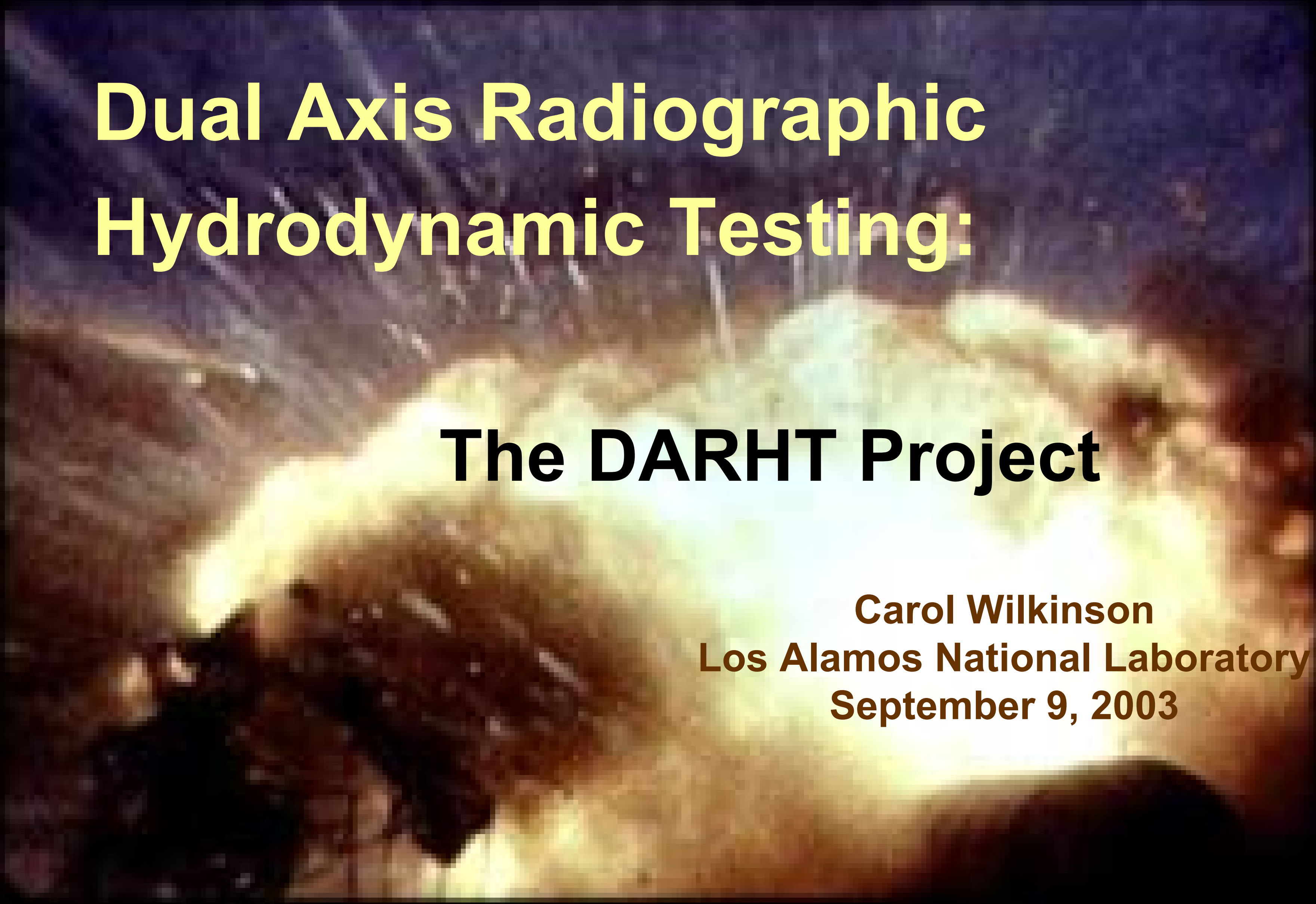


Dual Axis Radiographic Hydrodynamic Testing:

The DARHT Project

Carol Wilkinson
Los Alamos National Laboratory

September 9, 2003

Talk Outline

- **Radiographic Hydrotesting**
  - The Why and the What

- **The DARHT Accelerator as X-Ray Source**
  - Principles of Operation

- **The DARHT Project**
  - Multi-organizational Project
  - Construction/Operations Interface

What is Hydrodynamic Testing?

High explosives (HE) driven experiments to study nuclear weapon primary implosions.

- **Radiographs of chosen instants during dynamic conditions.**
- **Metals and other materials flow like liquids under high temperatures and pressures produced by HE.**

Static Cylinder Set-up

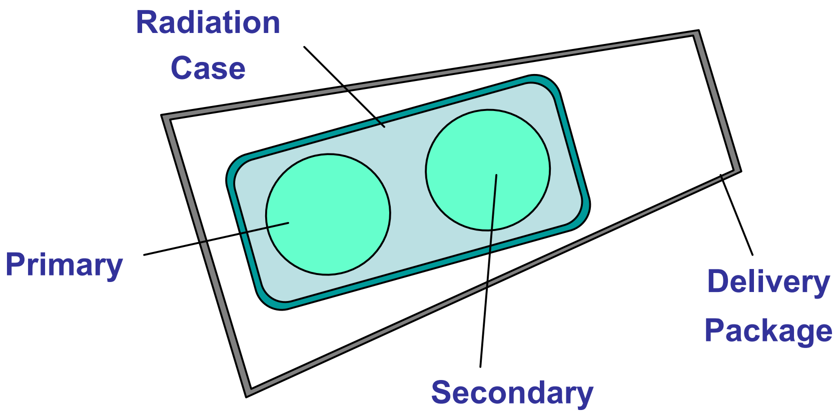
Static cylinder shot

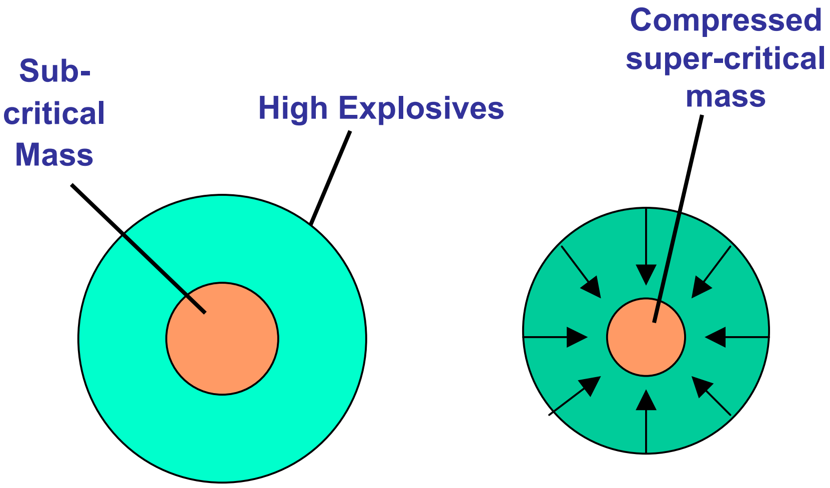
Static Cylinder Radiograph

Nuclear Weapon Primer

Nuclear weapons comprised of

- Primary
- Secondary
- Radiation Case
- Delivery Packaging





Pit before firing

Immediately after firing

Primary Pit:

- Sub-critical fissile mass surrounded by HE.
- Implosion creates super-critical mass.
- Chain reaction energy and radiation "initiate" the secondary.

Hydrotesting Purpose

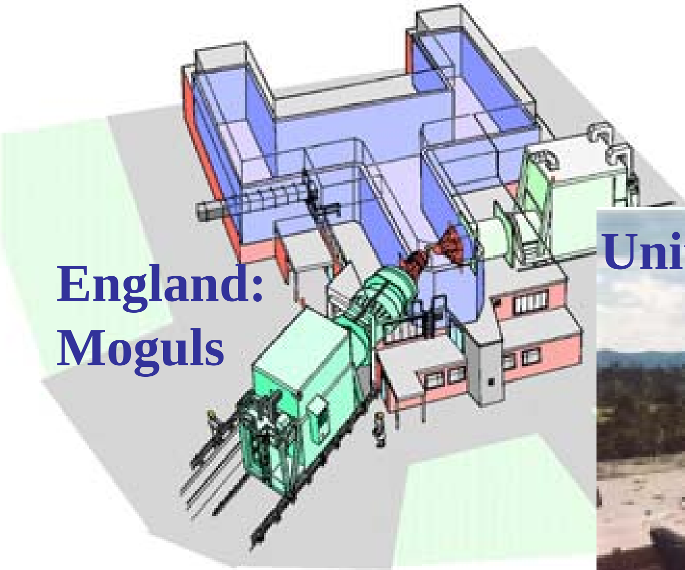
Radiographic images from hydrotesting help ensure the credibility of our enduring nuclear weapon stockpile.

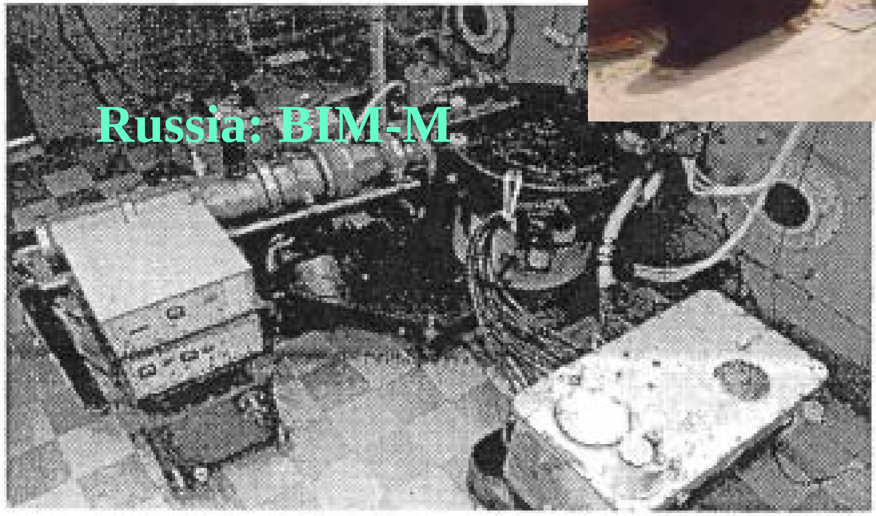
- **Evaluating effects of aging on materials**
- **Fine tuning computer modeling of weapon performance and behavior.**
- **Evaluating re-manufactured components.**
- **Certification of existing weapon systems in stockpile.**

Atmospheric Testing

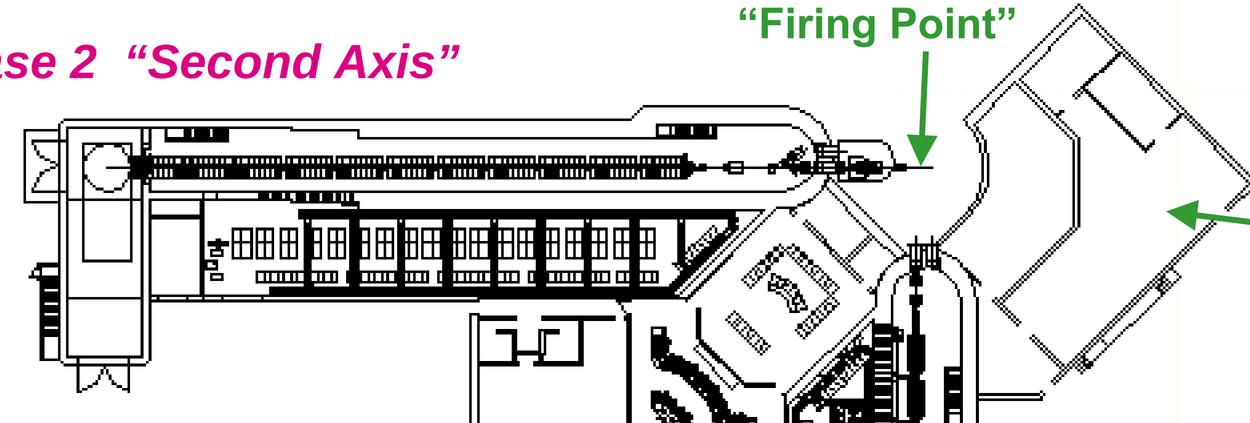
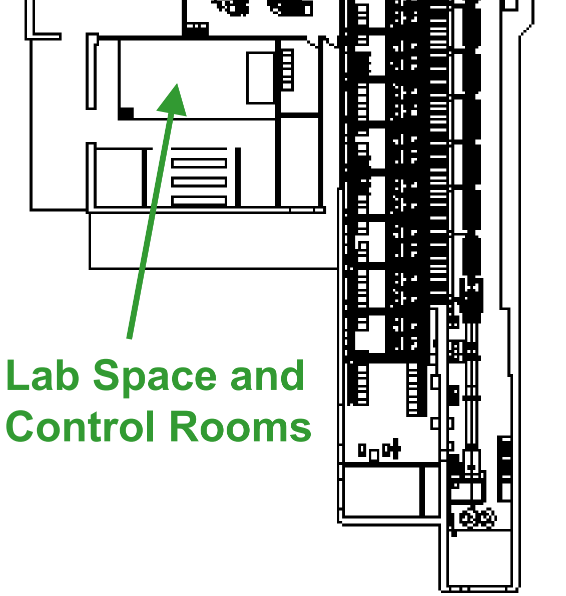
Underground Testing

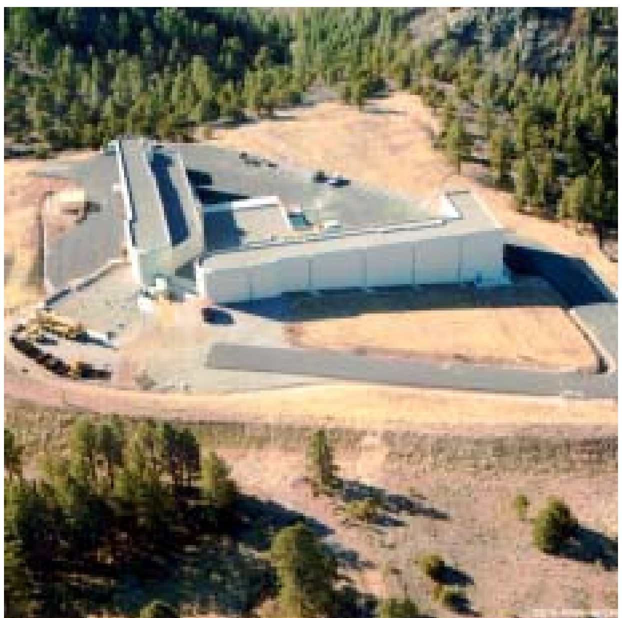
Types of Hydrotesting Facilities Worldwide





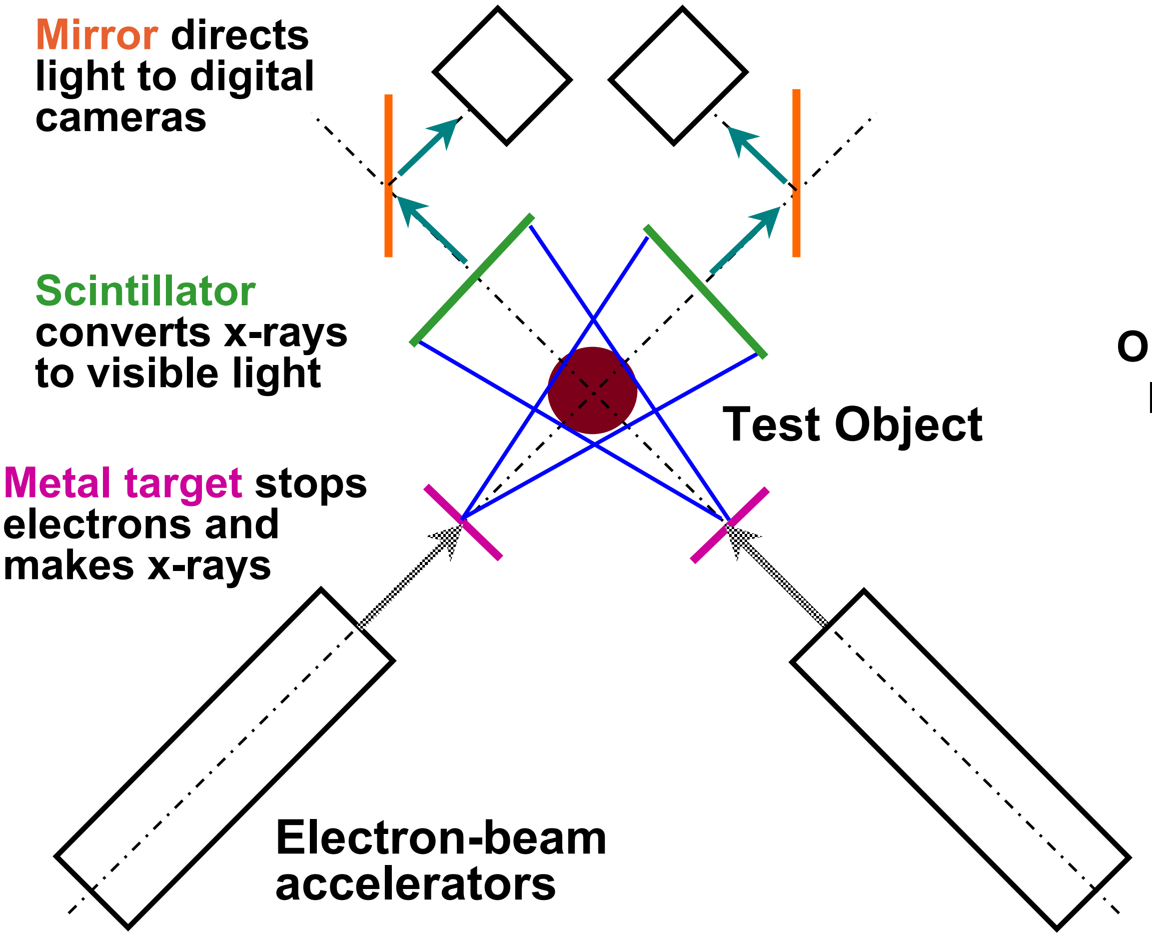
Newest Hydrotesting Facility - DARHT

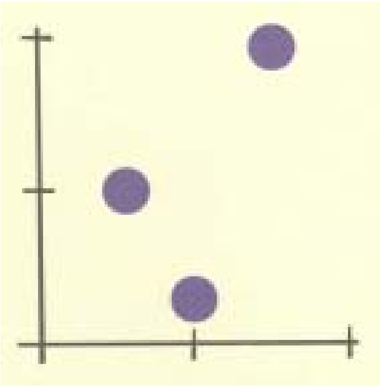





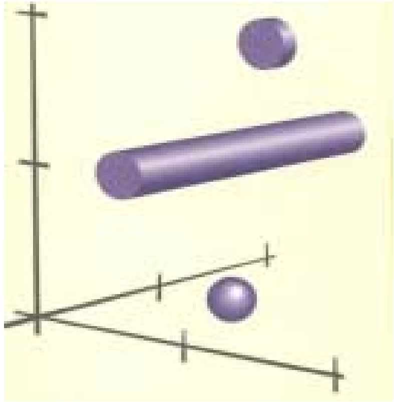
DARHT X-Ray Images With 3D Information

Two linear induction accelerators at right angles





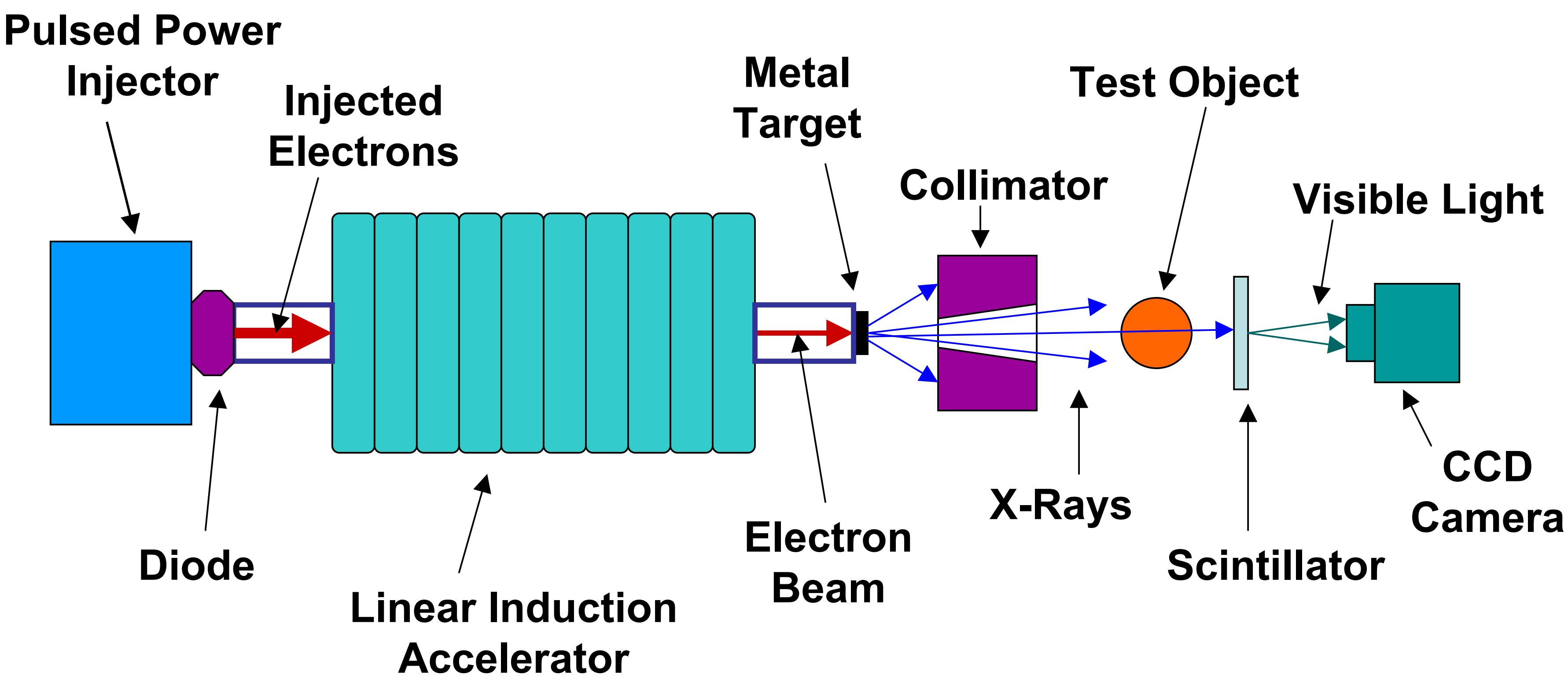
One-view gives 2D information
Items appear to be identical



Two-views give basic 3D information.

9/9/03

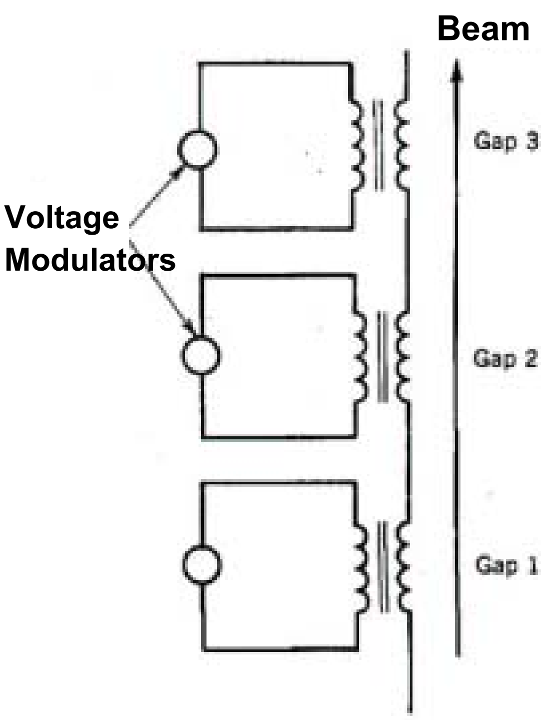
Overview of Linear Induction X-Ray Sources

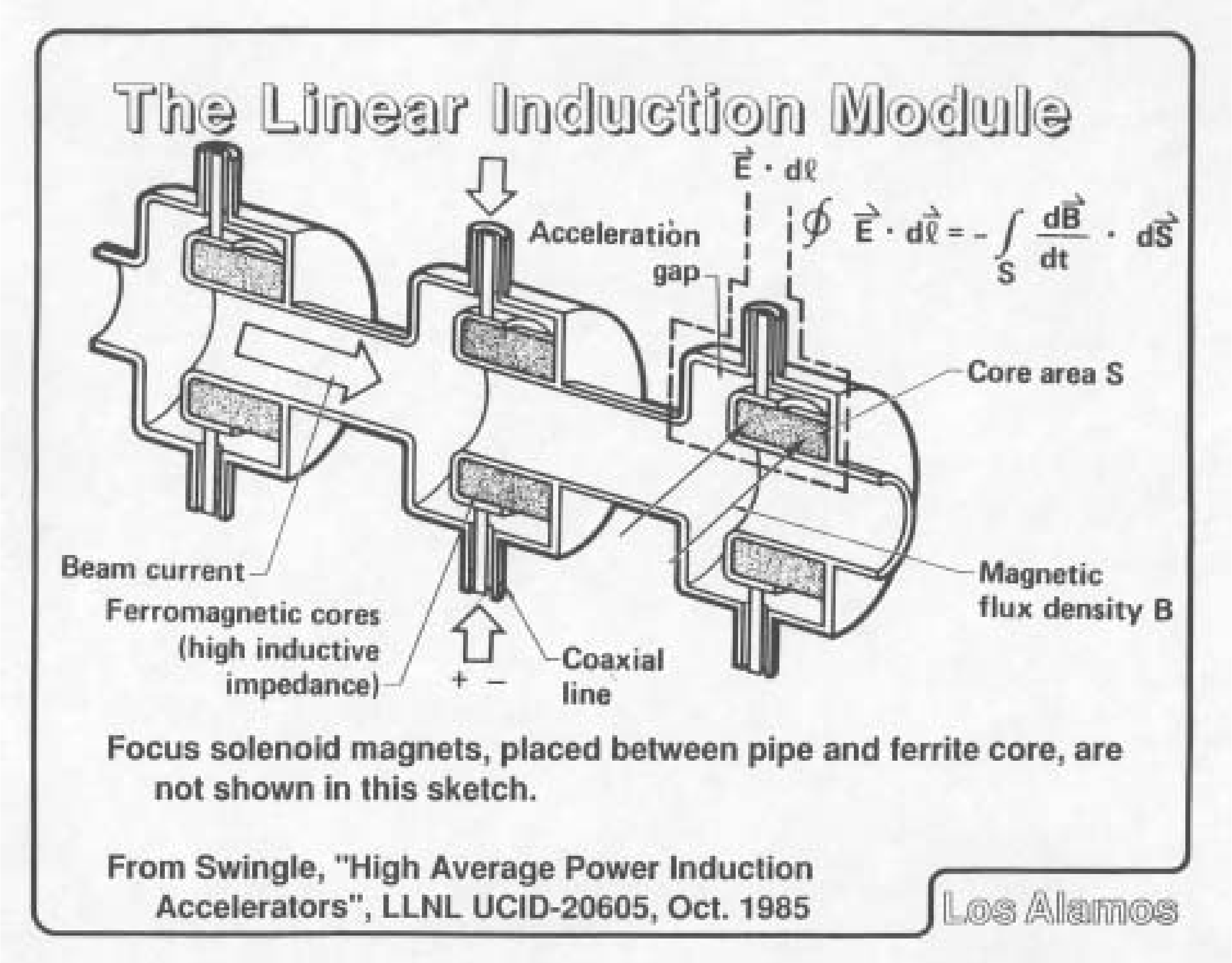


Linear Induction Accelerators (LIA) used for high dose at moderate energy with short pulse width & small spot (~2 mm).

LIA accelerating gaps

Cells and beam act like
1:1 transformers





Changing Magnetic Fields generate accelerating electric field

DARHT Accelerator Principles of Operation

The DARHT accelerators use pulsed power sources to produce and accelerate a single electron beam pulse. DARHT Axis 2 chops the beam into 4 pulses just before the target.

The two machines use different pulsed power technology.

DARHT Axis 1 Accelerator

- 60-ns, 2-kA, 19.8-MeV electron beam for single pulse radiography.
- Linear Induction Accelerator with ferrite cores and Blumlein pulsed power.
- The injector uses a capacitor bank and a Blumlein at 4-MV.
- Cold velvet cathode.
- Single 60 ns pulse.
- Operation began in July 1999.

DARHT Axis 2 Accelerator

- 2-μs, 2-kA, 18.4-MeV electron beam for 4-pulse radiography.
- Linear Induction Accelerator with wound Metglass cores and Pulse Forming Networks (PFNs) .
- The Injector uses a MARX bank with 88 type E PFN stages at 3.2 MV.
- Thermionic cathode.
- 4 micropulses - variable pulse width.
- Commissioning now.

DARHT 1 Pulsed Power Systems - Injector

Pulsed power

- 3-mF/120-kV cap. bank pulse charges 6ft-dia. Blumlein thru a 1:15 x-fmr.
- 4 parallel laser-triggered Blumlein switches with 0.7-ns, 1-s jitter
- 3 series transmission lines with impedance changes step-up the voltage to the diode.

Nominal 4-MV diode

- 64-mm/90-mm velvet cathode (2/4-kA)
- 170-Ω liquid resistor in parallel with
- 181-mm AK gap. 1-kΩ diode.
- 10-90% risetime of 20-ns
- Norm. emittance ~ 0.12 π cm-rad

DARHT-1 Pulsed Power Systems - Accelerator

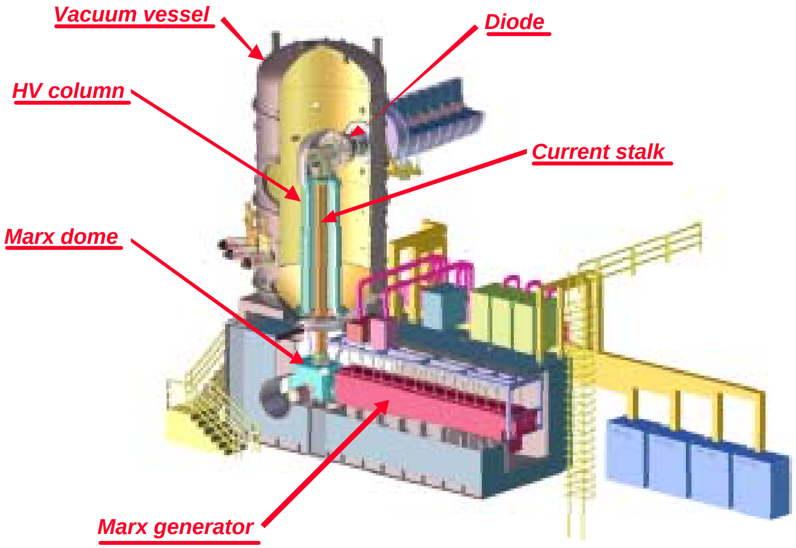
32 water-insulated Blumleins

- 11-Ω, 250-kV, charged with a 1.4-μF/40-kV capacitor Bank thru a 1:11 xfmr.
- separate triggers with 30-nF/70-kV cap. Bank, 1:4 xfmr, magnetic pulse-compression line
- mid-plane triggered SF_6 switch
- < 1-ns (1σ) jitter for any consecutive 100 shots
- 67-ns pulse to accelerator
- 0.6% rms energy variation over 60-ns beam pulse.

Induction cells

Induction cell pulsed power

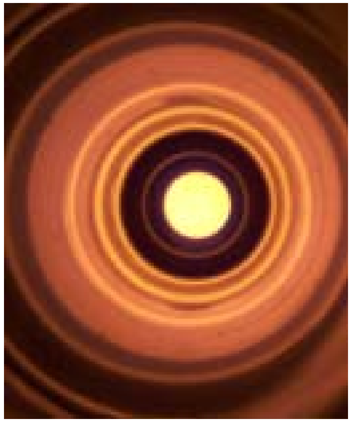
DARHT 2 Pulsed Power Systems - Injector



- 3.2 MeV
- 16.5-cm dia. dispenser cathode
- Marx bank with 88 type E PFN stages
- 444.5-cm tall insulating column with Mycalex and ceramic rings
- Design emittance (norm., 4-rms) is 0.05 π cm-rad

DARHT 2 Pulsed Power Systems - Diode

- 16.5cm diameter B-type
- 2kA => 9.35A/cm^2
- 3.2MeV Gap Voltage
- Aligned with hexapod
- 1-m dia. polished cathode shroud
- 4-μm finish, 120 kV/cm field stress



Thermionic Cathode

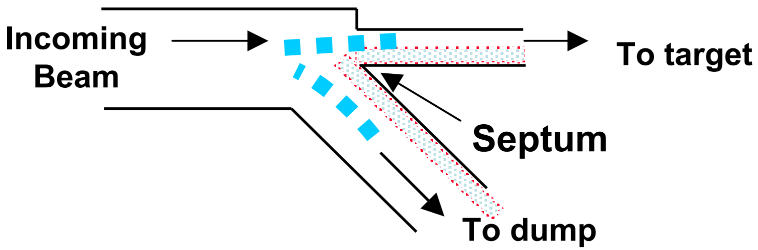
Anode and shroud

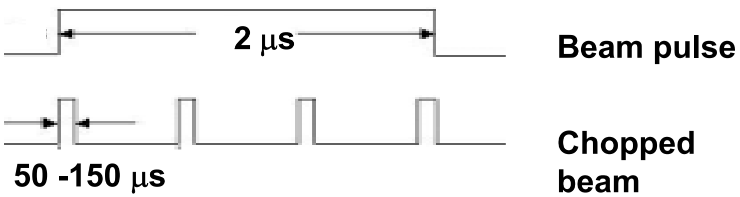
Cathode inside vacuum vessel

DARHT 2 Pulsed Power Systems - Accelerator

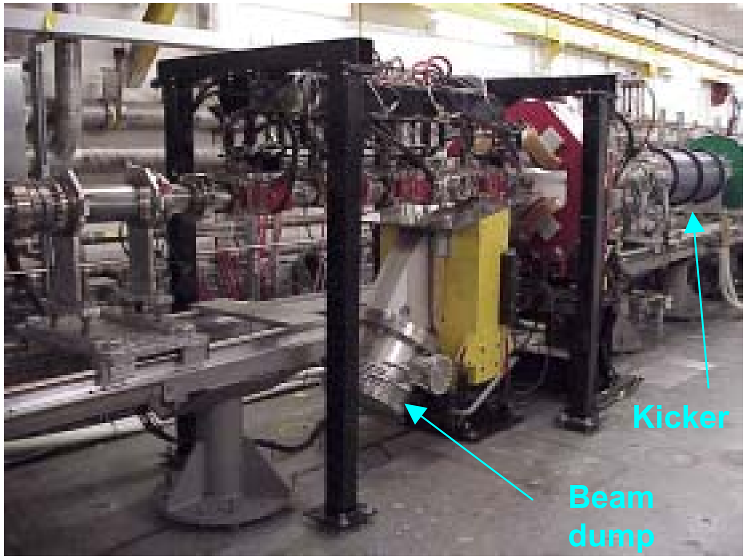
- Oil-insulated monolithic cross-section with 4 cores of Metglass (0.43-0.48 V-sec)
- Mycalex conical insulator
- Solenoid magnet and steering coils in each cell.
- Ferrite damping to reduce Q's
- Pulse Forming Networks 7-section Type-E network, 4-stage Marx.
  - Total Z = 20Ω
  - 195-kV output
  - 1 shot/min. (12 shot/min for tests)
  - 2.02-μs flat-top ($\Delta V/V \leq \pm$ 0.5%)
  - 10-90% risetime ≤ 250-ns
  - Jitter ≤ ± 20-ns (3-σ)

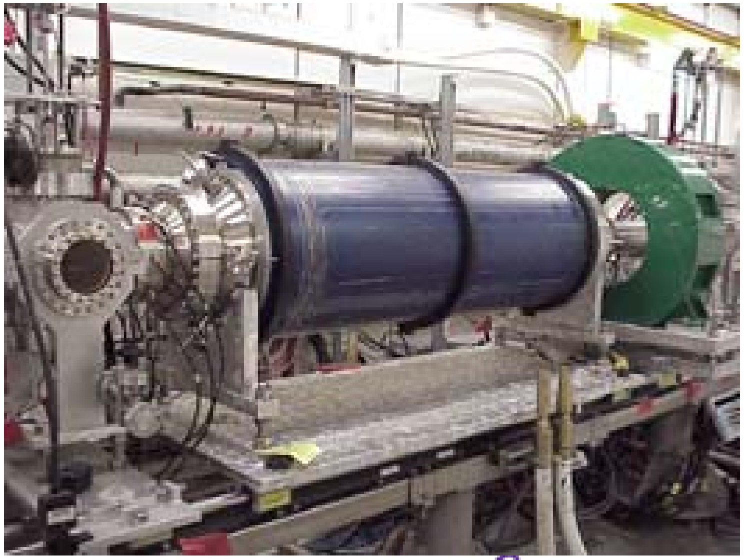
DARHT 2 Beam Chopping - Kicker





- 2 μsec chopped into 4 pulses of variable width
- Weak static dipole steers beam off-axis into a septum
- Quadrupole magnet for deflection into the dump beamline.
- Electrodes driven by a solid-state modulator overcomes dipole to select beam pulse directed ahead to x-ray target





DARHT X-Ray Conversion Targets

DARHT 1 X-ray conversion target

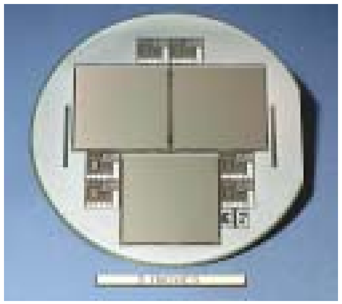
DARHT 1 target wheel

DARHT 2 multi-foil target

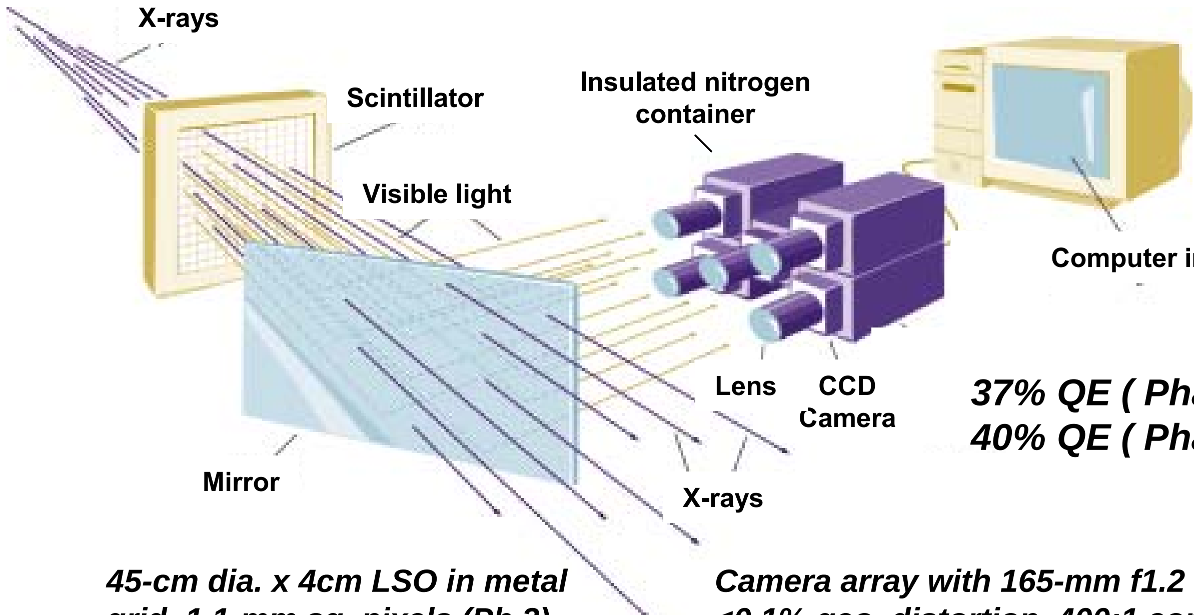
DARHT 2 target wheel in target box

DARHT 2 distributed target for 4 pulses

Gamma Ray Camera Detector

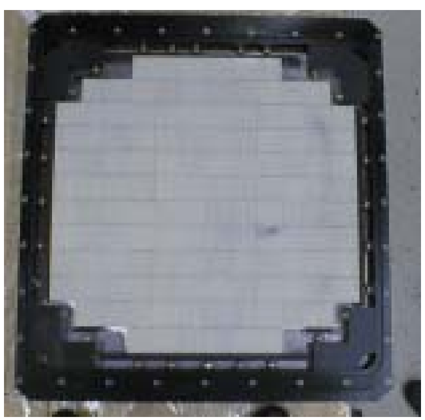


Fast-framing CCD chip prototypes @ MIT/LL



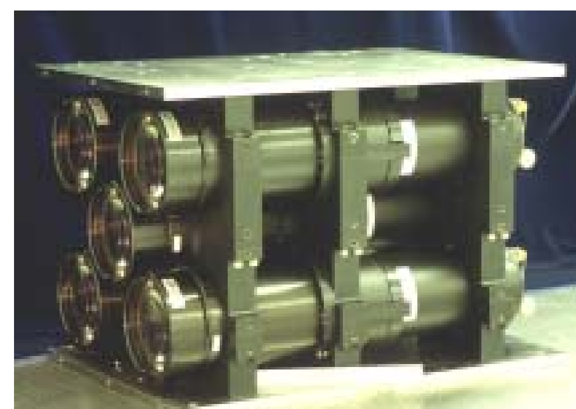
37% QE (Phase 1)
40% QE (Phase 2)

55-cm x 2cm BGO, 0.9-mm sq. pixels (Ph.1)



45-cm dia. x 4cm LSO in metal grid, 1.1-mm sq. pixels (Ph.2)

Camera array with 165-mm f1.2 lenses, <0.1% geo. distortion, 400:1 contrast ratio

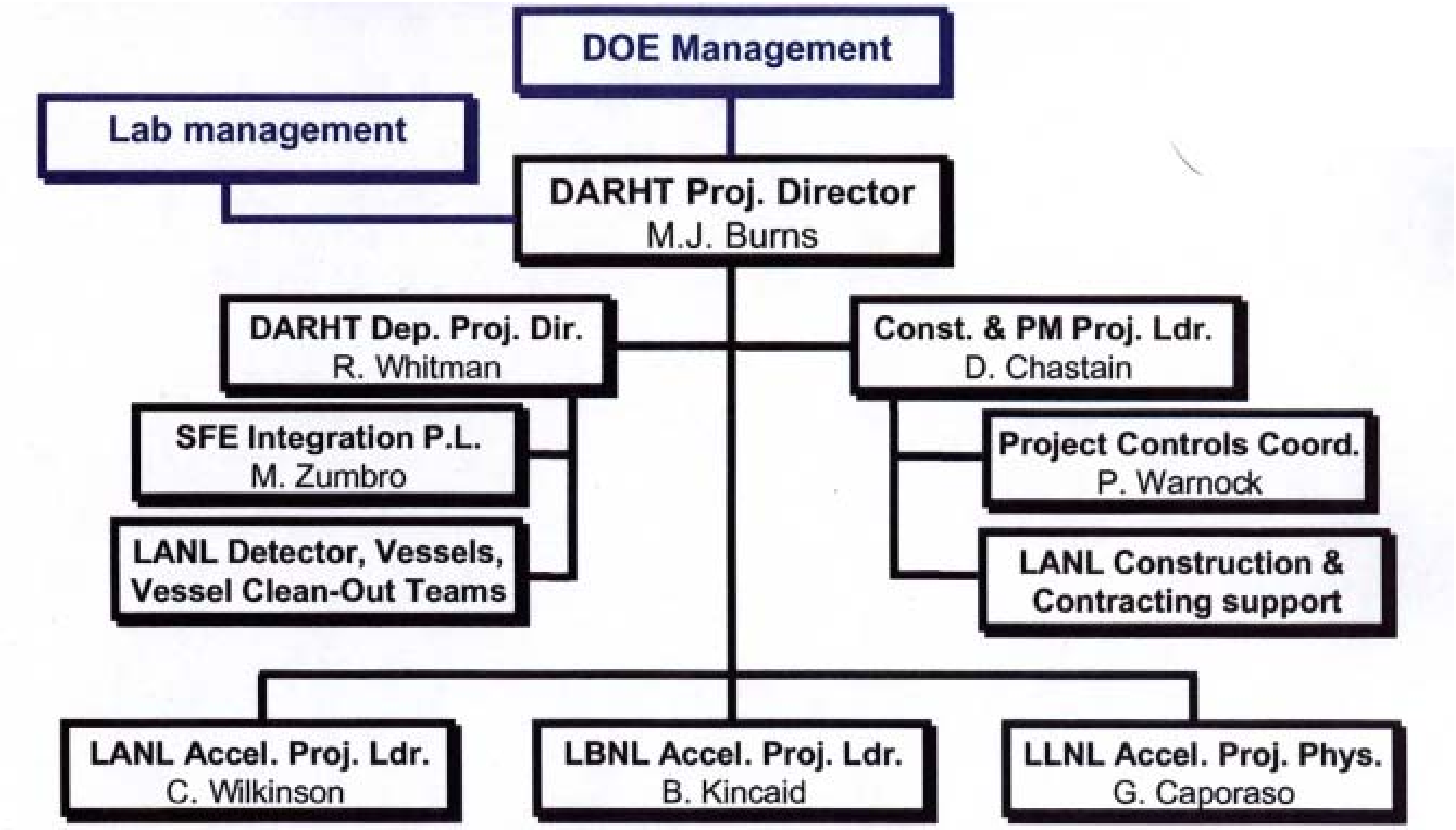


The DARHT Construction Project

- Congressional line-item project (97-D102)
- Involved all UC-managed DOE national laboratories plus MIT/LL
- Two phases :
  - Phase 1 : single-pulse source and detector, DARHT facility building, 27,000 sf lab building, 1 containment vessel and clean-out process, firing site instrumentation and controls.
  - Phase 2 : 4-pulse/2-μsec source and detector, 6,000 sf vessel building with clean-out process, 2nd containment vessel, more firing site instrumentation and controls.

WBS	Name	Baseline Estimate ($K)
1.	DARHT (TPC)	$275,880
1.1	*Phase 1 OPC*	*$8,764*
1.2	*Phase 1 TEC*	*$105,775*
1.3	*Phase 2 OPC*	*$1,343*
1.4	*Phase 2 TEC*	*$159,998*

DARHT Project Management Organization



“Forward Looking” Project Management Processes

- *“Earned Value” tracking and variance analysis* - done monthly to establish project performance to date and analyze deviations with respect to baseline plan. Earned value based on detailed, cost-loaded schedule updates.

- *Trending Program -* monthly process to identify, characterize, assess, and prioritize threats to the project and to develop mitigation plans

- *Current Working Estimate -* monthly bottoms-up update of project schedule developed from earned value calculations

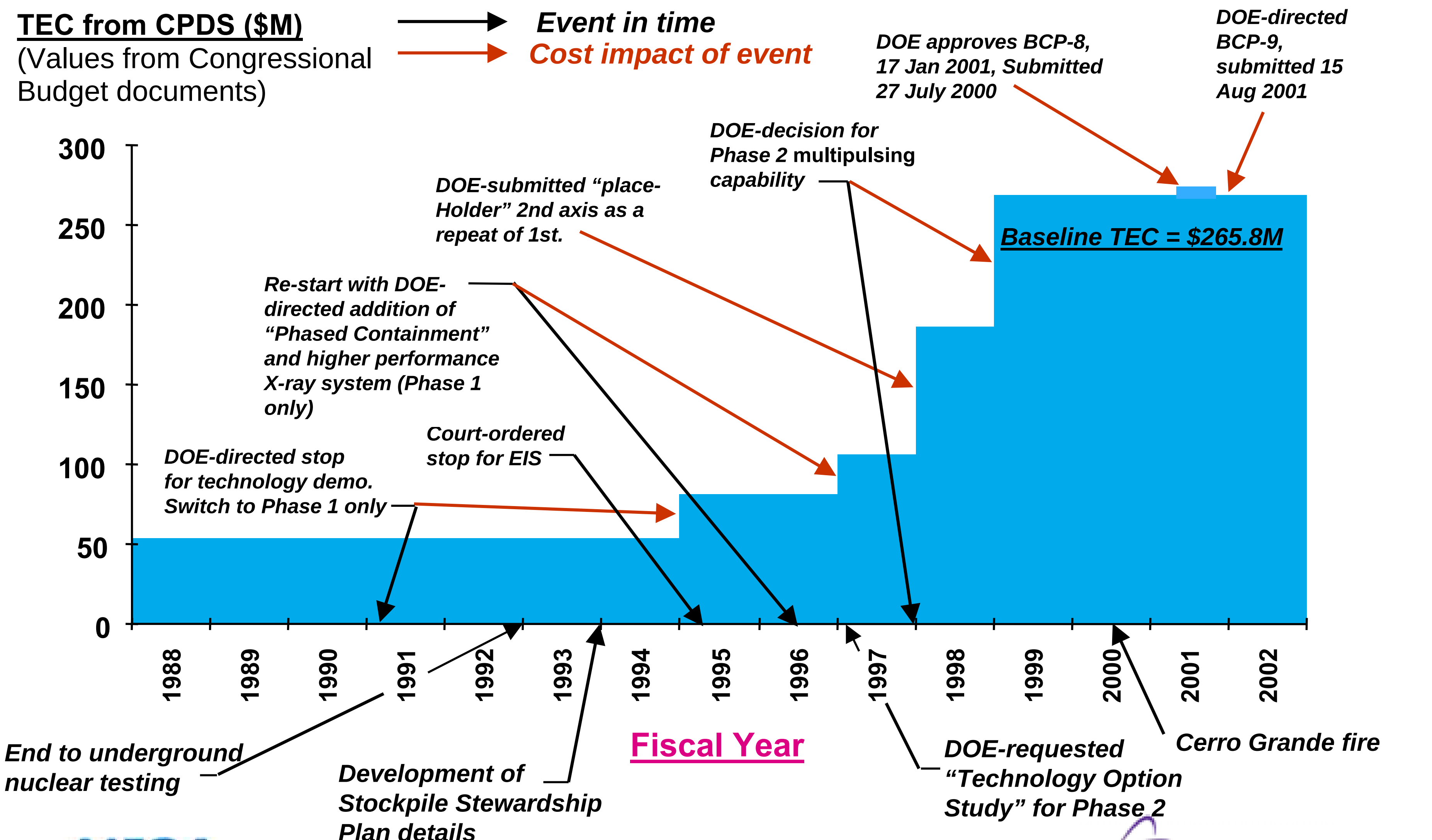
- *Contingency Analysis -* monthly update of possible future budget adjustments, contingency on remaining work, EAC, and identification of possible budget cuts that may be needed to remain within TEC.

- *Project Reviews -* Two-tiered review process to assess technical and overall project progress and status. Monthly DOE review. Weekly Director’s report.

Technical, Cost, and Schedule Contingencies

- Technical contingency found in conservative definition of CD-4 criteria
- Cost contingency developed from risk-based assessment of WBS Level-5 items. Changes as project matures.
  - mature designs well into fabrication & installation
  - 8.6% overall cost contingency rate
  - Specific elements carry much higher rates
    - X-ray target: 39%
    - Remaining accelerator fab : 24%
    - Transport beamline : 21%
    - Installation : 13%
- 20% overall scheduled contingency
  - Results of Monte Carlo simulation of schedule with error distributions applied to estimated task durations

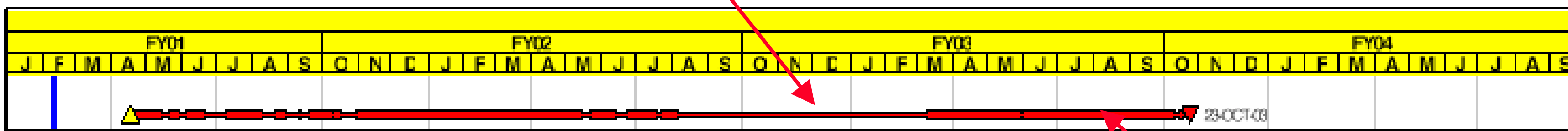
Requirements-Driven Scope Changes Have Characterized the Project



Experimental and Construction Schedules Integrated

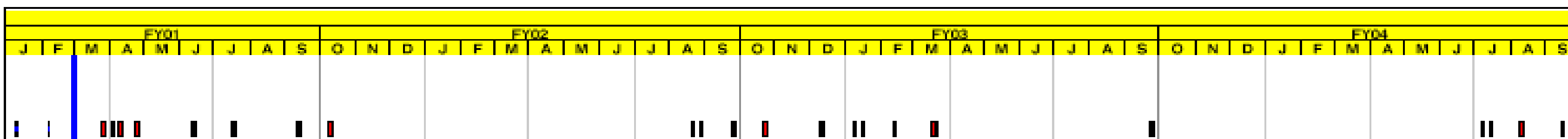
DARHT Project

A good time for a shot "window"



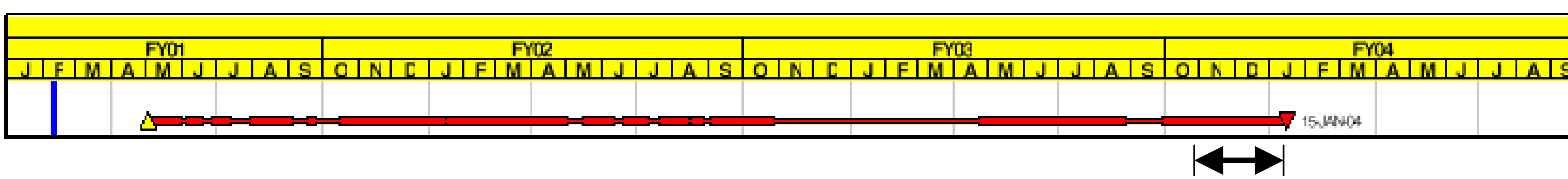
DARHT activities heavily impacted by shot work

DARHT Shots



Note shots moved to largest open window

Combined Project & Shots

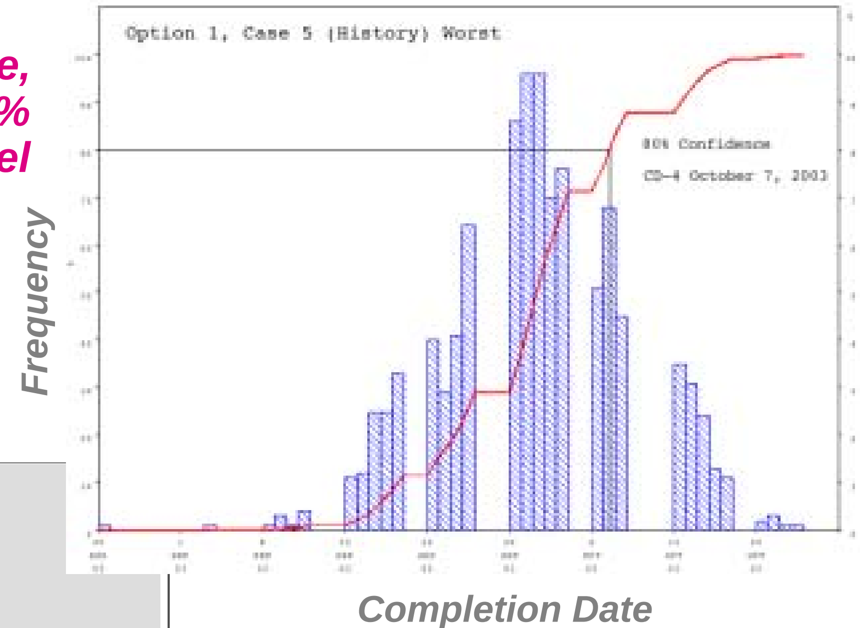


~ 3-month impact from future shots

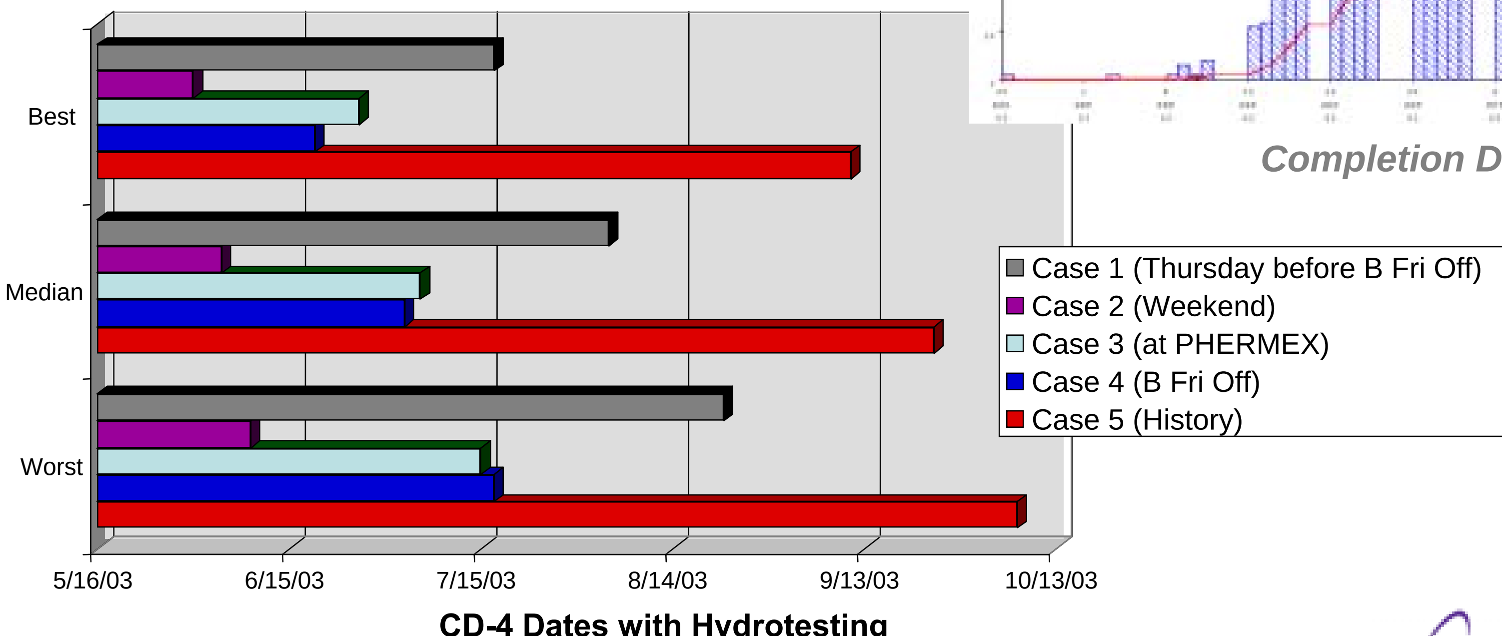
(minimize impact on project)

Experimental Schedule Affects DARHT CD-4 Date

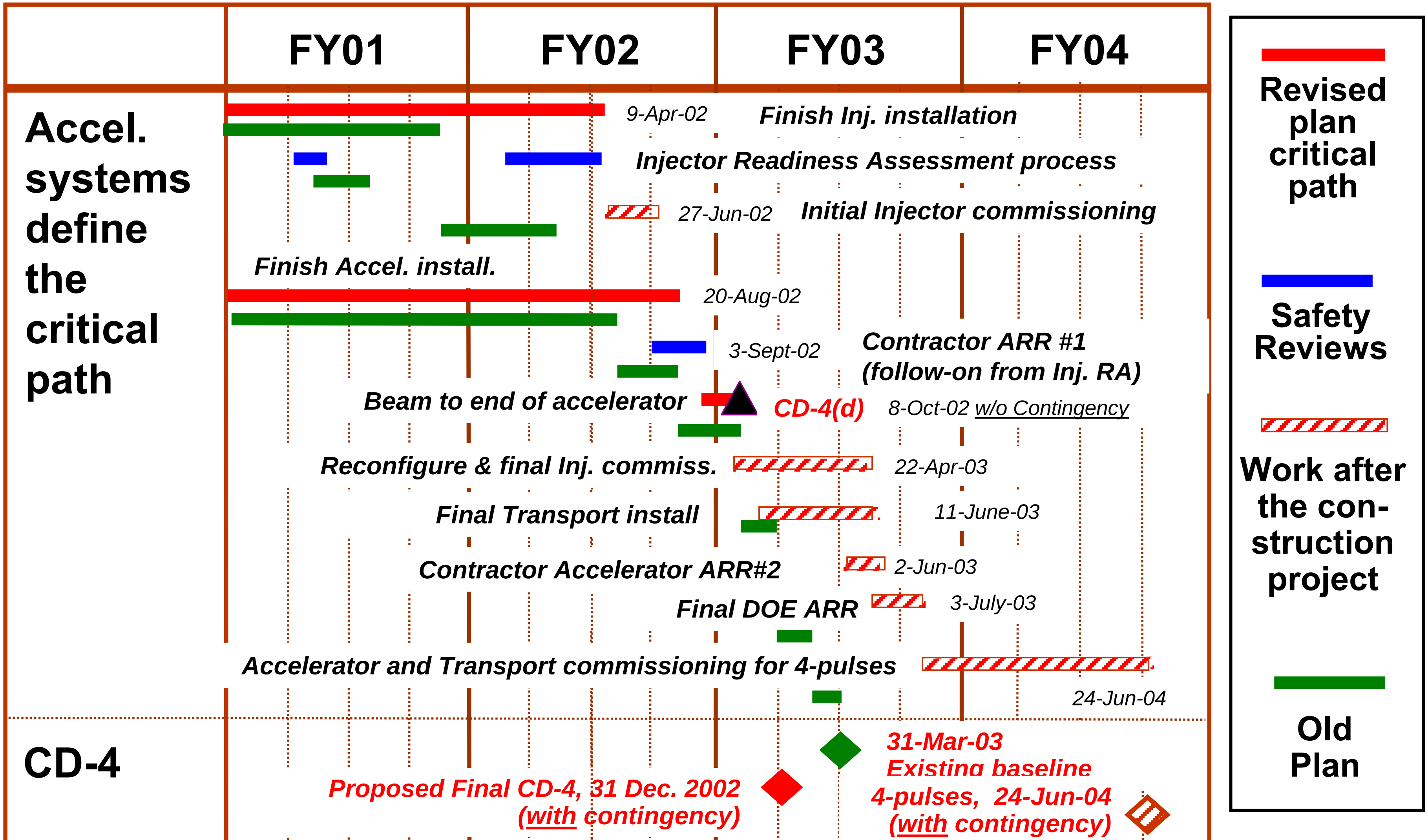
Sample Monte Carlo output for a single case, one calendar, all types of shots, showing 80% confidence level



Tabulation of completion dates with hydrotesting



The Revised Schedule for Phase 2



Transition to Commissioning and Operations

- Project Closeout March 26, 2003
- Project group dismantled
- Operations group took over all operations and commissioning.

- Final commissioning period for Axis 2.
- Optimization and operations for Axis 1.
- Dual-axis operations expected by end of 2004.