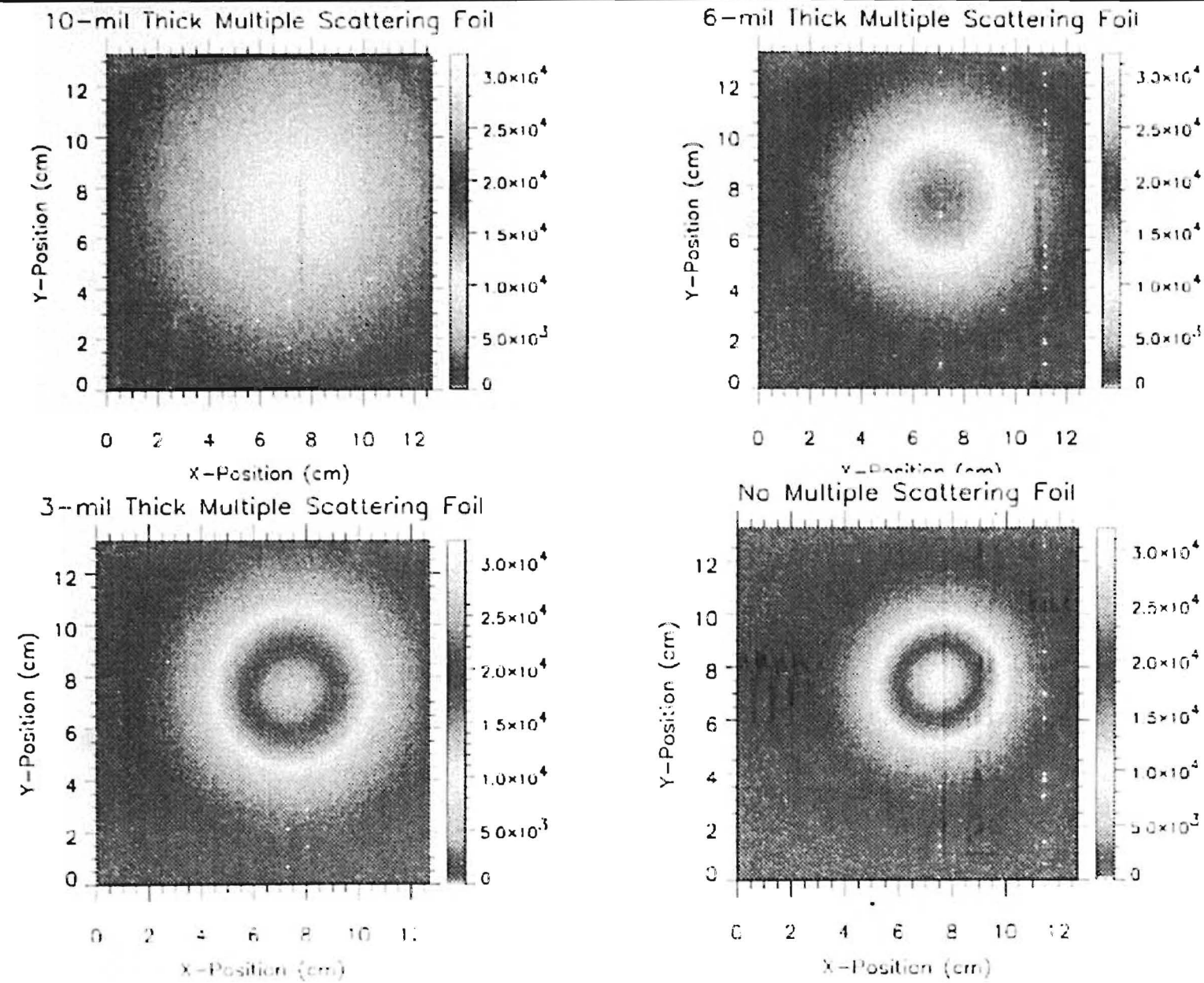
$$\theta_0 \approx \frac{14.1}{p\beta}\sqrt{\sum \frac{l_i}{L_R}}$$

Material	λ_i (gm/cm^2)	L_R (gm/cm^2)	1/dE/dx (gm/cm^2/MeV)
D	55.	123.	0.5
Be	75.	65.	0.6
Fe	132.	14.	0.7
U	199.	6.	0.9

LANSCE Area C with three four-quad -I lens



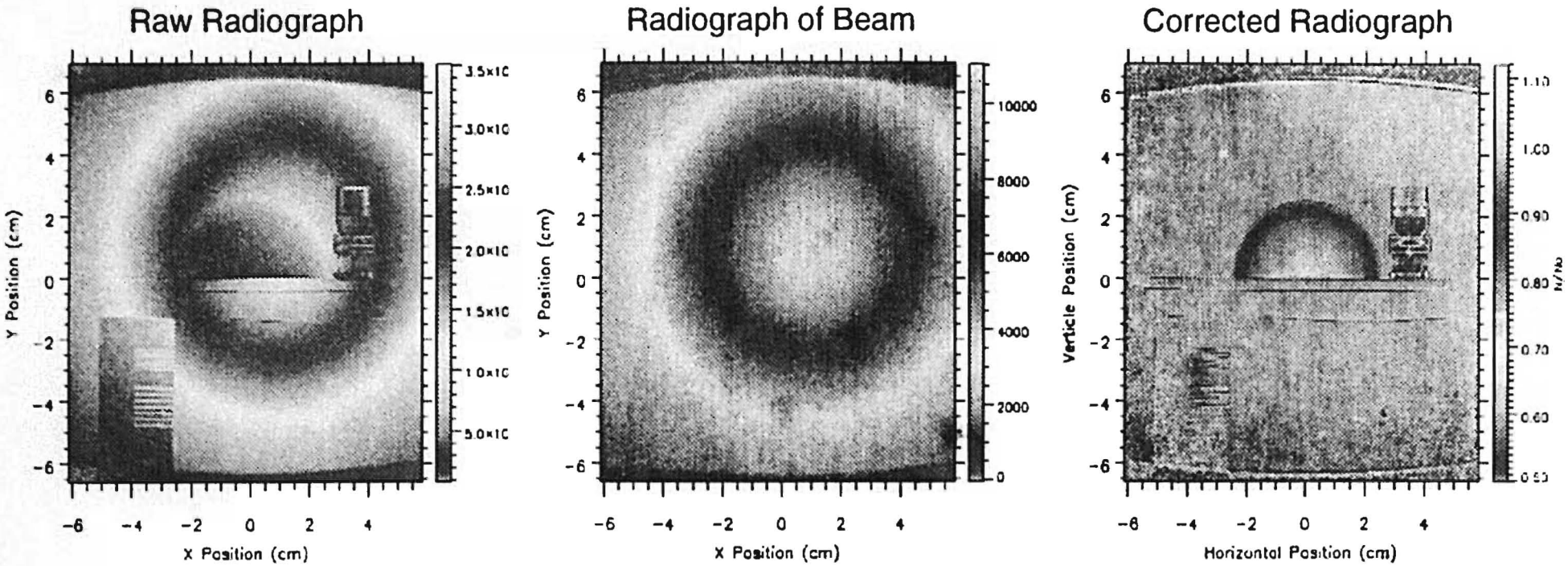
Multiple-Scatting Foil (Diffuser) Contribution to Beam Size (Identical Intensity Scales)



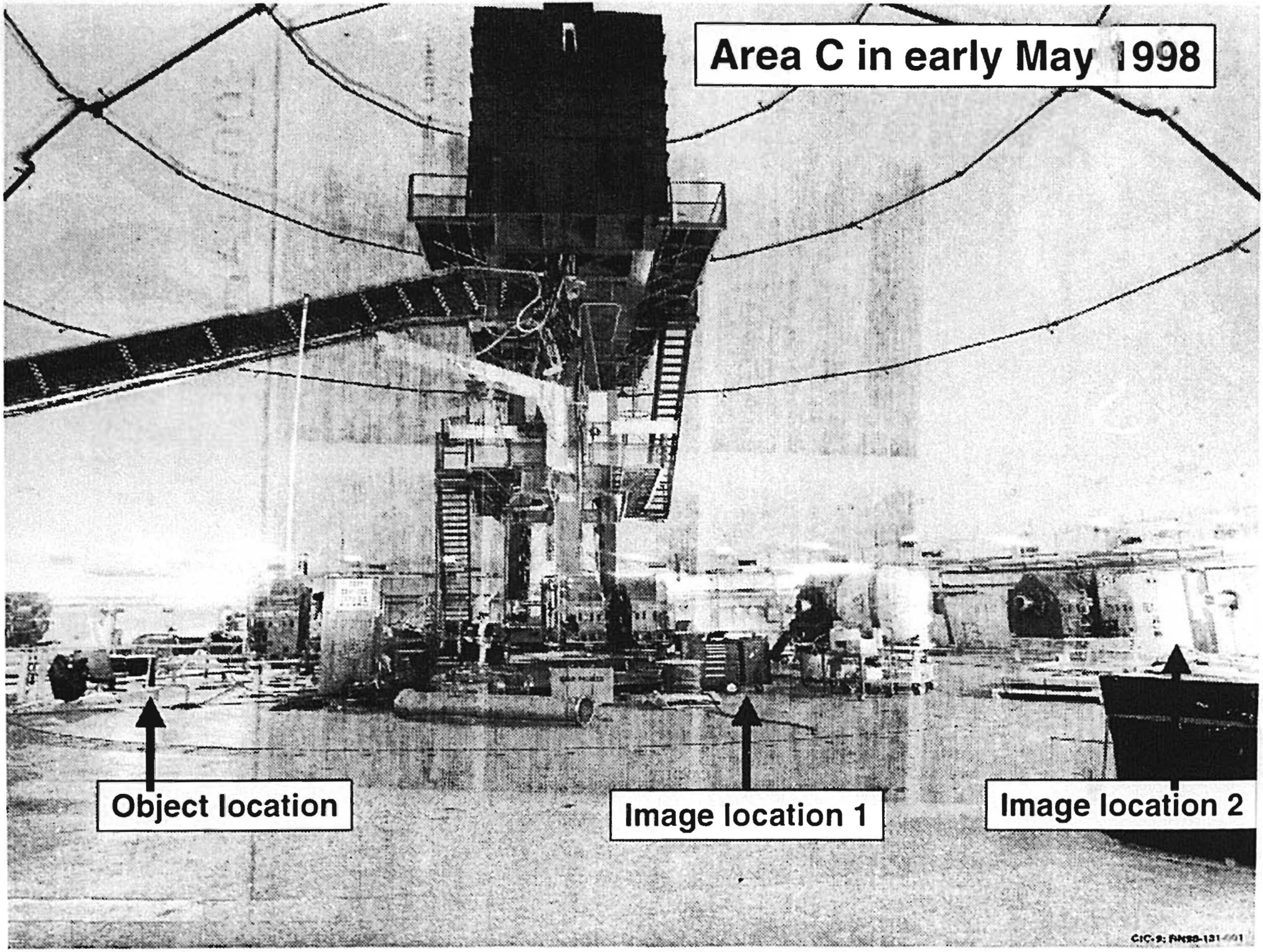
FY97 data with the Line B system

Los Alamos

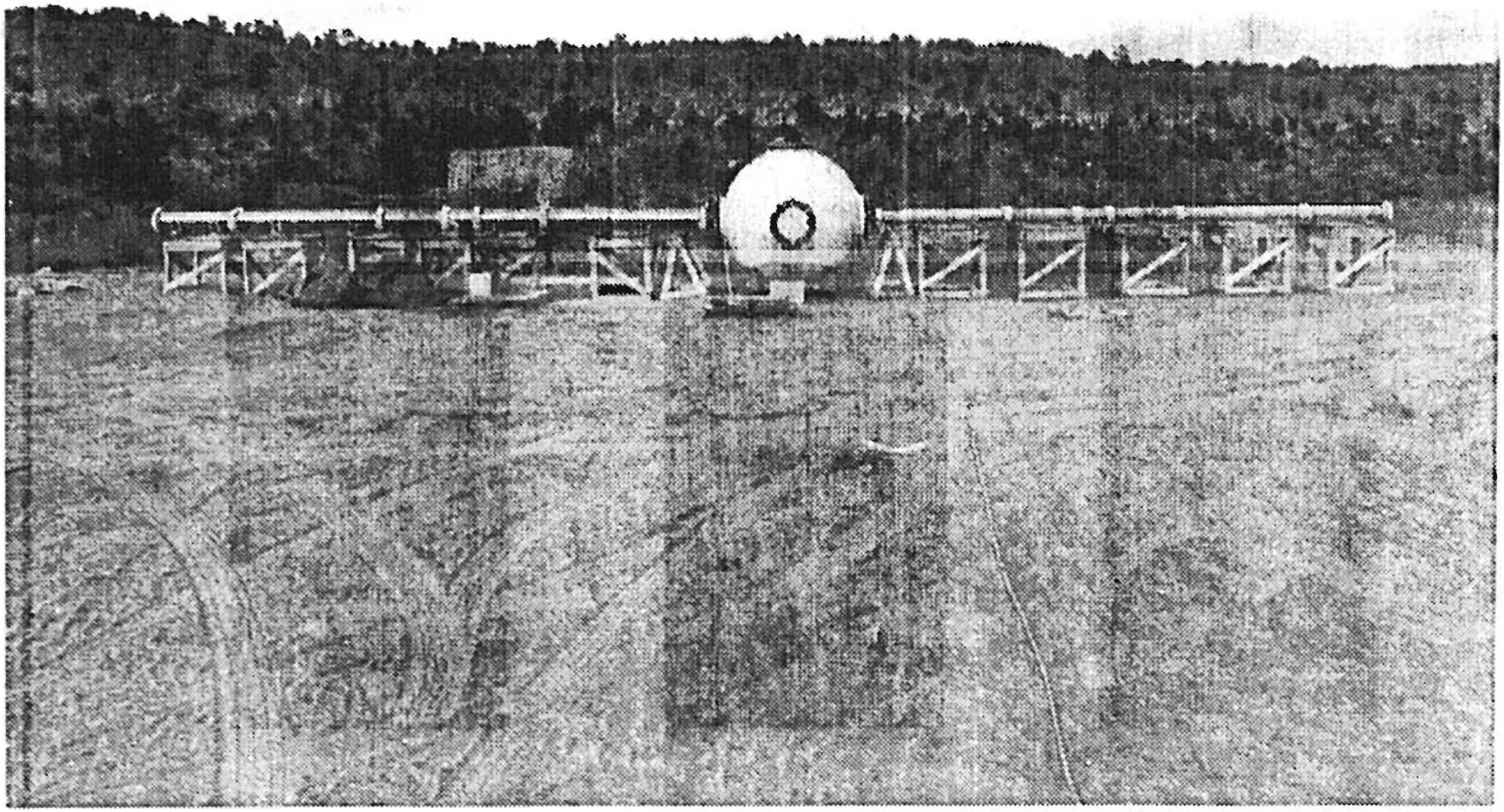
Radiograph-to-Beam ratio



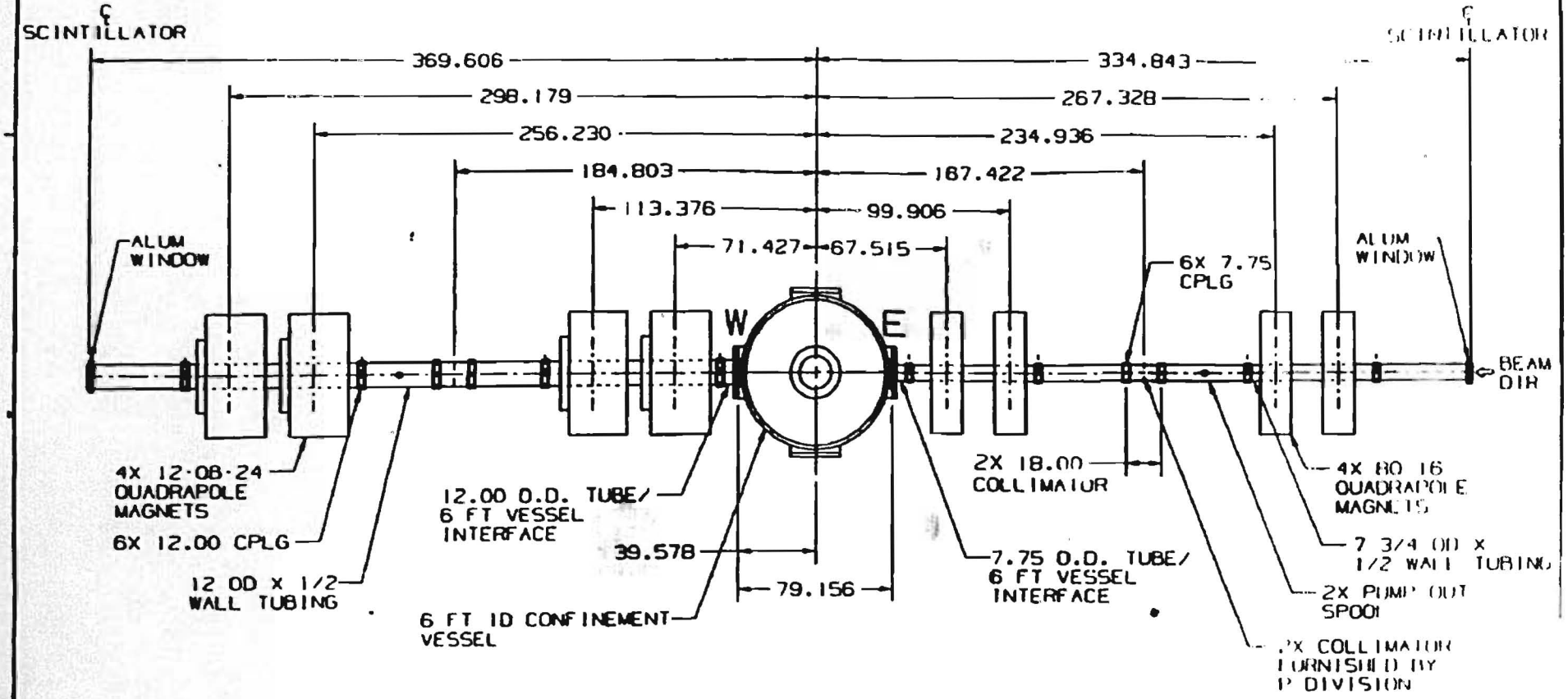
Data taken on
24 March 1997
in Line B


Area C in early May 1998
Object location
Image location 1
Image location 2

6'-ID vessel with containment tubing at DX firing site



NOTES:
1. APPLICABLE STANDARDS/SPECIFICATIONS:
ANSI Y14.5M-1982, DIMENSIONS AND TOLERANCES



PROTON RADIOGRAPHY

Los Alamos National Laboratory
Los Alamos, New Mexico 87545

BEAMLINE SCHEMATIC

B 88516 47Y115924

NONE

1 OF 2

Proton Radiography
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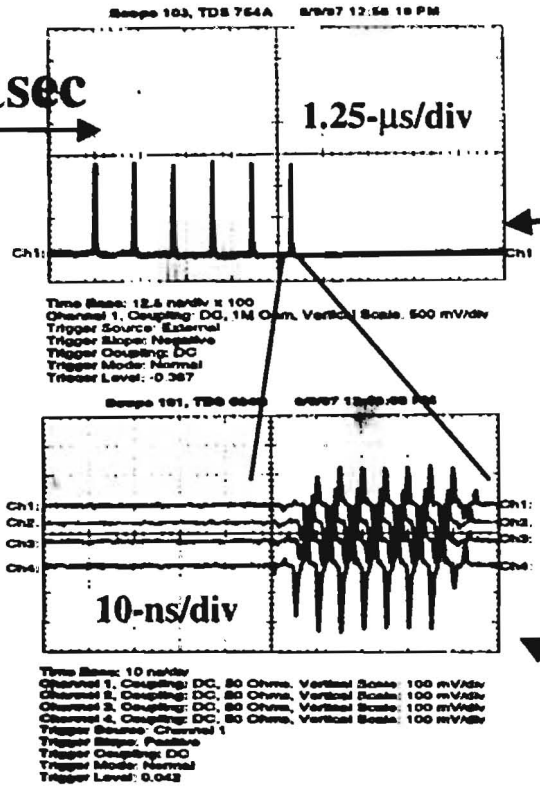
LANSCE accelerator timing

MPEG - beam gate from the accelerator

50 - 625 μs (1 ms max)

Macropulse; up to 120/sec

~90 μsec

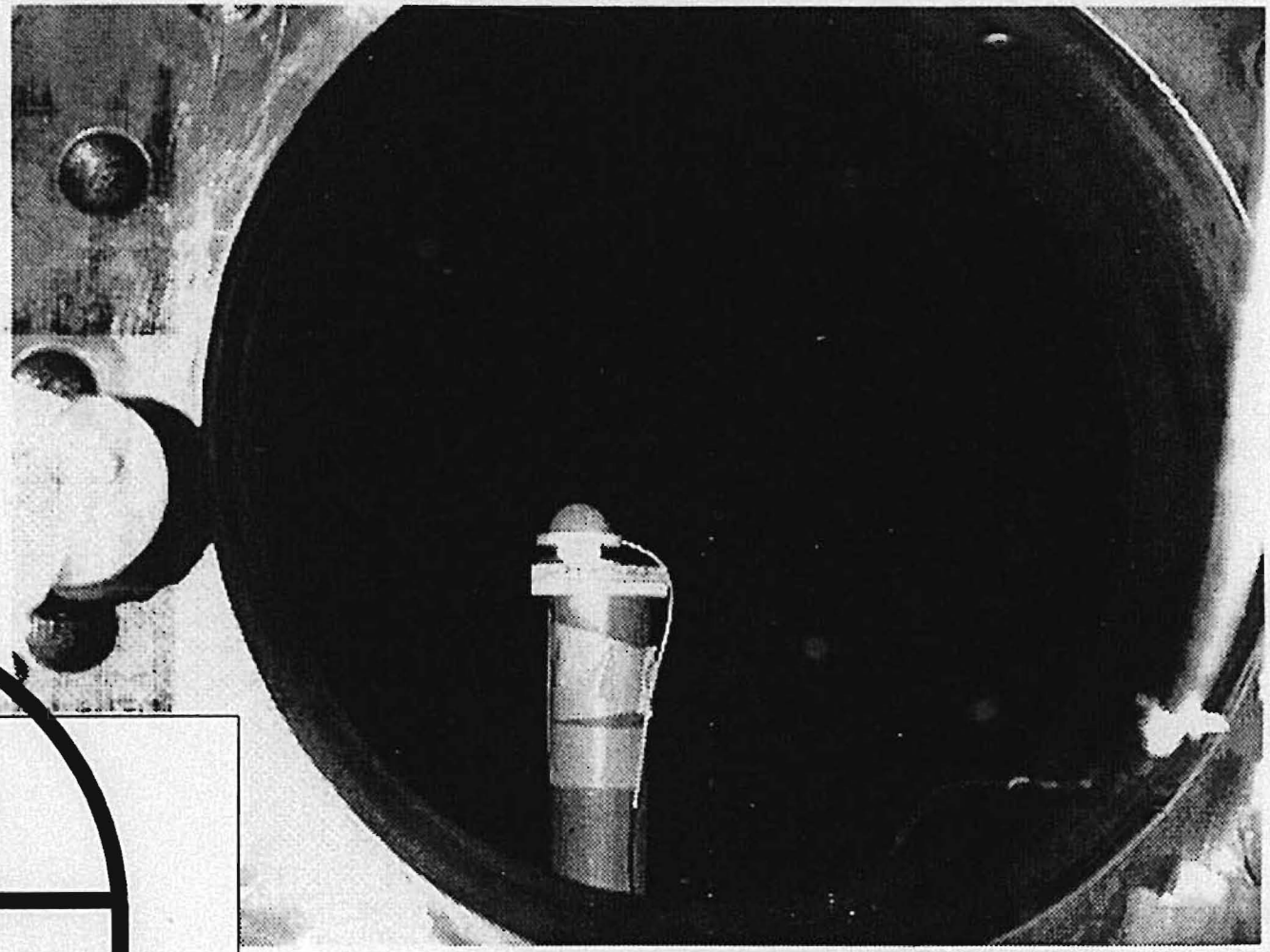


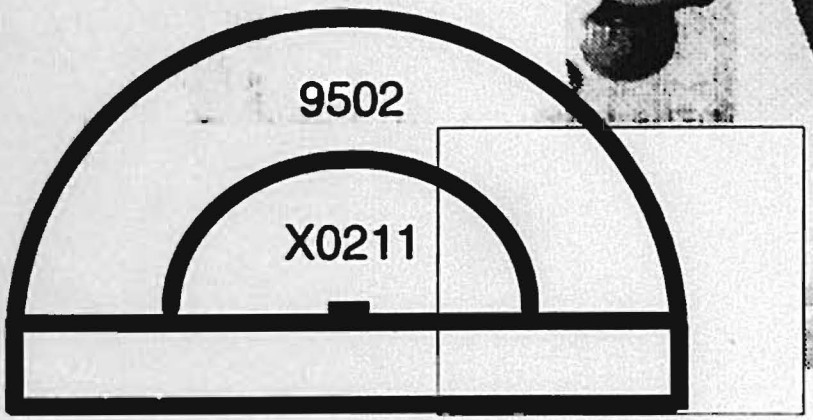
Pulse with proton μbursts; the μbursts have a spacing of N×357-ns/2

Start things with the beginning of MPEG

The width of a μburst is variable in 5-ns increments of the ~200-ps μpulses to about thousands of ns. There are 2-3×10^8 protons per μpulses.

Onionskin in place





Seven-Shooter Onion Skin

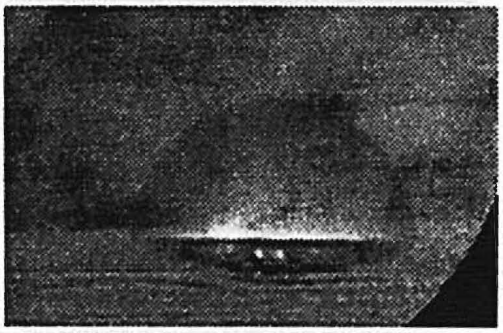
PRAD-0026

Camera 2
-0.147 μsec

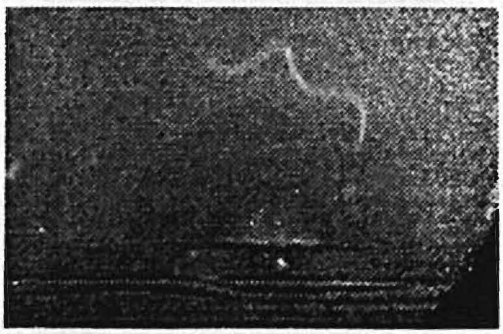
Camera 5
2.715 μsec

Camera 1
0.569 μsec

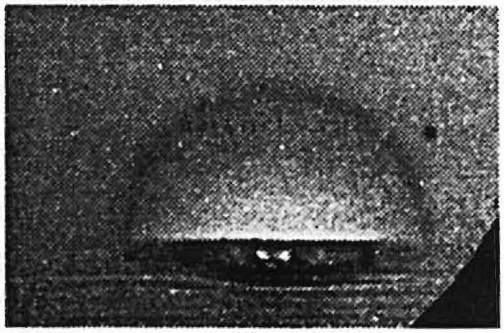
Camera 7
3.431 μsec



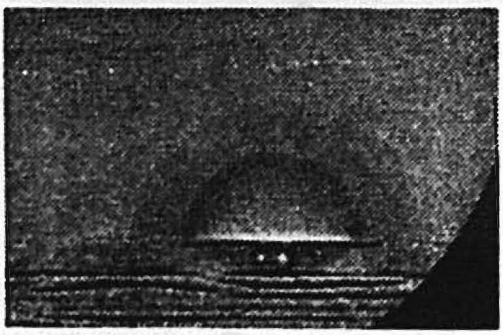
Camera 3
1.284 μsec



Camera 6
4.146 μsec



Camera 4
2.000 μsec



6/29/98

Proton Radiography
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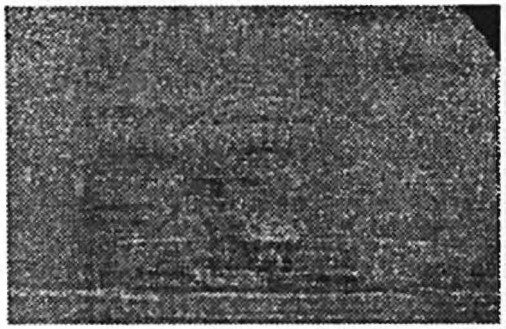
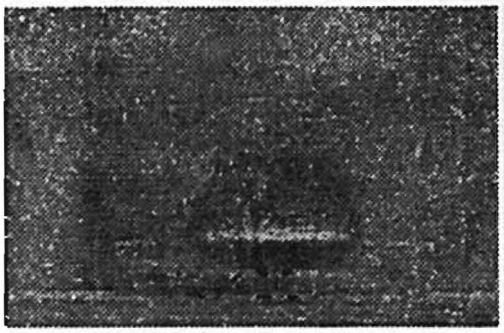
Onion-Skin Radiographs

1997

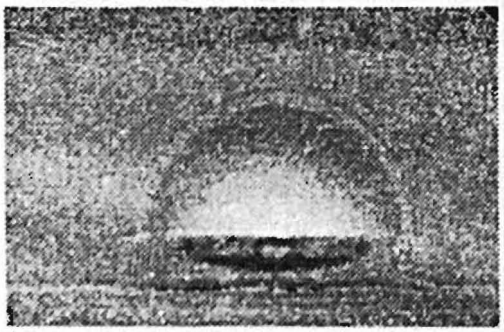
1.031 μsec



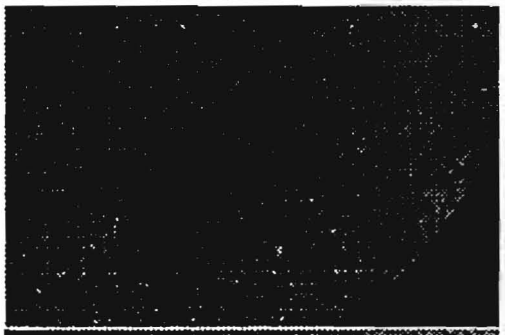
2.104 μsec



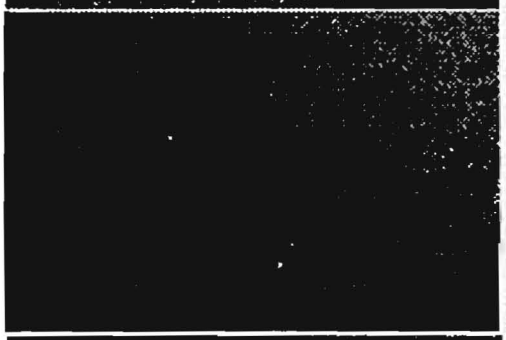
3.178 μsec



1998

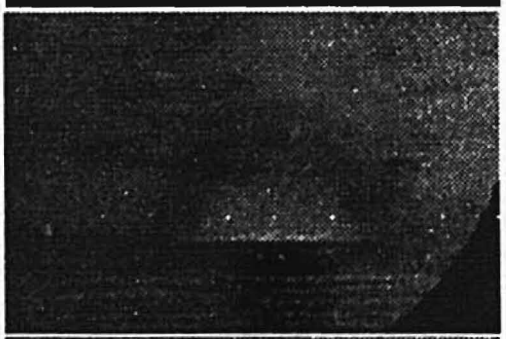


0.569 μsec

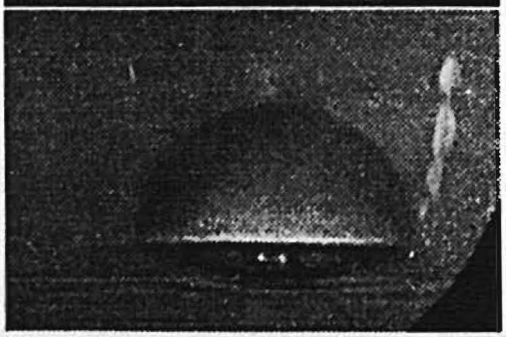


1.284 μsec

2.000 μsec



2.715 μsec



3.431 μsec

FY97 Onion skin data

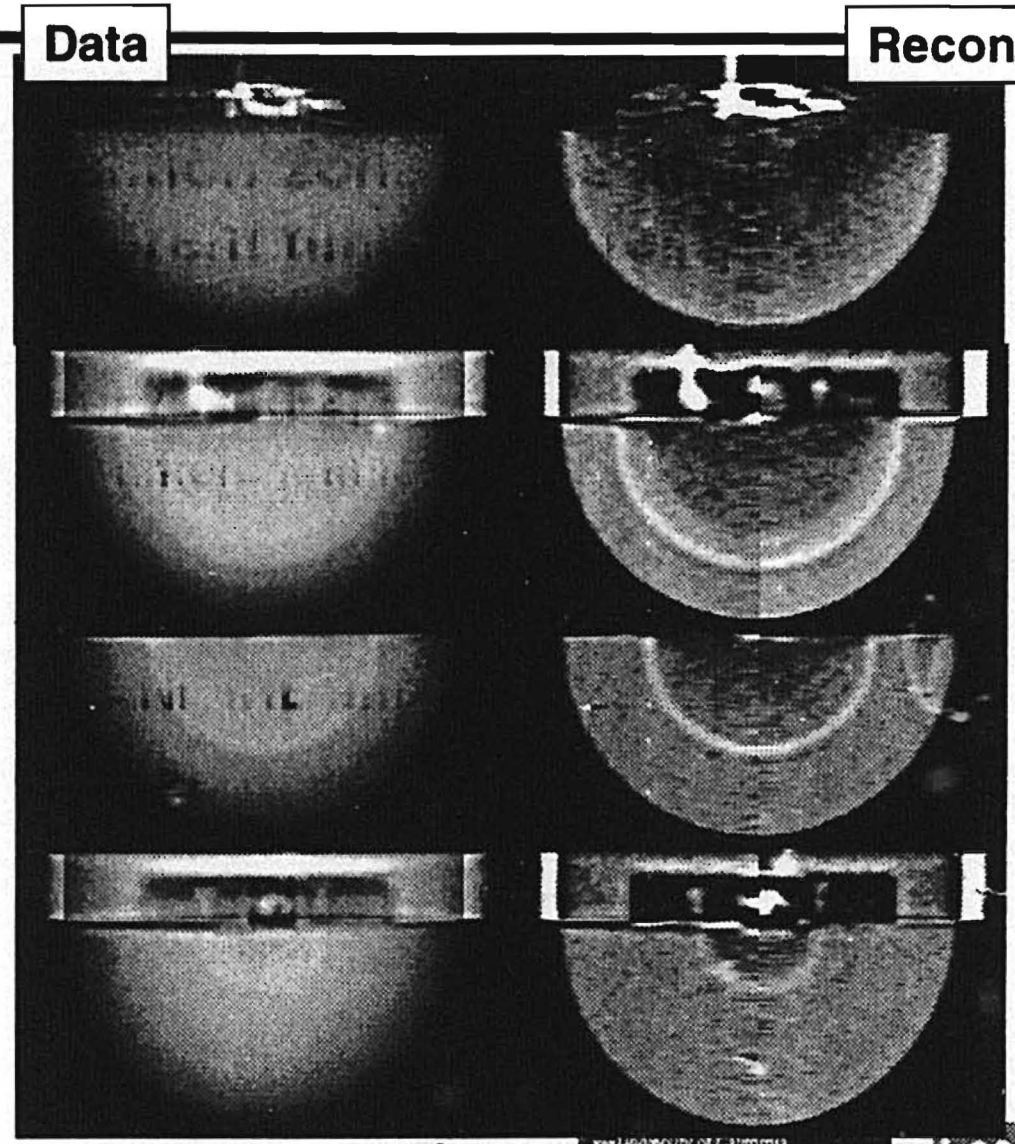
Times with respect to detonator breakout

3.25 μsec

2.50 μsec

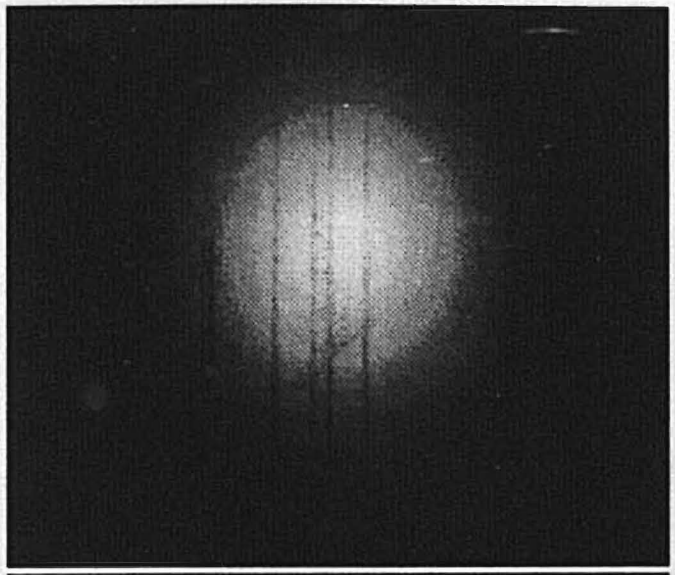
1.90 μsec

0.99 μsec

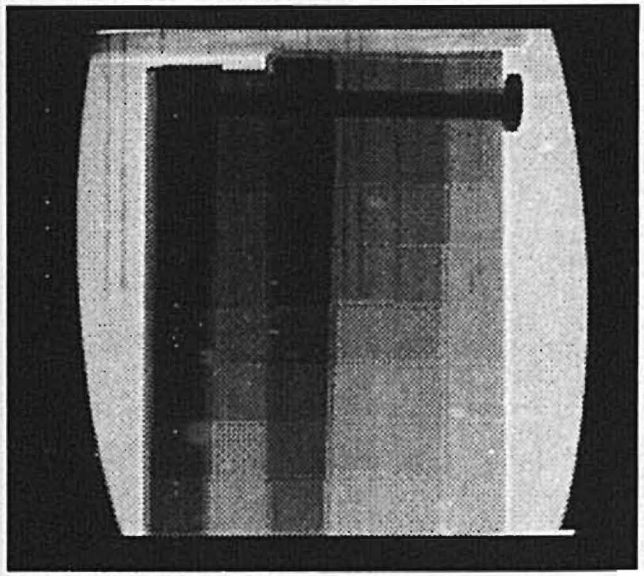


LLNL step wedge data

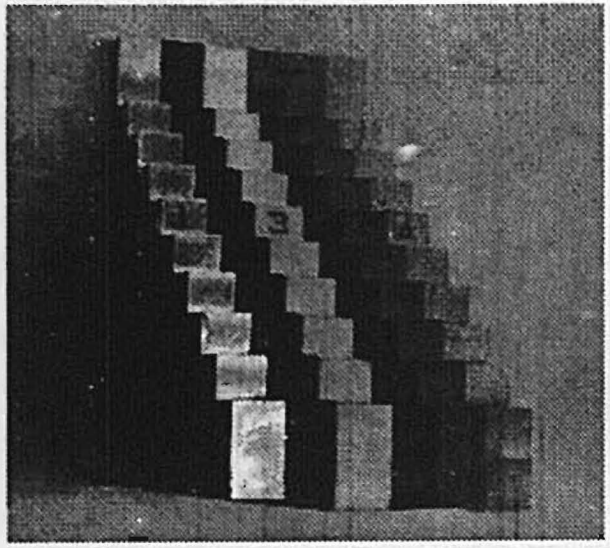
Beam

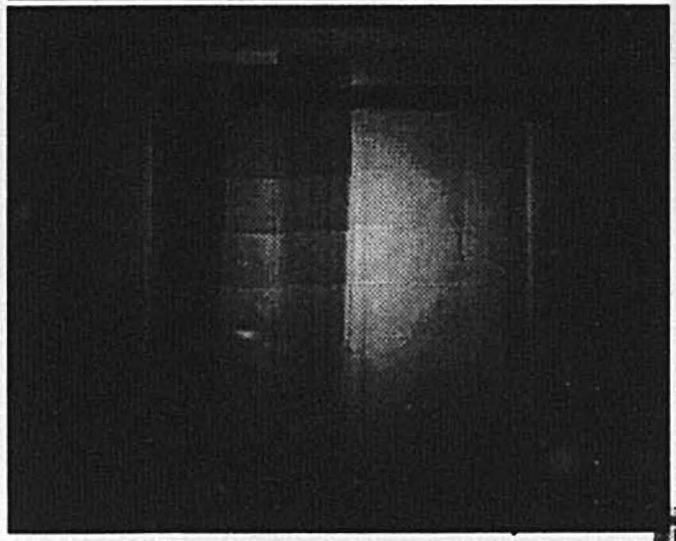


Ratio



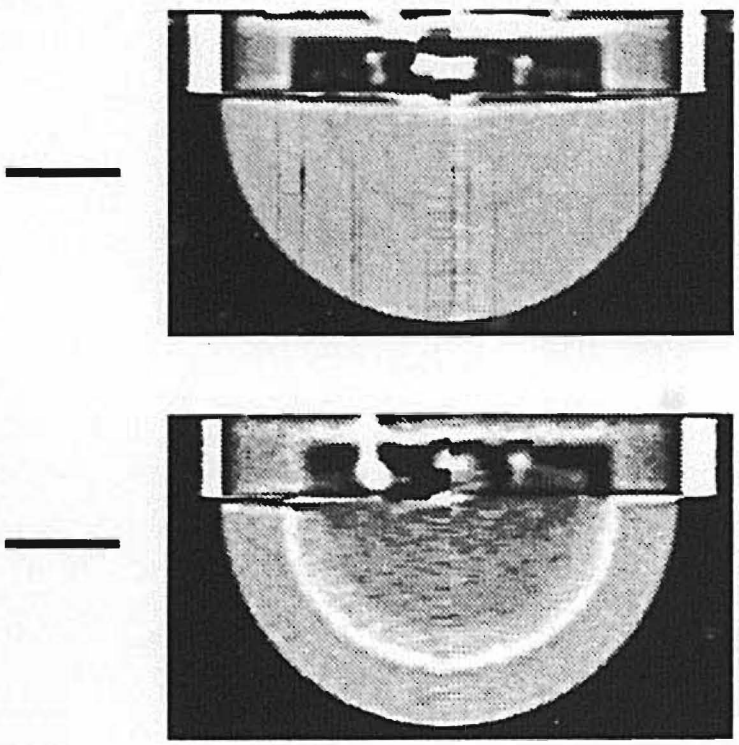
Photograph

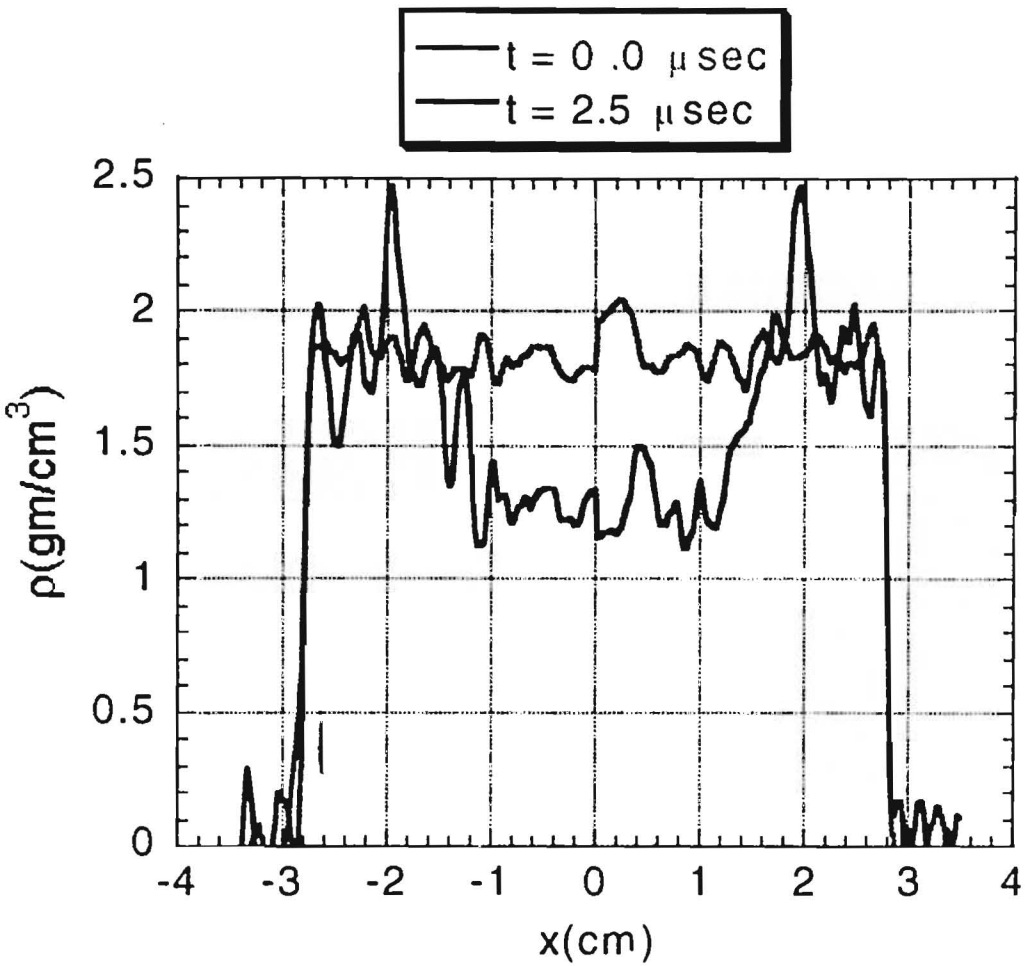




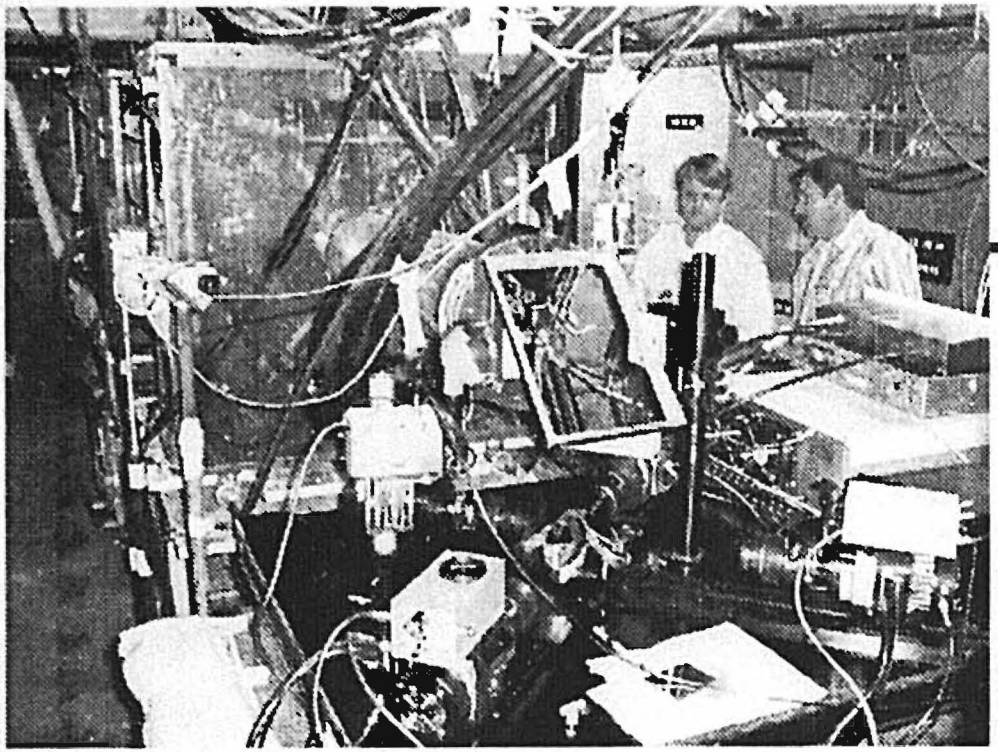
Radiograph

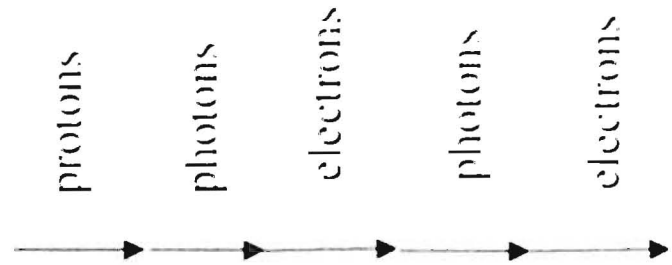
Onion skin - quantitative results

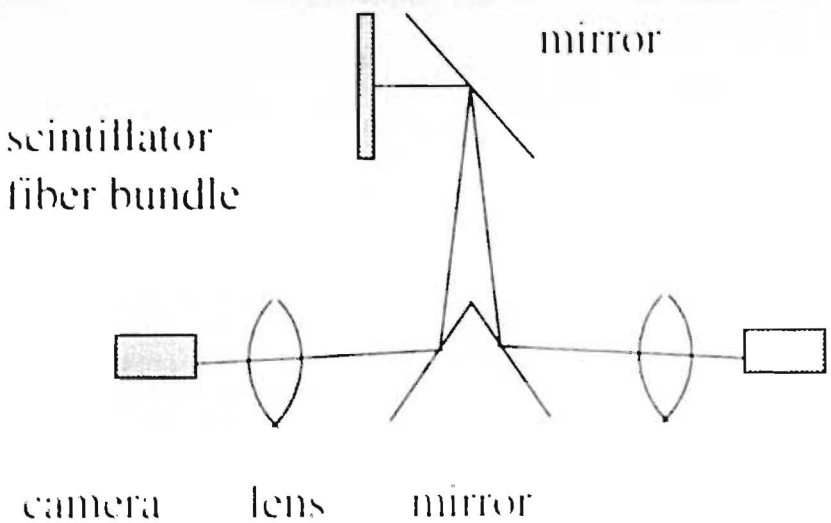




Multiple detectors in Line B (August 1997)



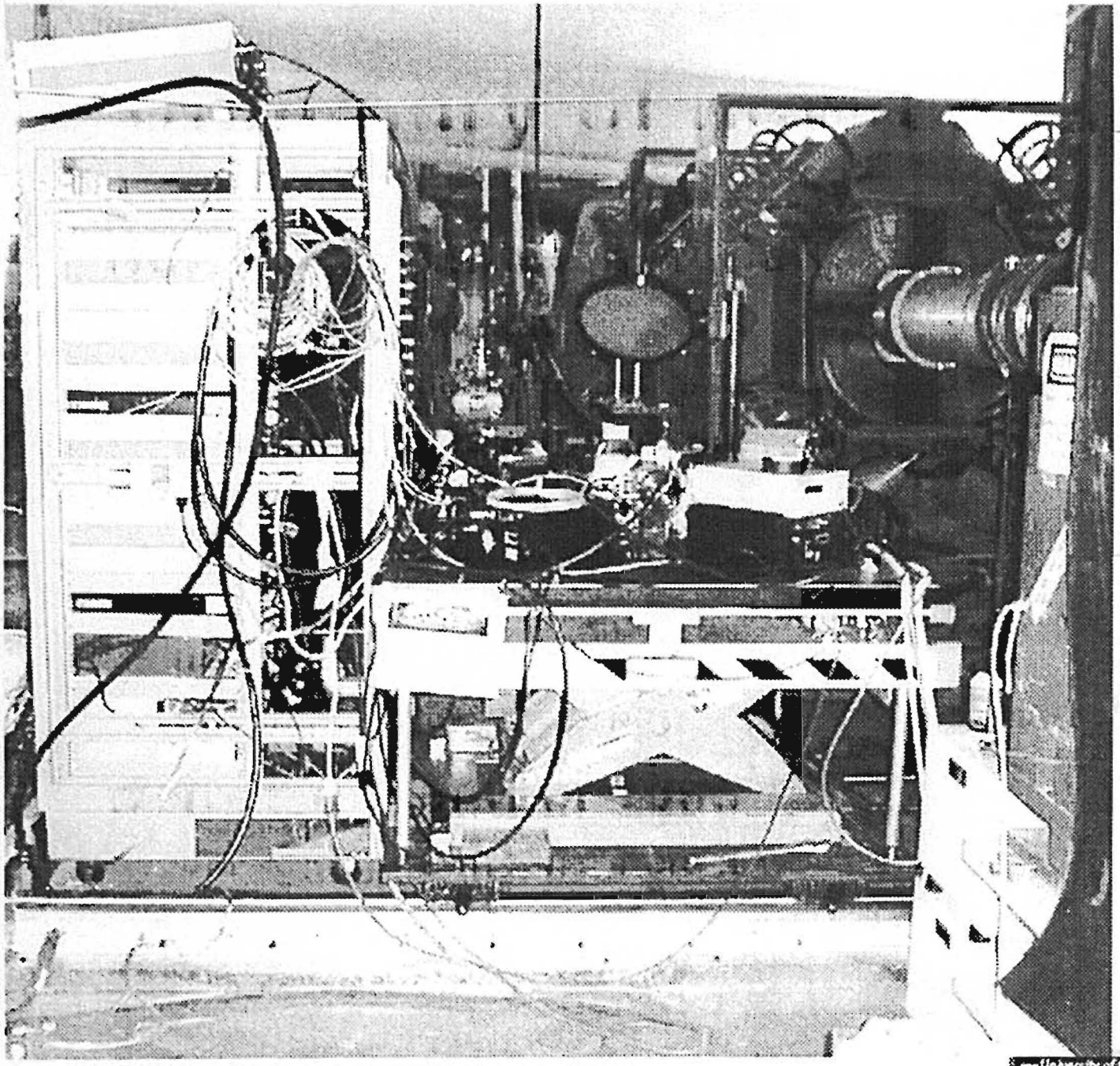




$$n_c = \sum_{n_p} g_1 g_2 g_3 \cdots$$

$$= \overline{n_p g_1 g_2 g_3 \cdots}$$

$$\frac{\sigma(n_c)}{n_c} = \sqrt{\frac{1}{n_p}\left(1 + \frac{1}{g_1} + \frac{1}{g_1 g_2} + \frac{1}{g_1 g_2 g_3} + \cdots\right)}$$



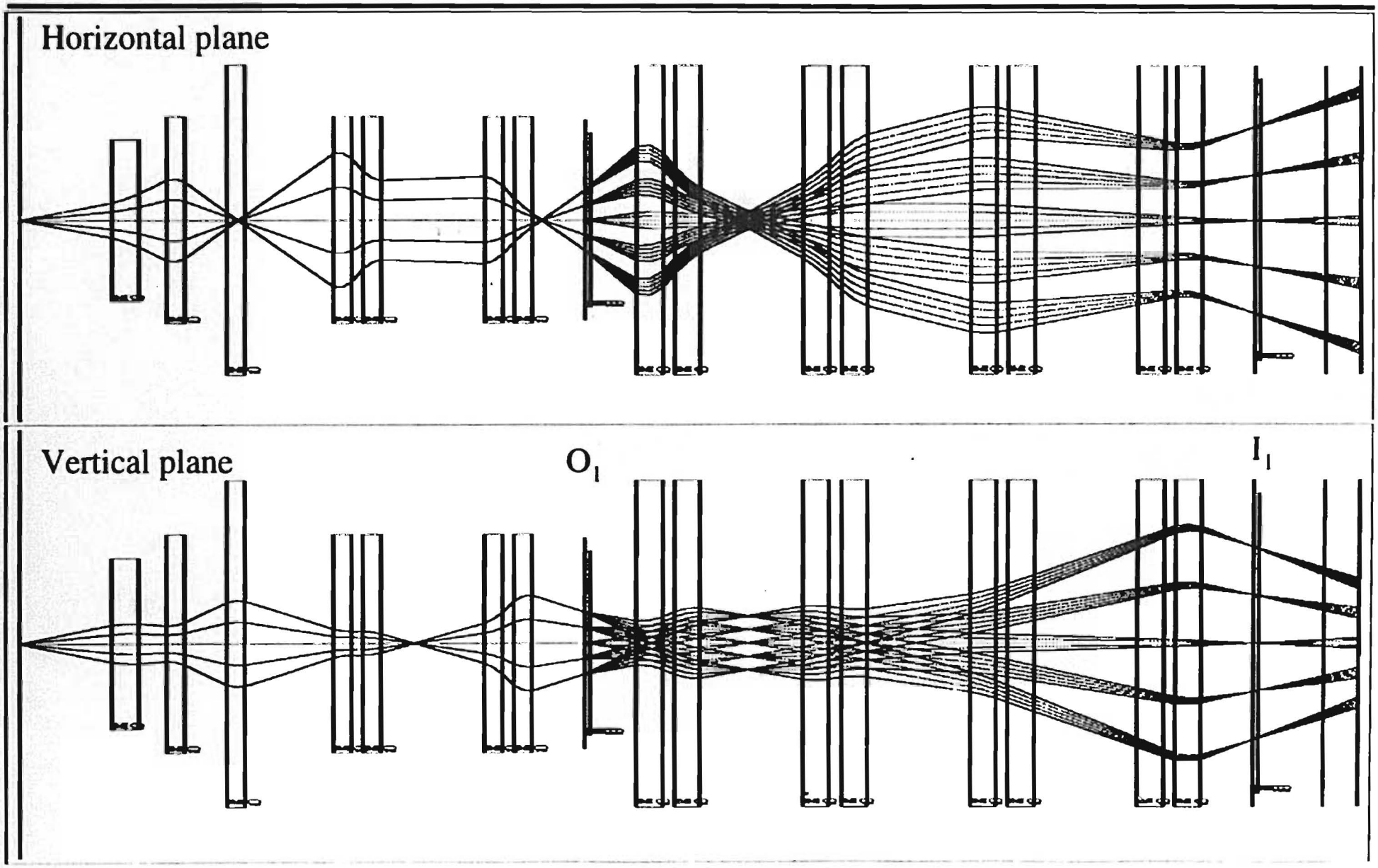
Area C Image location 1 seven shooter (July 1998)

- seven cameras with gated 1024x1024 CCDs
- 12 KV diode gates

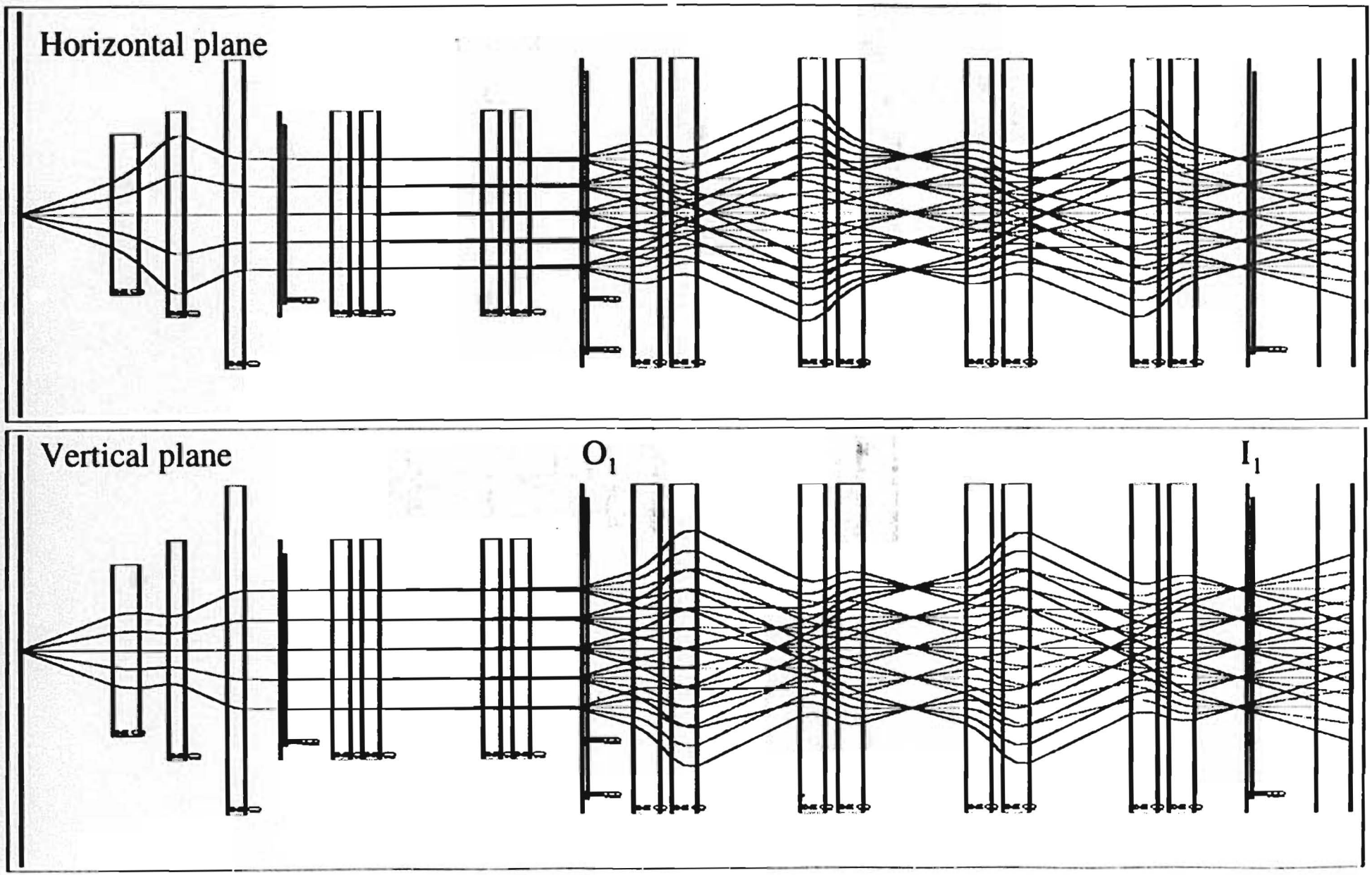
Proton Radiography at LANSCE
Summary of Dynamic Results (FY97 and FY98)

- Thirty-three (33) dynamic experiments to date radiographing the reaction-zone in Insensitive High Explosive (IHE) at different times and temperatures
  - twenty-five in FY97 [6 Mod-1 (92-grams) / 19 Mod-2 (620-grams)]
  - eight in FY98 [1 Mod-1 / 7 Mod-2]
    - » seven radiographs at different times on all eight experiments this year
- before the end of calendar 1998
  - more Mod 2 objects (LANL IHE and LLNL IHE)
  - LLNL ejecta experiment(s)
  - SNL experiments
  - UK / AWE experiment
  - plus ???

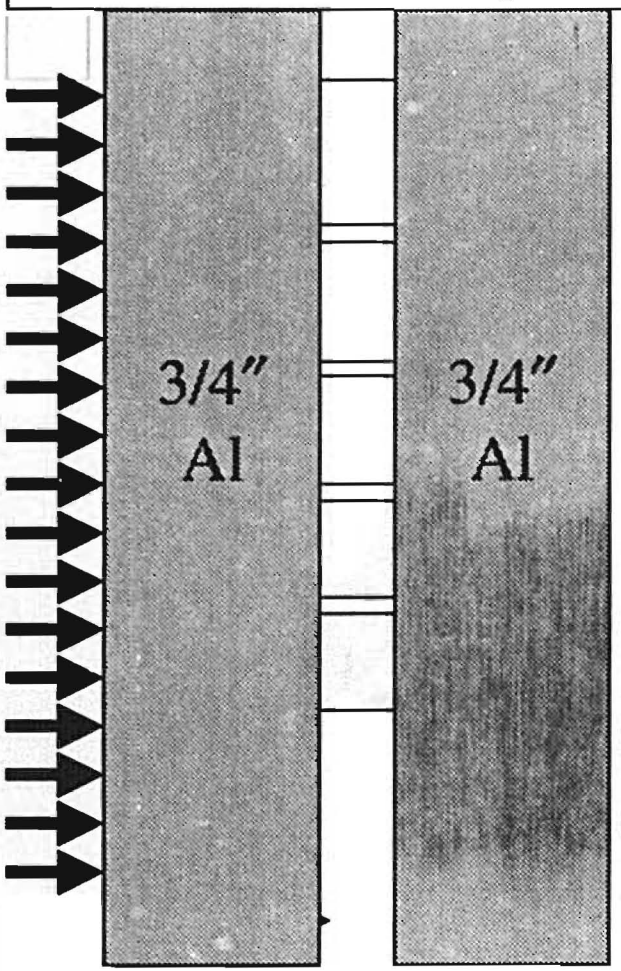
Area C as a x3.1 microscope

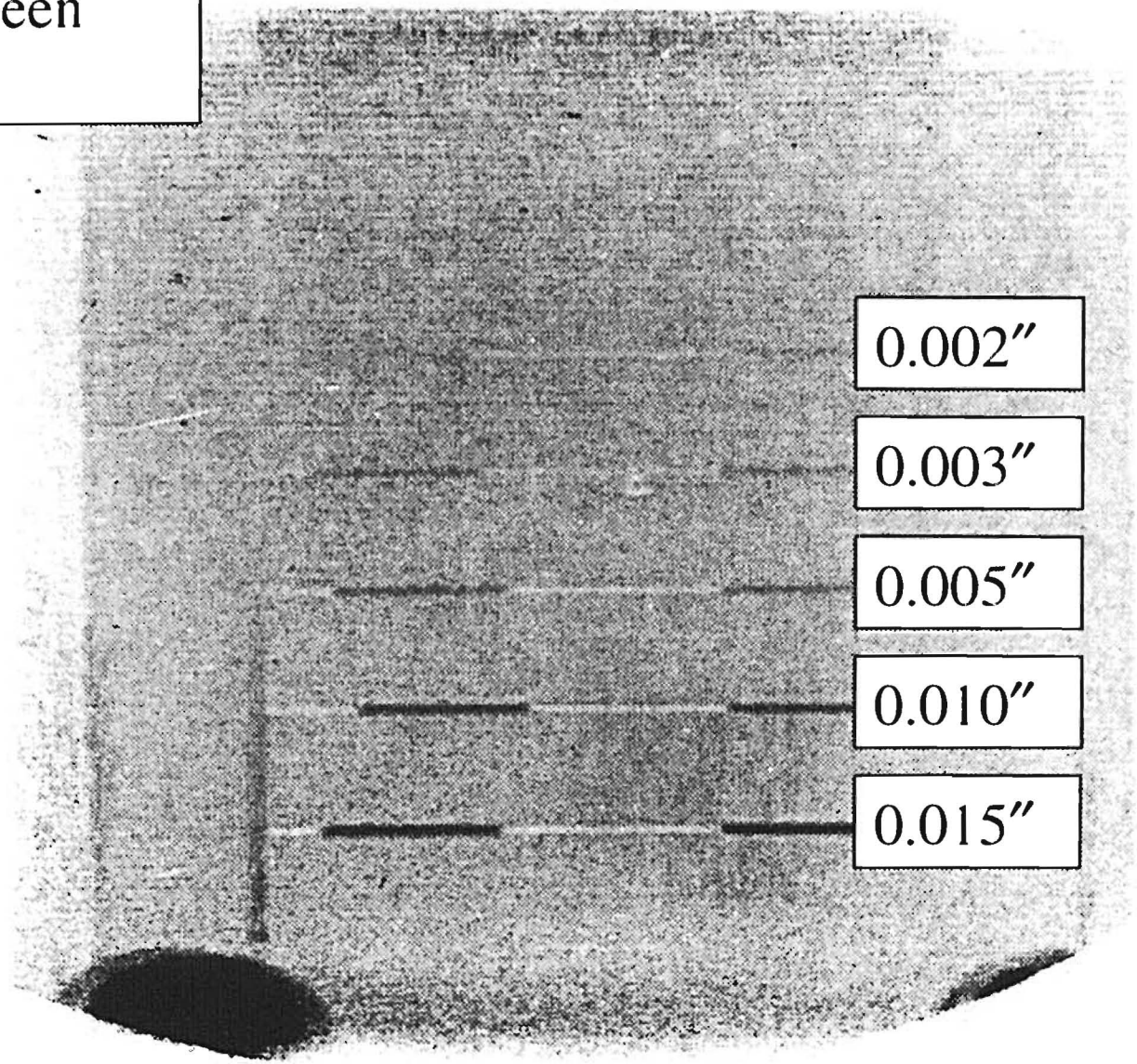


Area C with one eight-quad -I lens



Cookoff mockup assembly - Plastic with cracks between two 3/4″-thick Al plates





Summary of new capabilities

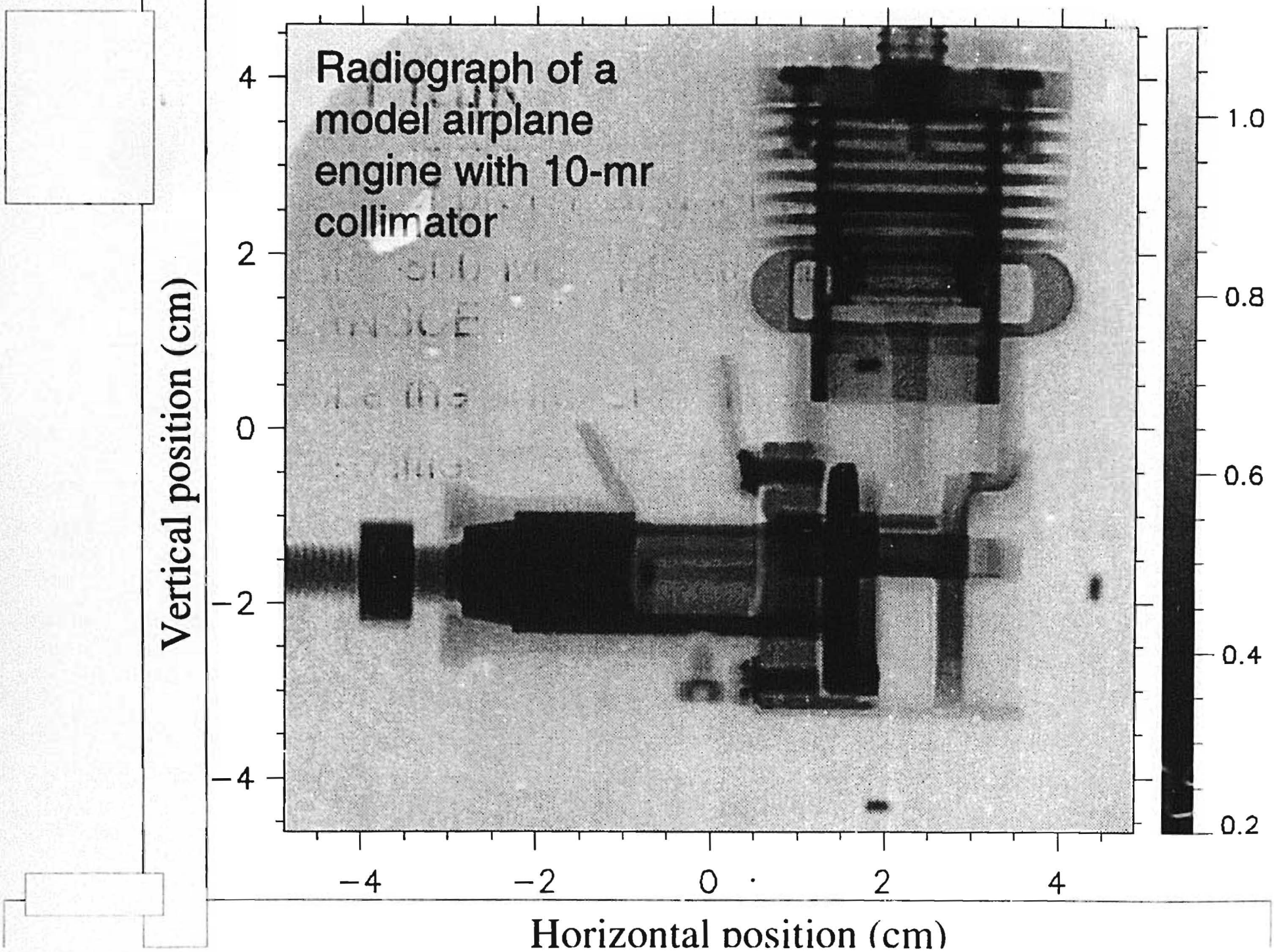
- New capabilities in Line C
  - Position resolution
    - » 40% modulation of 2-lp/mm feature in first imaging lens
  - Multiple images through different angle-cut collimators (IL1 and IL2)
  - Ability to use different size containment vessels
  - Operation of the chopper at 5.6-MHz (i.e. picture spacing of ~178-ns is possible)
  - Seven pictures of each dynamic event to date
- Before the end of 1998
  - will configure the magnets as a x3.1 magnifier

Future improvements

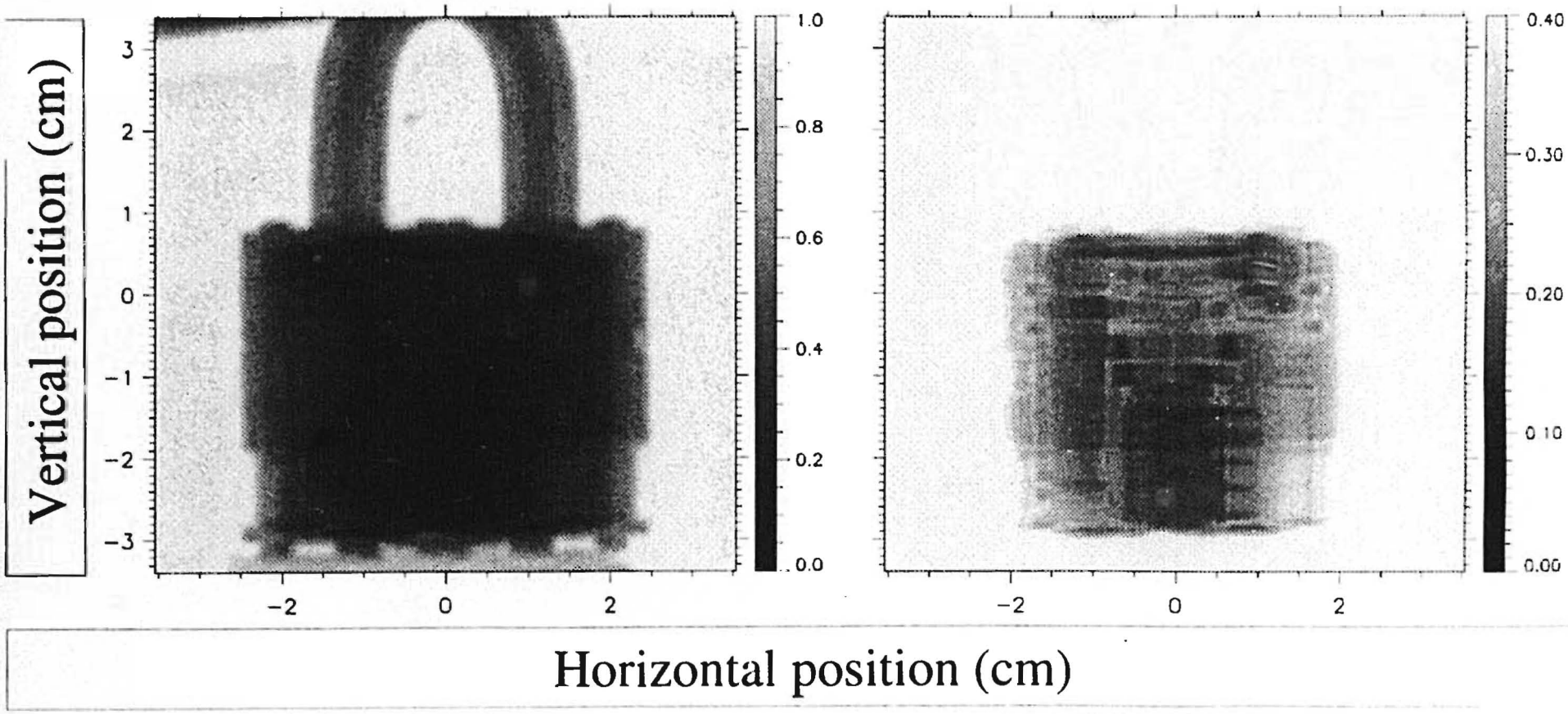
- Relocate the radioactive gas delay line
- Switchyard kicker
  - Line X / B / C operation takes the beam away from Line D / PSR operation
  - a switchyard kicker would allow both operations simultaneously
    - » WNR would miss the pulse(s) that go to PRad in Area C
- detector development (near term)
  - replace individual CCD with framing cameras
- new H- ion source (some time in 2000)
  - more protons in the same amount of time
  - or the same number of protons in a shorter exposure time

Accomplishments

- To date
  - flash radiography
  - dynamic demonstration
  - burn front imaging
  - material identification
  - detector development
  - containment development
  - PC based DAQ
  - multi-lenses
    - » material identification (single axis)
    - » incident beam diagnostic/tailoring
- Future
  - convergent geometry
  - x3 microscope
  - LLNL exjecta experiment
  - detector demonstration
    - » including an energy loss or Cherenkov detector
  - containment development
  - more experiments
  - operation independent of the rest of the accelerator (when it is on)


Radiograph of a model airplane engine with 10-mr collimator
Vertical position (cm)
Horizontal position (cm)
4
2
0
−2
−4
−4
−2
0
2
4
1.0
0.8
0.6
0.4
0.2

Proton radiograph of a MasterLock™ lock



Proton Radiography

Science Based Stockpile Stewardship

Bechtel Nevada

University of California Lawrence Livermore National Laboratory

Los Alamos NATIONAL LABORATORY