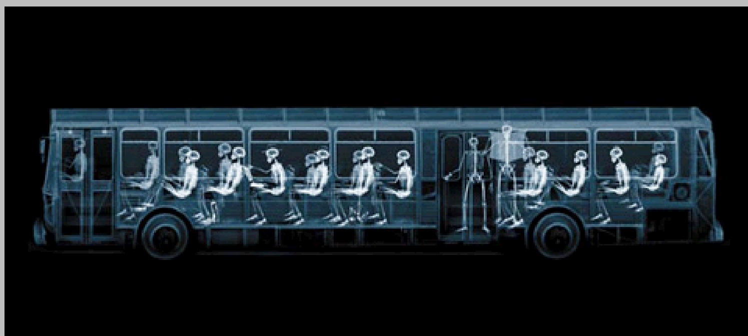
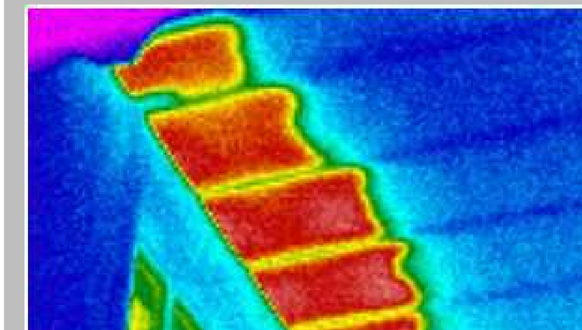
Sandia National Laboratories

SAND2012-1623P





Diagnostic Tools and their Applications

Enrico Quintana

U.S. DEPARTMENT OF ENERGY

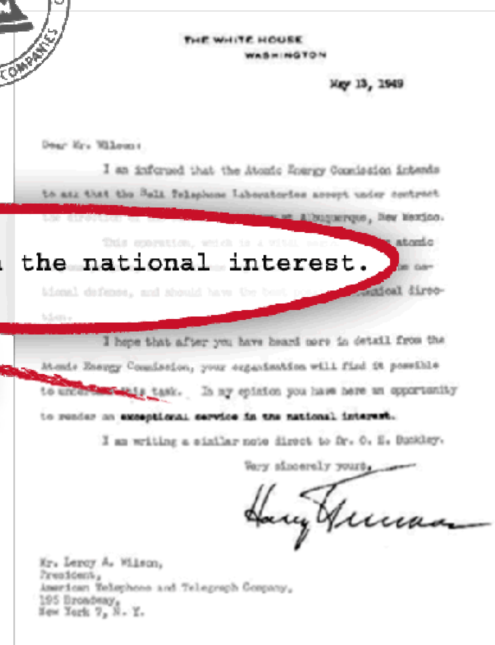
NNSA National Nuclear Security Administration

Outline

- Background on Sandia National Laboratories
- Organization 1522
- Diagnostic Capabilities
- Ultrasonic Imaging
- Thermal Imaging
- X-ray and Computed Tomography

Sandia's History

exceptional service in the national interest.



THE WHITE HOUSE
WASHINGTON

May 13, 1949

Dear Mr. Wilson:

I am informed that the Atomic Energy Commission intends to ask that the Bell Telephone Laboratories accept under contract the direction of ... at Albuquerque, New Mexico.

This operation, which is a vital ... atomic ... national defense, and should have the best possible technical direction.

I hope that after you have heard more in detail from the Atomic Energy Commission, your organization will find it possible to undertake this task. In my opinion you have here an opportunity to render an **exceptional service in the national interest.**

I am writing a similar note direct to Dr. O. E. Buckley.

Very sincerely yours,

Harry Truman

Mr. Leroy A. Wilson,
President,
American Telephone and Telegraph Company,
195 Broadway,
New York 7, N. Y.

Sandia's Governance Structure

Sandia Corporation

- **AT&T: 1949–1993**
- **Martin Marietta: 1993–1995**
- **Lockheed Martin: 1995–present**
- **Existing contract expires Sept. 9, 2012**

Government owned, contractor operated

Federally funded research and development center

Sandia's Sites

Sandia National Laboratories

Albuquerque, New Mexico

Livermore, California

Tonopah, Nevada

Waste Isolation Pilot Plant, Carlsbad, New Mexico

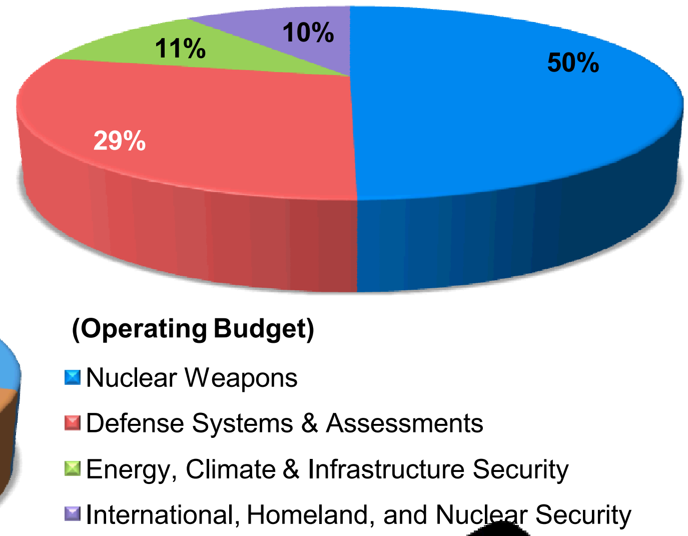
Pantex, Texas

People and Budget

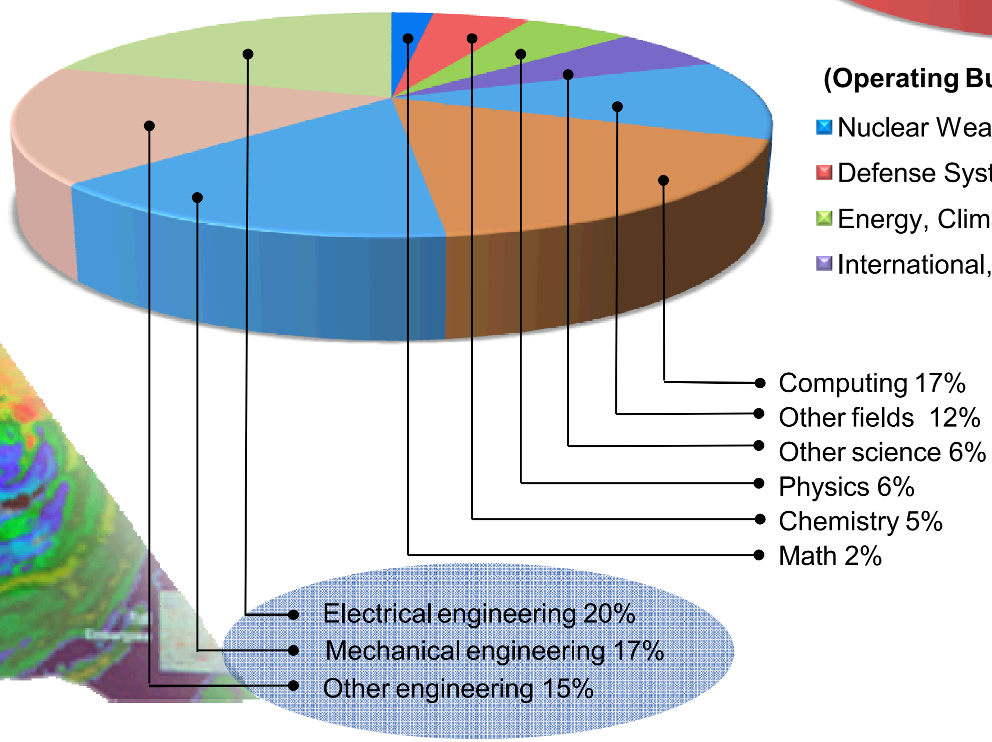
(As of October 11, 2011)

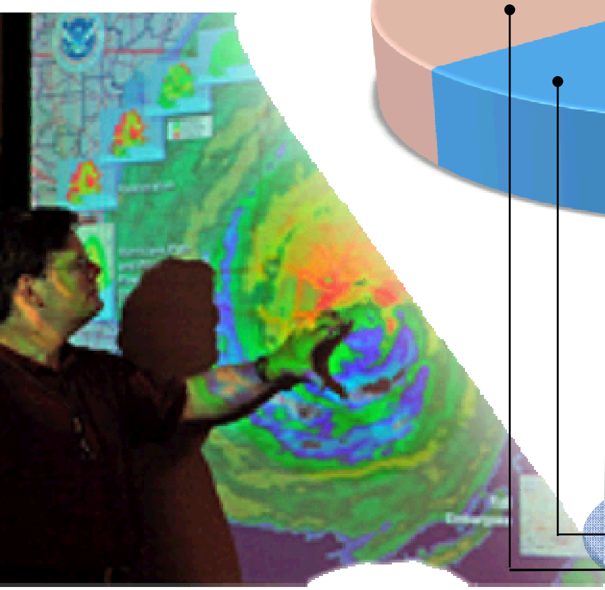
- On-site workforce: 11,876
- Regular employees: 9,122
- Gross payroll: ~$943 million

FY11 Operating Revenue
$2.4 billion



Technical staff (4,557) by discipline

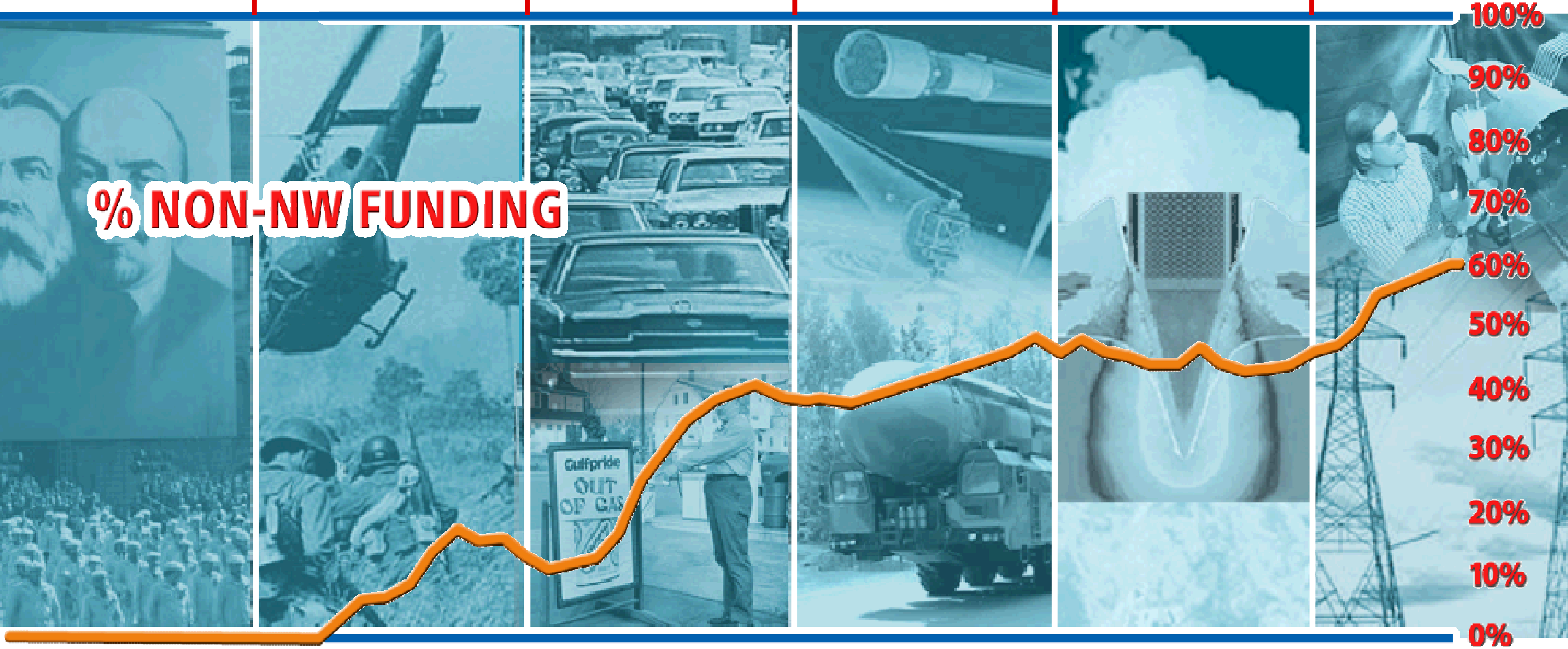




The Mission Has Evolved for Decades

Sandia National Laboratories

1950s	1960s	1970s	1980s	1990s	2000s
Production engineering & manufacturing engineering	Development engineering	Multiprogram laboratory	Research, development and production	Post-Cold War transition	Broader national security challenges

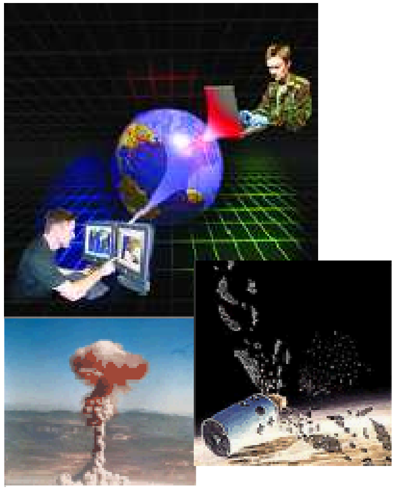


Addressing Our Evolving National Security Environment is of the Greatest Importance

Traditional strategic nuclear threats

Threats from other nation states

Threats from non nation states



Threats of tech surprise

Other threats: natural disasters, climate change, energy supply

Partnerships and Collaboration Accelerate Innovation

Sandia National Laboratories

University of Florida 1853

Harvey Mudd College 50 Years

University of Wisconsin System

Harvard

The University of Texas

University of California

Yale

The University of New Mexico

University of Notre Dame

The Academic Seal of Rice University

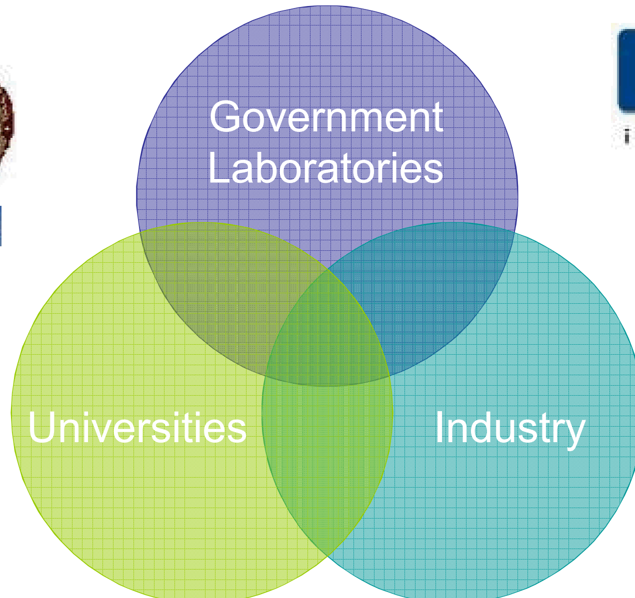
Rensselaer Polytechnic Institute 1824

清華大學 Tsinghua University

NUS National University of Singapore

CAERC

AIST National Institute of Advanced Industrial Science and Technology (AIST)



National Institute for Nano Engineering NINE

CORNING

P&G

intel

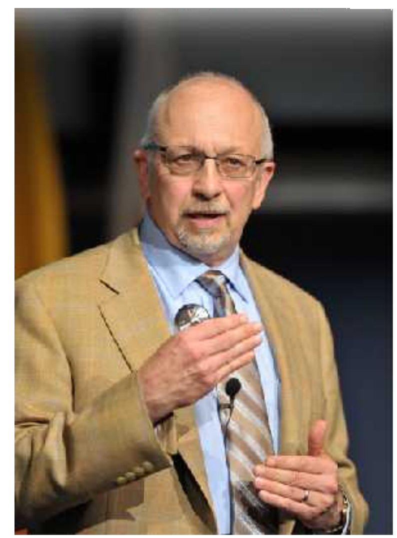
GOODYEAR

IBM

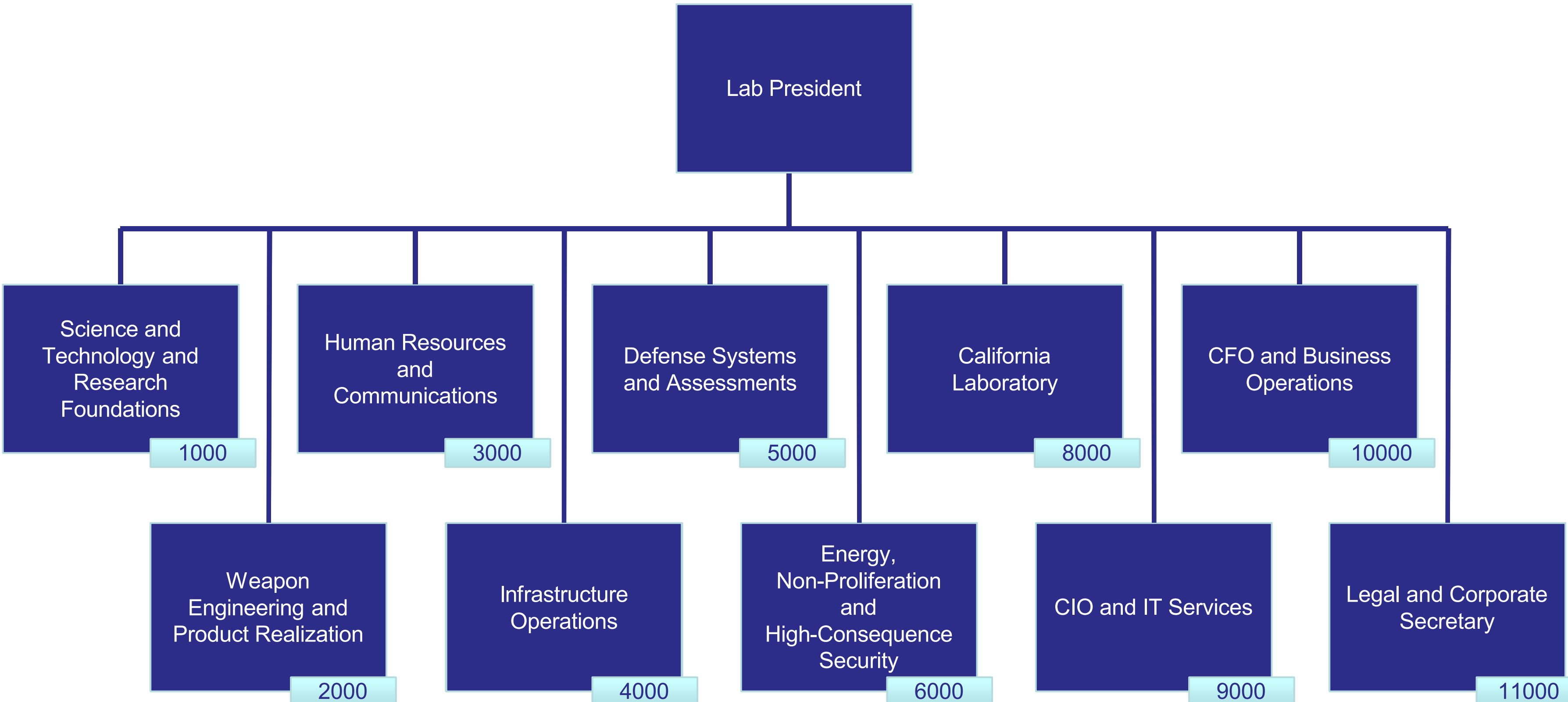
hp invent

LOCKHEED MARTIN

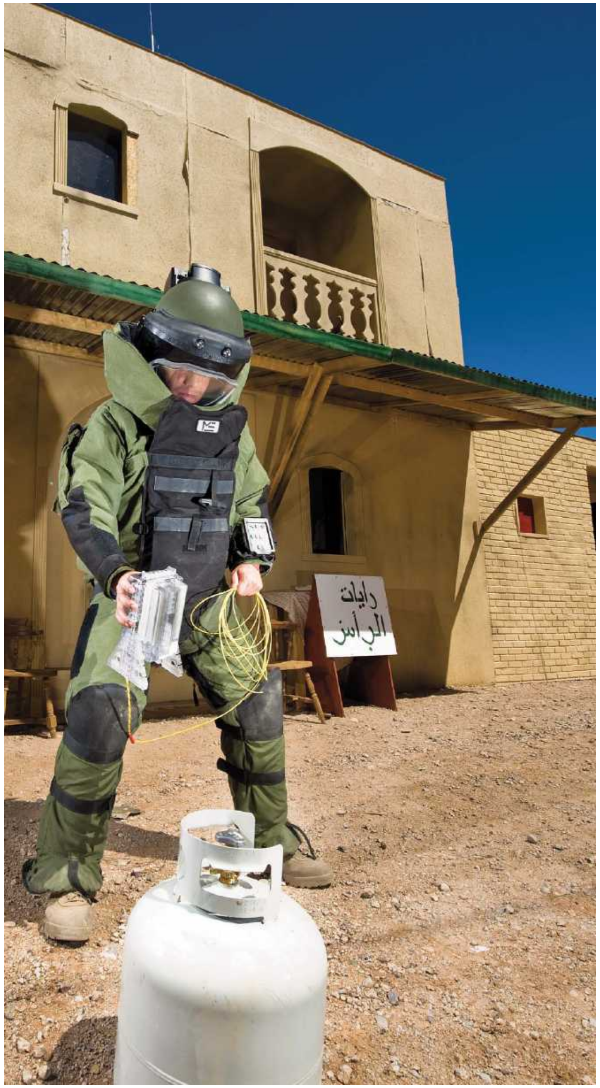
ExxonMobil
Taking on the world's toughest energy challenges.



Lab Structure



Some of Sandia’s Exciting Work



TIME Magazine selected a device developed by Sandia researchers, which disables improvised explosive devices, as one of its “50 Best Inventions of 2010.”

As a measure to defeat roadside bombs and other IEDs, the disruptor shoots a thin blade of water capable of penetrating steel. The high-speed, precise blade penetrates the IED and is followed by a water slug that performs the general threat disruption. So far, about 7,000 units have been shipped to warfighters in Afghanistan.

Some of Sandia's Exciting Work

- Self guided bullet that can hit a target a mile away
- Built from commercially available parts
- Optical sensor in the nose detects laser on target
- Electromagnetic actuators steer tiny fins that guide the bullet


Some of Sandia's Exciting Work

- Decontamination foam developed 10 years ago for killing anthrax
- Effective in meth lab cleanup

Organization 1522

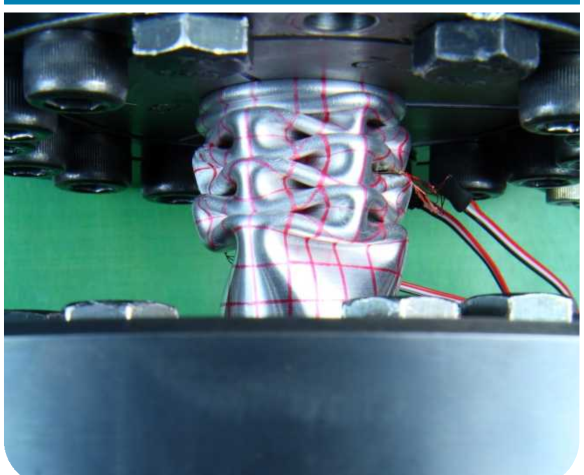
- Division 1000 : Science and Technology and Research Foundations
  - Center 1500 : Engineering Sciences
    - 1520 : Solid Mechanics and Structural Dynamics
      - Organization 1522 : Experimental Mechanics, NDE, and Model Validation

Organization 1522 Mission

To accurately characterize the structural response of systems to pressure, temperature/humidity, load, and acceleration environments. To provide design expertise for fixturing and development of experimental configurations. To develop and apply state of the art radiographic and acoustic diagnostics.

Solid Mechanics

Provide experimentation for deformation mechanics and specialize in characterization and development of models for materials, components, and sub-assemblies for a breadth of activities ranging from applications to research & development.



Structural Dynamics

Perform experimental structural dynamics tests to validate analytical models, develop experimental models, and characterize hardware dynamics and operational environments.

Non-Destructive Evaluation

Provide independent, non-destructive evaluation capabilities during model development, qualification, production, and post-production activities; characterize component performance and mechanical failure; and develop new diagnostic techniques.

Non-Destructive

- NDEvaluation, NDInspection, NDTesting
- Evaluate properties of a material, component, or system without causing damage
  - Radiography
  - Ultrasound
  - Dye Penetrant
  - Magnetic Particle
  - Infrared and Thermal Testing
  - Magnetic Resonance
  - Visual Inspection
  - …

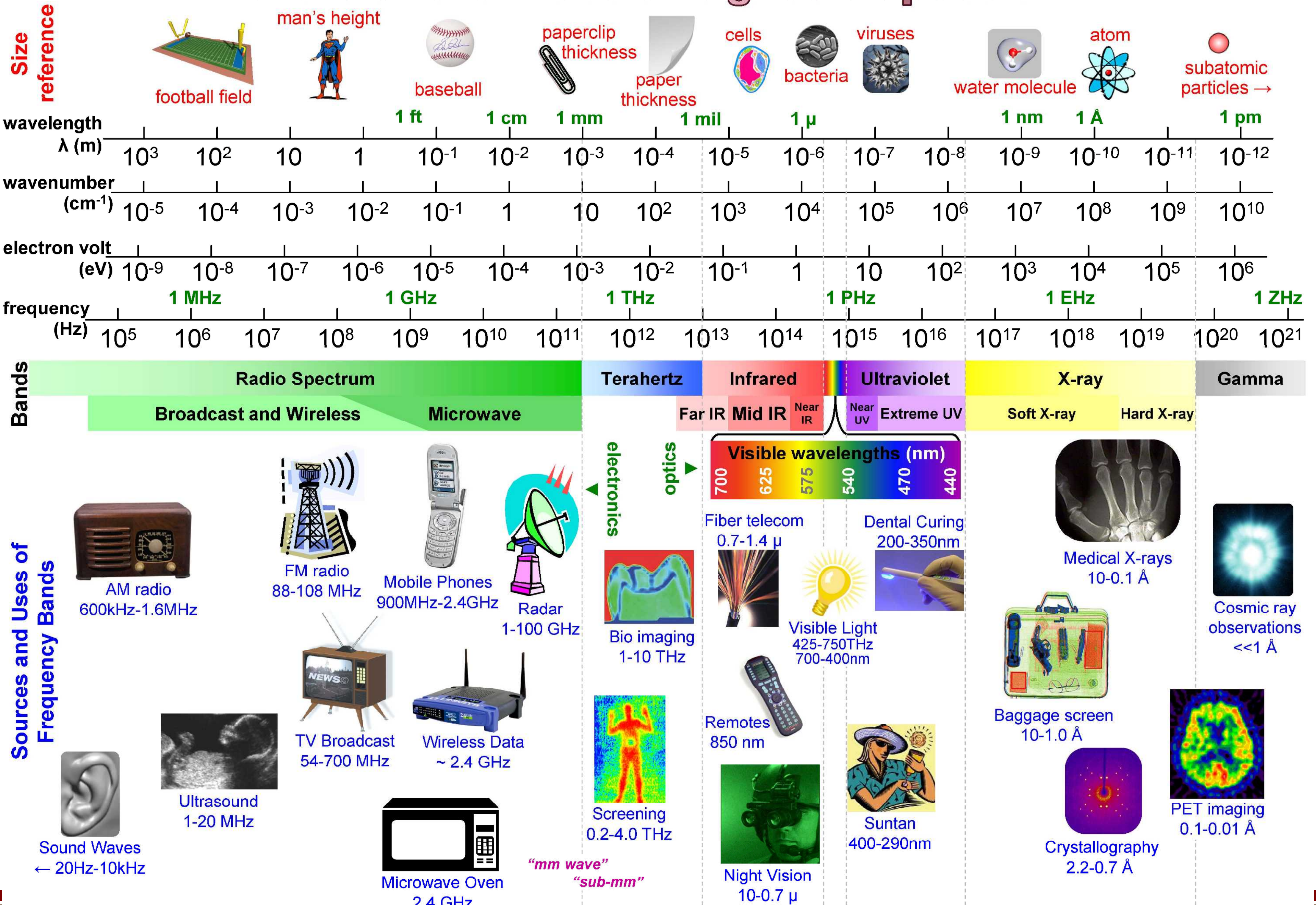
Why is NDE Important?

Sandia National Laboratories

Three Inspection Technologies

- Ultrasonics
  - Sound waves (1 MHz – 100 MHz : Frequency)
- Thermal Imaging
  - Temperature (750nm – 1mm : Wavelength)
- Xray and Computed Tomography
  - Ionizing Radiation (1 keV – 10 MeV : Electron Volt)

Chart of the Electromagnetic Spectrum



Ultrasonic Diagnostics

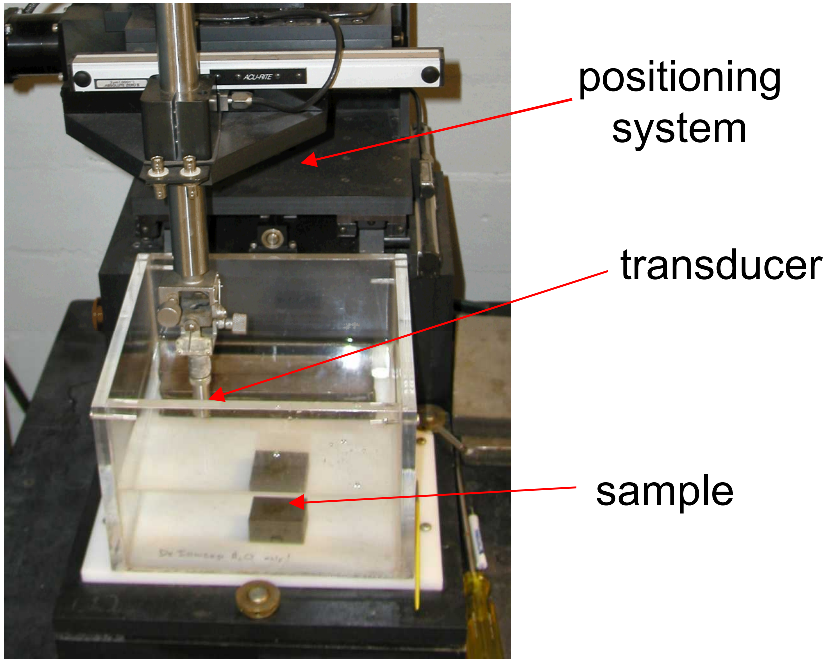
Volumetric Material Defect Detection and Imaging

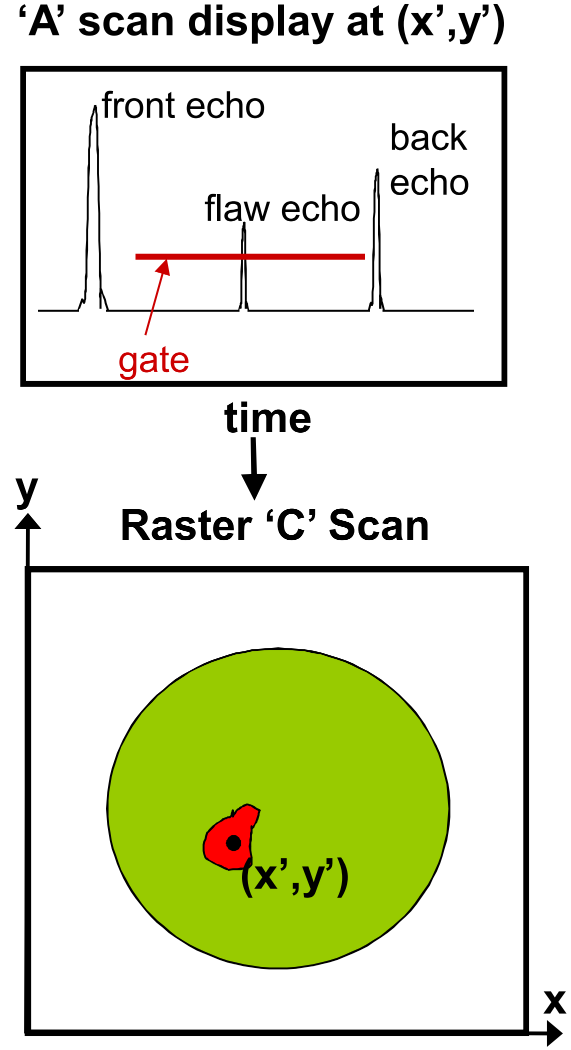
- Flaws
- Cracks
- Voids, Porosity
- Disbonds
- Composite Uniformity
- Quality Control

Determination of Material Elastic Properties

- Longitudinal Acoustic Velocity
- Shear Acoustic Velocity
- Elastic Constants C_{11}, C_{33}, C_{12}, etc.
- Young's, Shear, Bulk, Moduli
- Moduli Temperature Dependence to 1200 °C

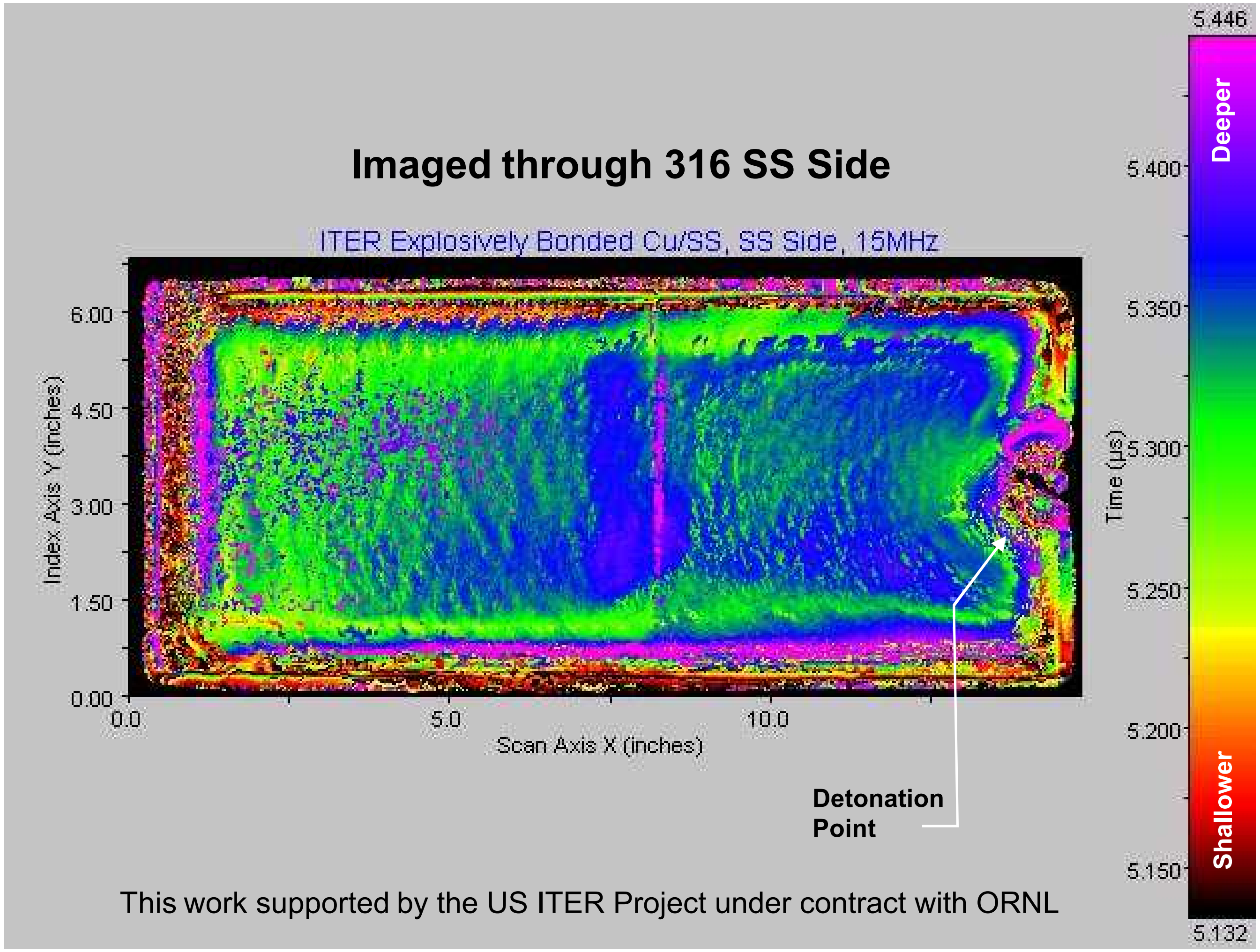
Typical UT System



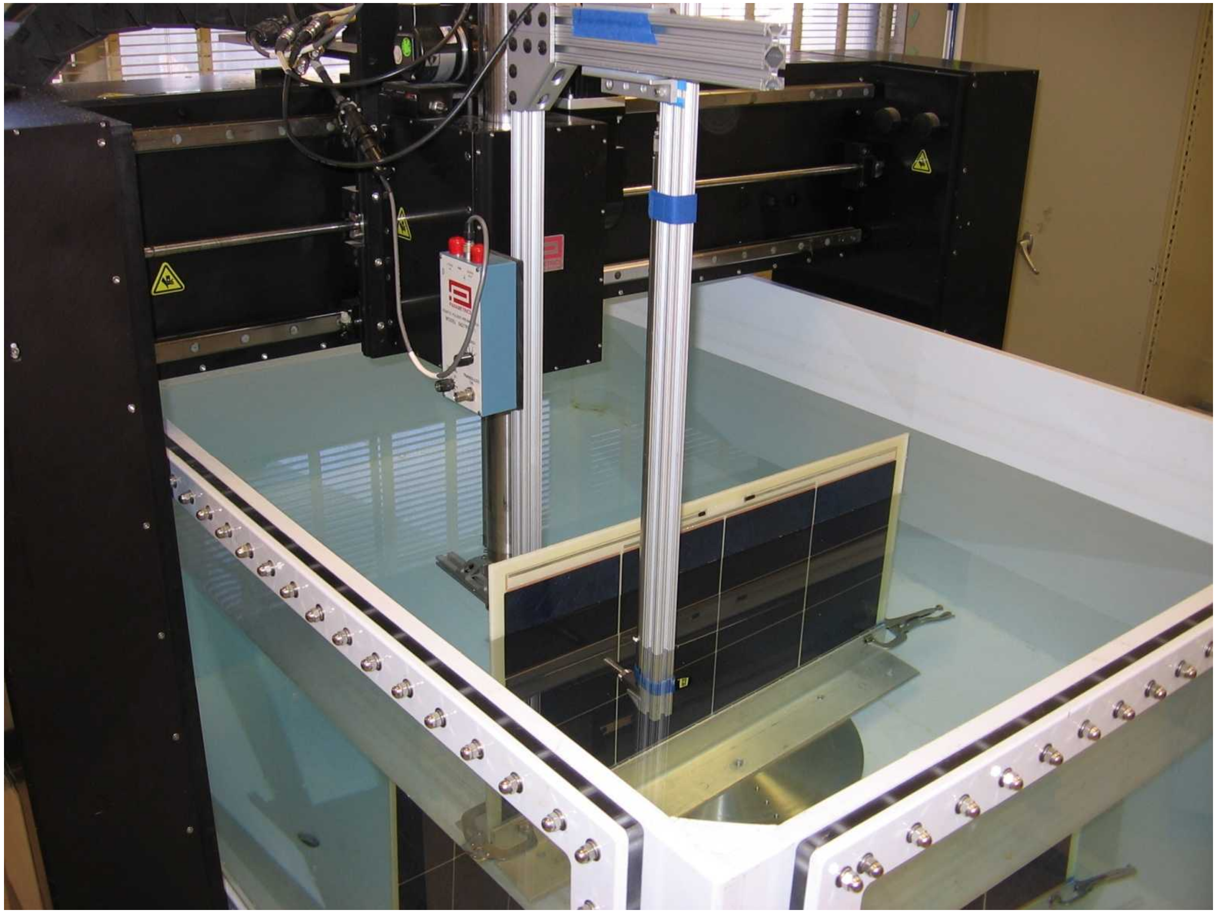


- Raster Scan, Pulse - Echo
  - Record amplitude and peak time
- Higher frequency = higher resolution, lower penetration

Scan of CuCrZr – 316SS Interface

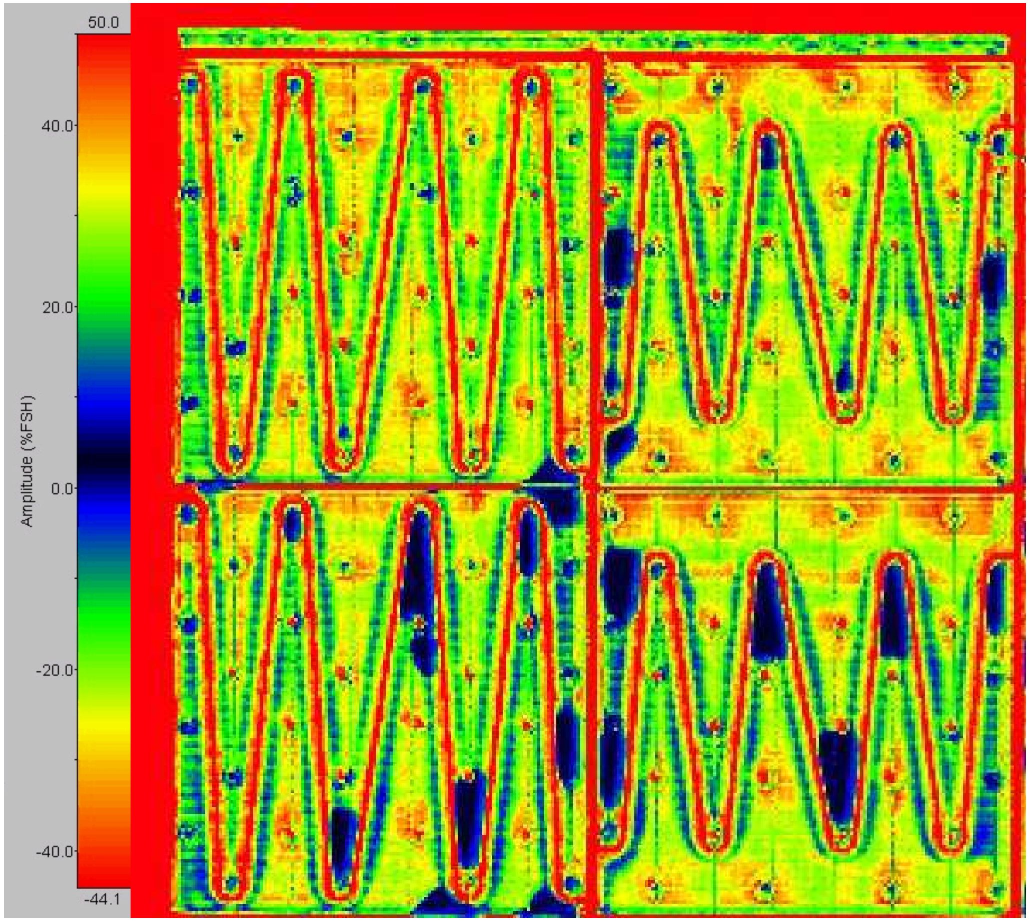


Inspection of Solar Panel



- Raster Scan, Thru-Transmission
  - Transducer and Receiver
  - Record amplitude of received signal
  - Decreased amplitude mean defect/material change that attenuated signal
- Higher frequency = higher resolution, lower penetration

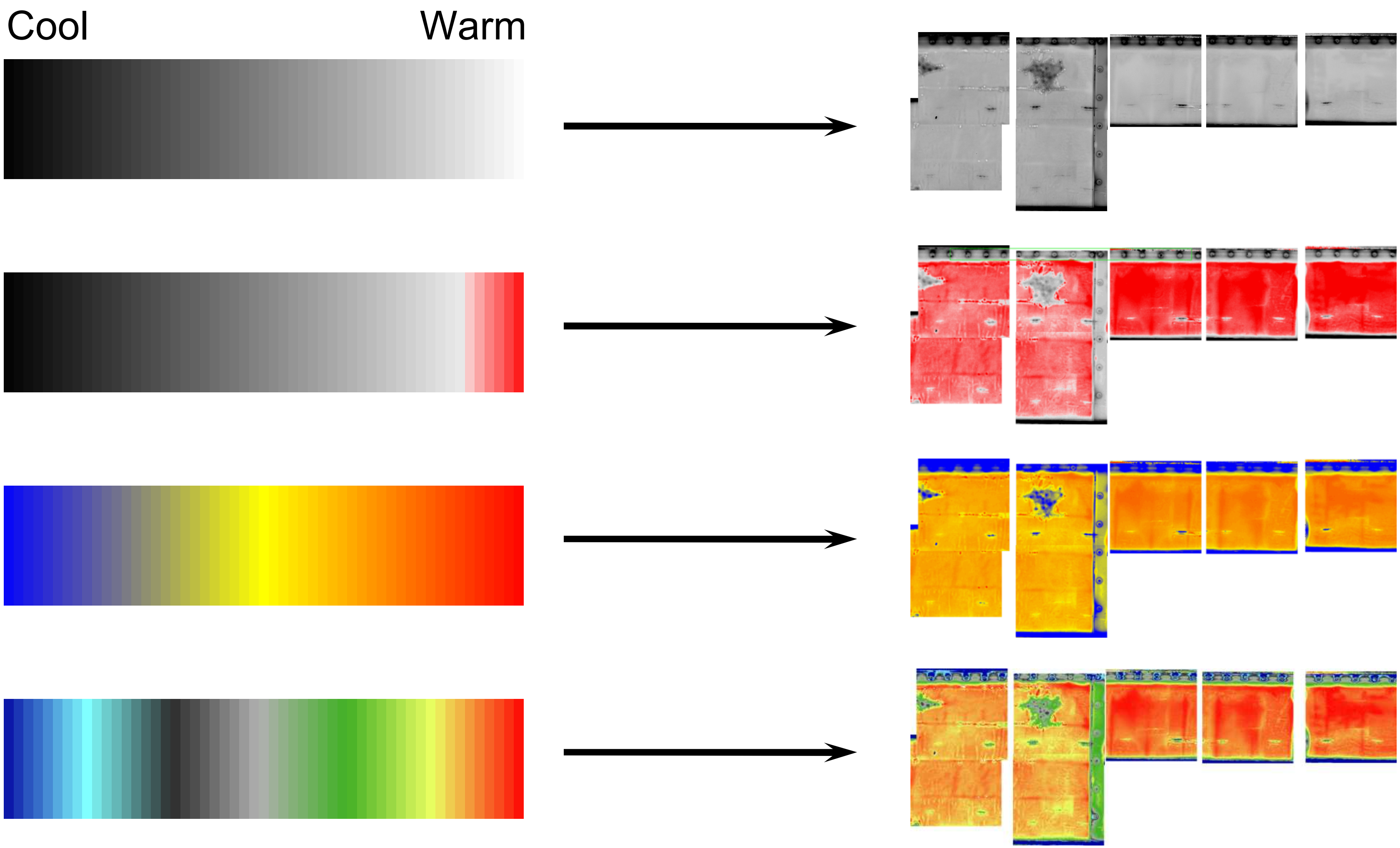
UT Image of Solar Panel



Thermography

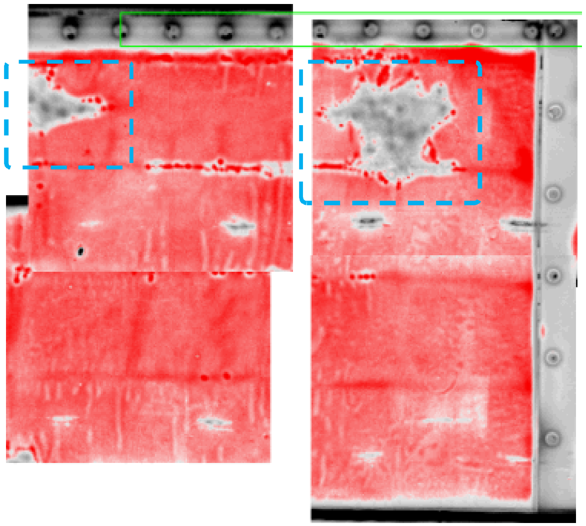
- Passive Thermography
  - Measurement and mapping of surface temperatures in-situ
- Active Thermography
  - Apply stimulus to a target causing the target to heat or cool
  - Measure and map temperatures as target responds to stimulus
  - Thermal response of target allows for analysis of subsurface structure and material properties
    - Different materials response to heating/cooling differently
  - Temperature change is more important than absolute temperature

Image Color Scales

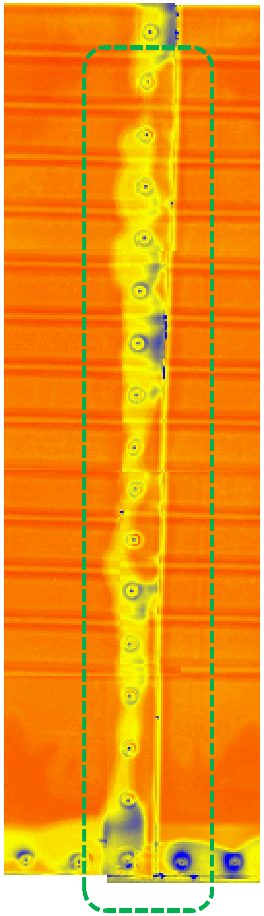


Thermography

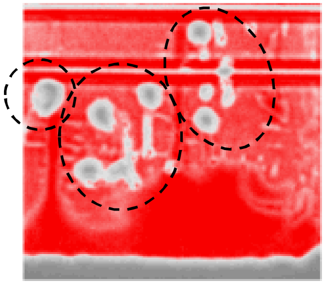
Indications of water



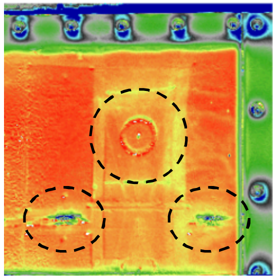
Thin Sealant



Other Notes



Sealant on the backside of the stainless steel. Likely from wiping it off hands during assembly.



Reflections of the camera lens (top) and Flash Bulbs (bottom two circles). These reflections are caused by the shinny stainless steel and thin paint. The bottom two are present on many images

X-ray Imaging

- Produce images by transmitting beam of x-rays through a part onto x-ray sensitive detector
- Image is result of variations in material thickness, density, chemical composition of part
- Typically use RGD's not sources

Medical	Industrial
Typically < 200keV	<10keV to >10MeV
Human Body	Low Z, High Z, Low Z in the presence of High Z
<0.5mm spatial resolution	<1um to mm spatial resolution
X-ray dose minimized	Parts may be x-ray sensitive but generally not
Large market – multiple machines in every hospital	Industrial market is relatively small

Uses and Applications

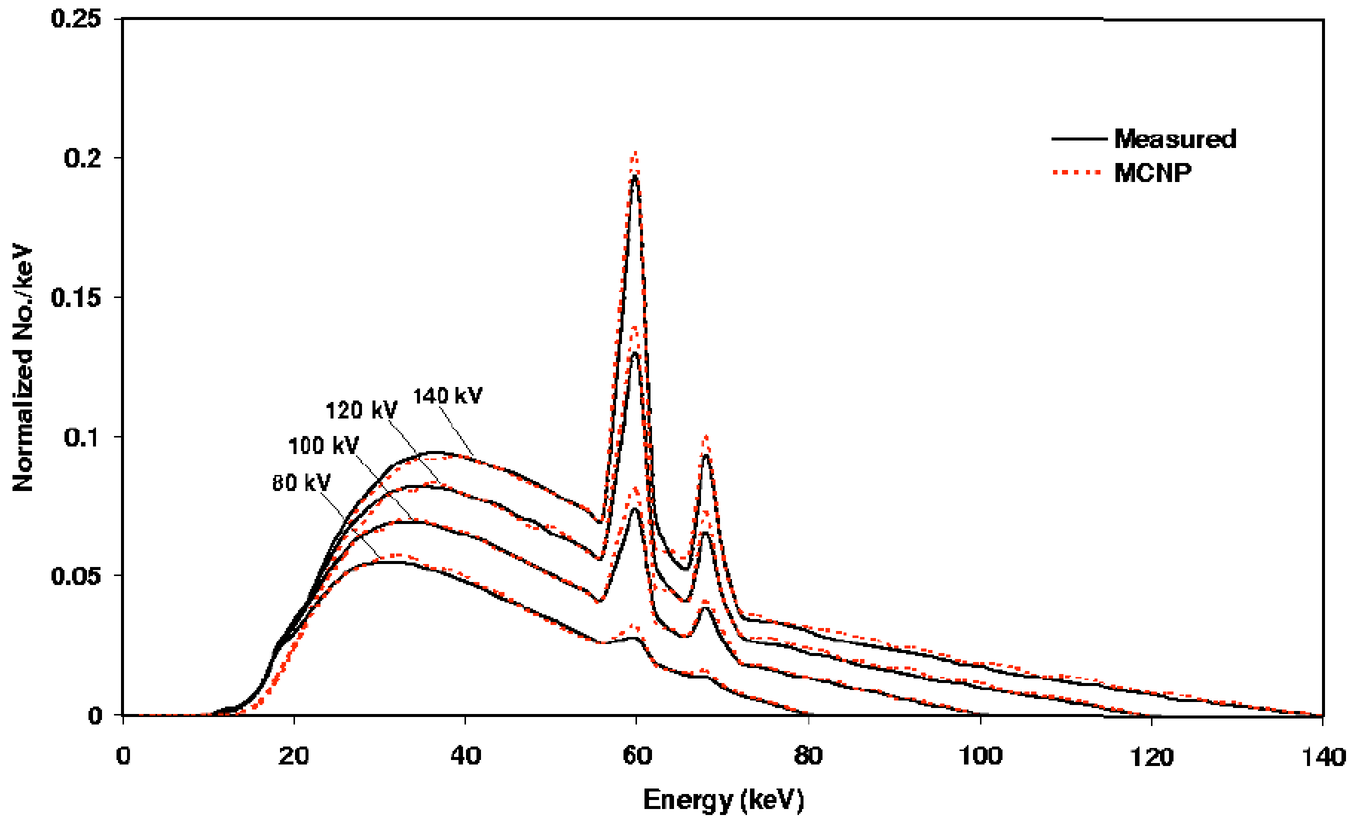
- Materials Research and Development
- Quality Control and Production Inspection
- Reverse Engineering
- Safety
- Verification of Internal Components
- Failure Analysis
- Testing Diagnostics
- Non-Visual Dynamic Event Monitoring
- Locate Minute/Hidden Cracks
- Locate Poor Electrical Connections
- Measure Internal Dimensions
- Locate/Quantify Density Variations

X-ray Machine Capabilities

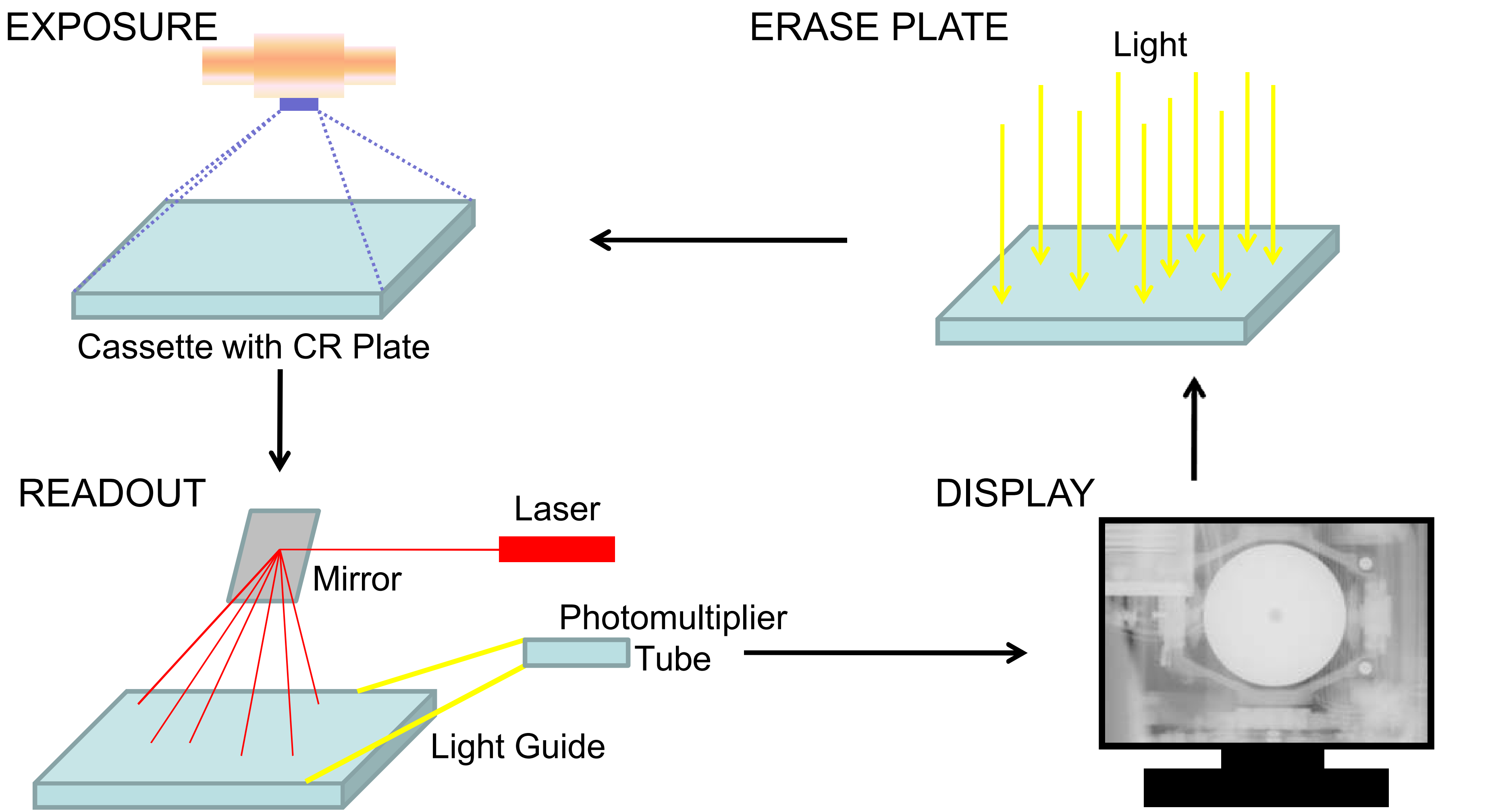
X-Ray System	X-Ray Energy Range	Typical Part Thickness
Microfocus	10-220KeV	<1" Steel
Mini focus	10-160KeV	~1" Steel
General Purpose	10-450KeV	~ 3" Steel
High Energy	6.0 MeV	> 12" Steel
Real-Time	30 KeV – 6 MeV	< 3" Steel
Flash	150KeV, 450KeV, 1MeV	~2" Steel
Portable	20KeV-6MeV	< 6" Steel

X-ray machines produce a Bremsstrahlung x-ray energy spectrum, i.e. a continuous spectrum with the peak energy at the machine setting and an average energy of approximately 1/3 of the peak energy.

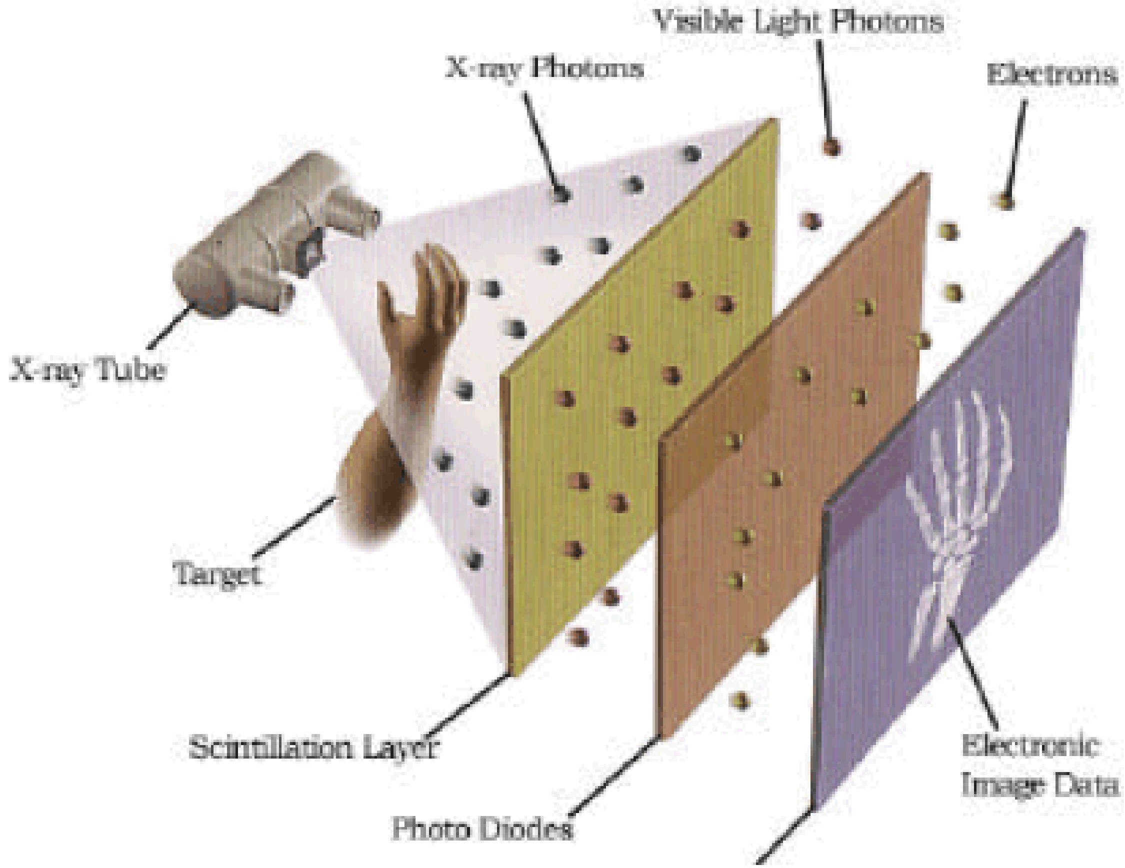
X-ray Beam Spectrum



Digital X-ray Imaging - CR

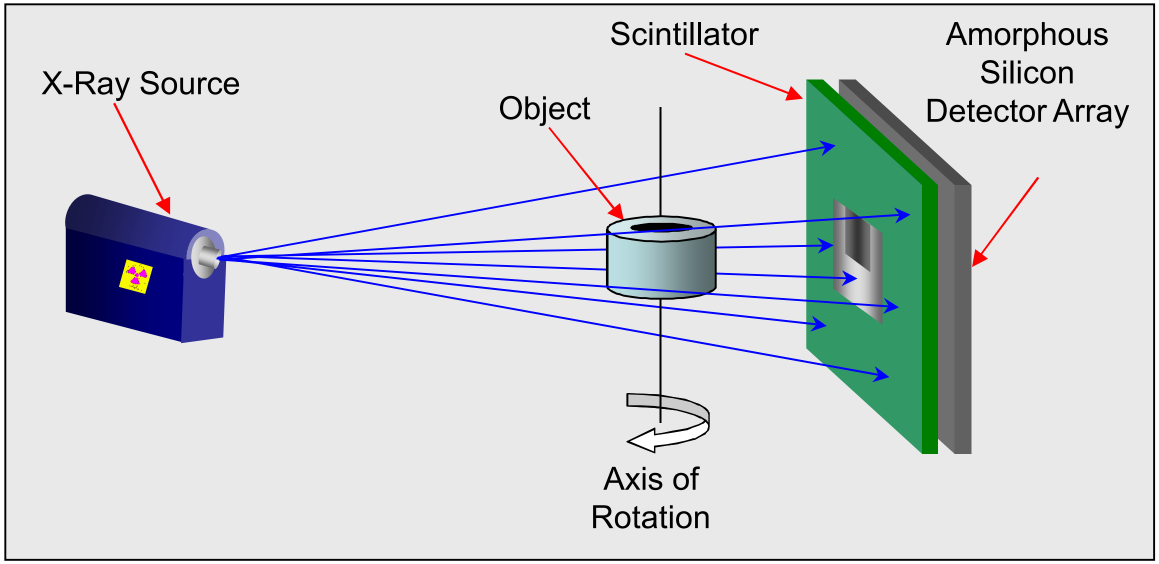


Digital Xray Imaging – Flat Panels

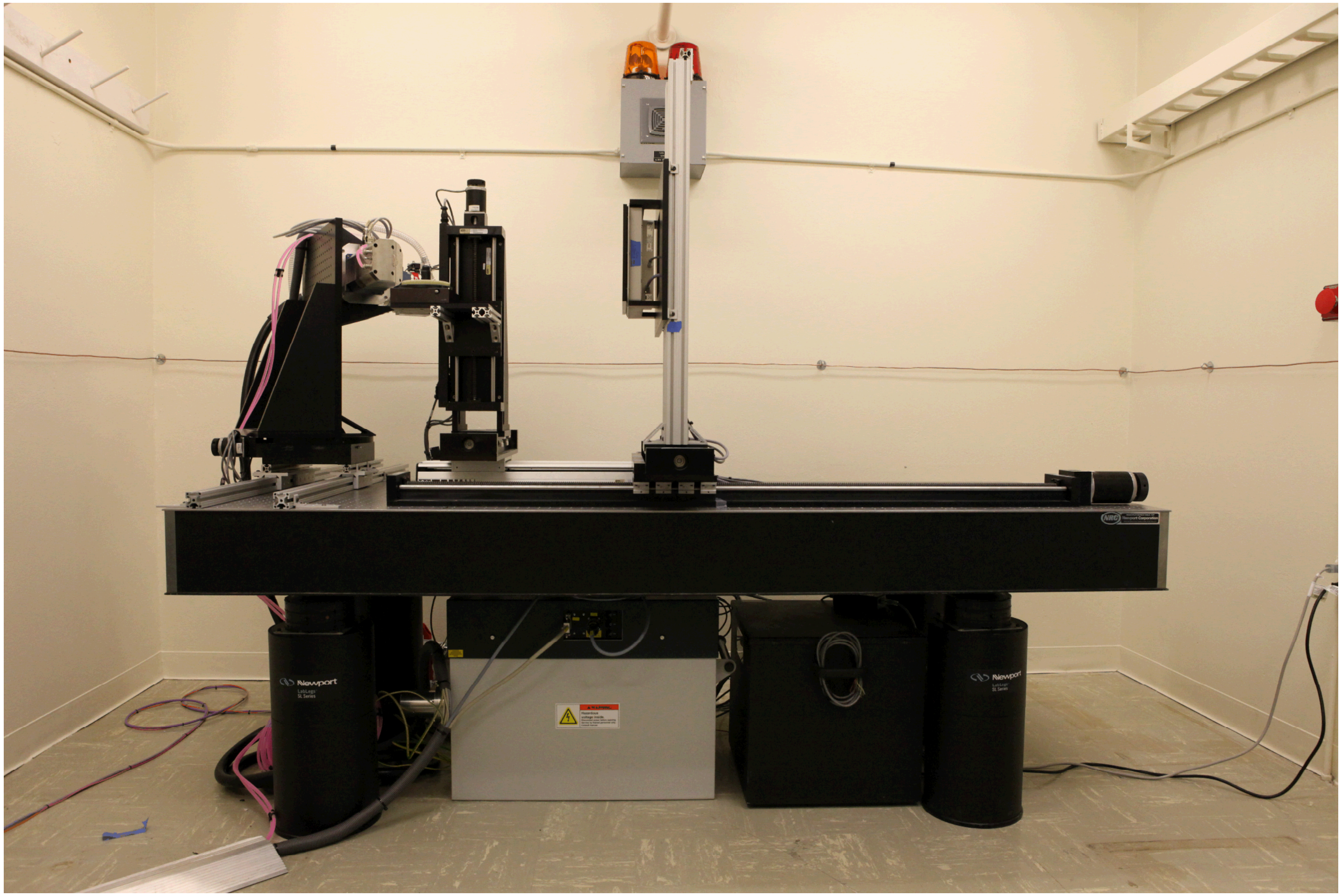


Computed Tomography

- X-ray Image – 2D picture of a 3D object
- Computed tomography (CT or CAT Scan) creates cross sectional view of part being examined
- CT slices generated from multiple x-ray images (projections)
- Data is reconstructed into thin cross sectional “slices”



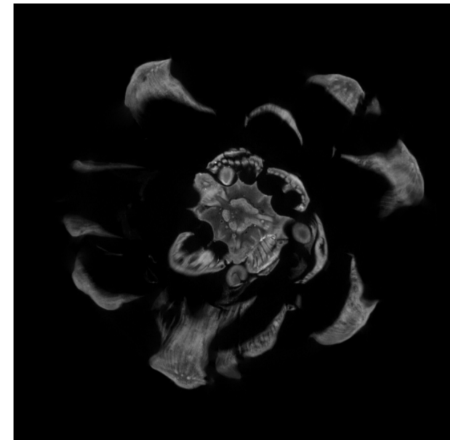
CT System at Sandia

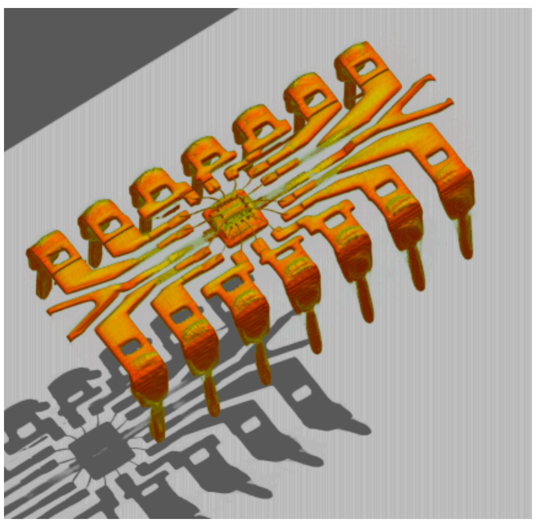


Micro CT (μCT)

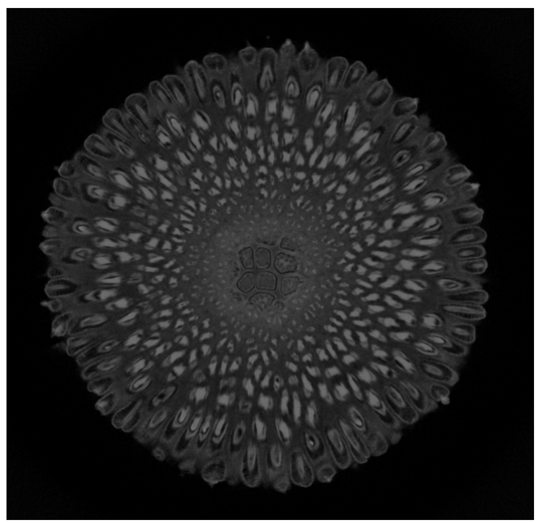
Sandia National Laboratories

- Microfocus X-ray Machine
- Geometric magnification
  - Increase spatial resolution

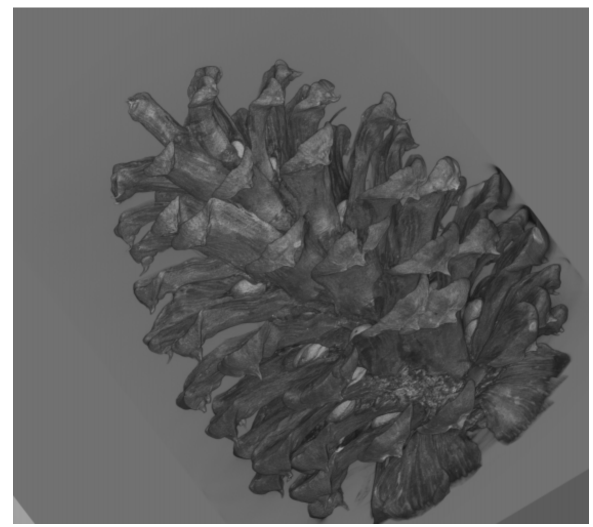




3D rendering of an integrated circuit (~10 micron resolution)

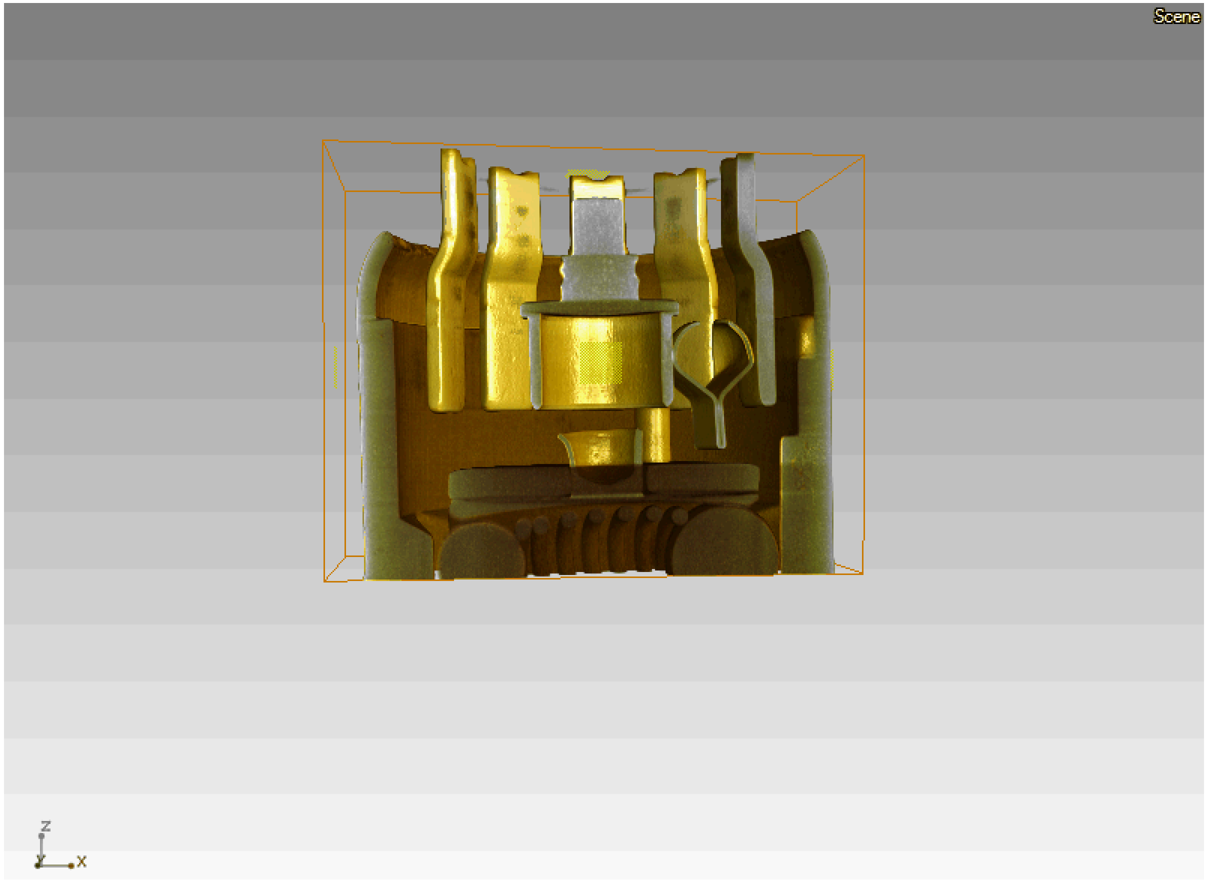


μCT image of a Sycamore seed pod (~25 micron resolution)

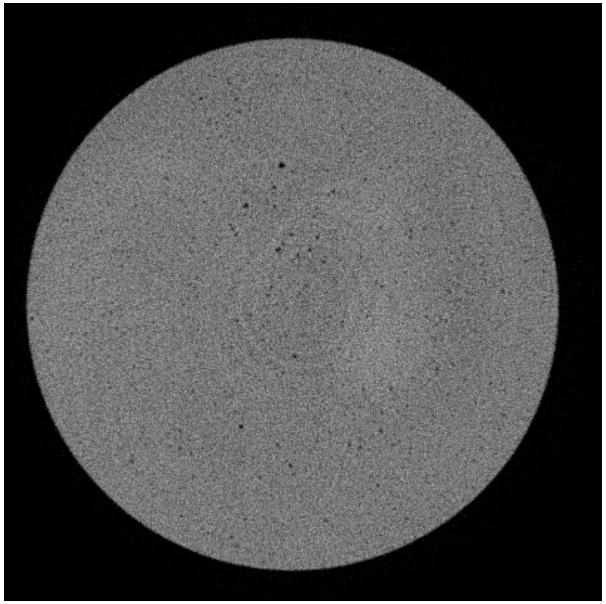


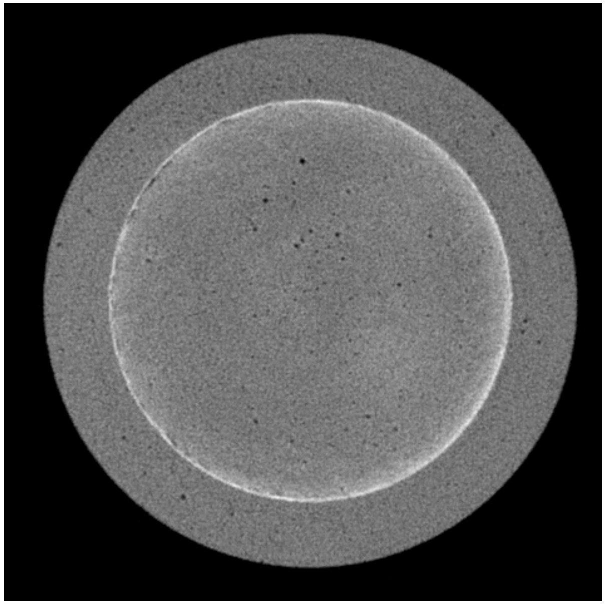
CT image and 3D rendering of a pinecone (~50 micron resolution)

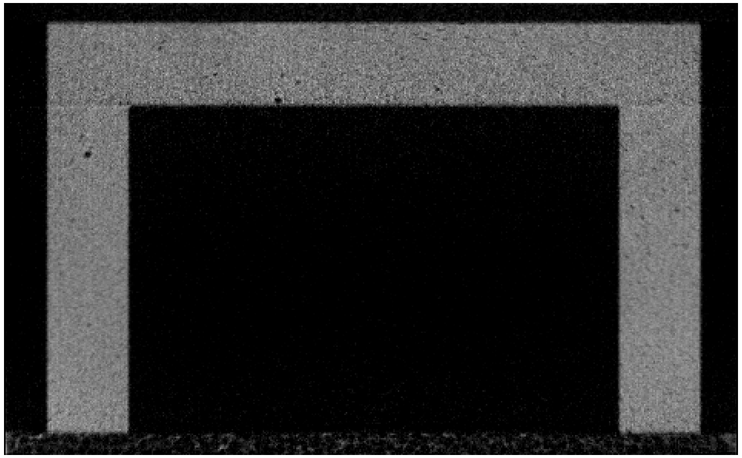
3D Rendering of Rotary Switch

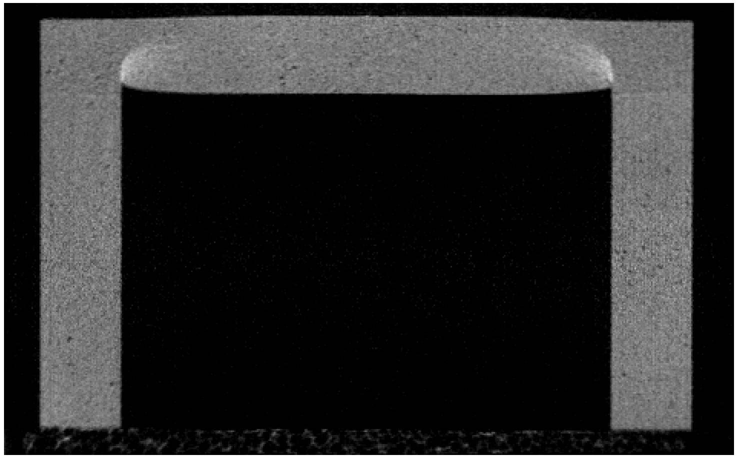


Foam Density Variations

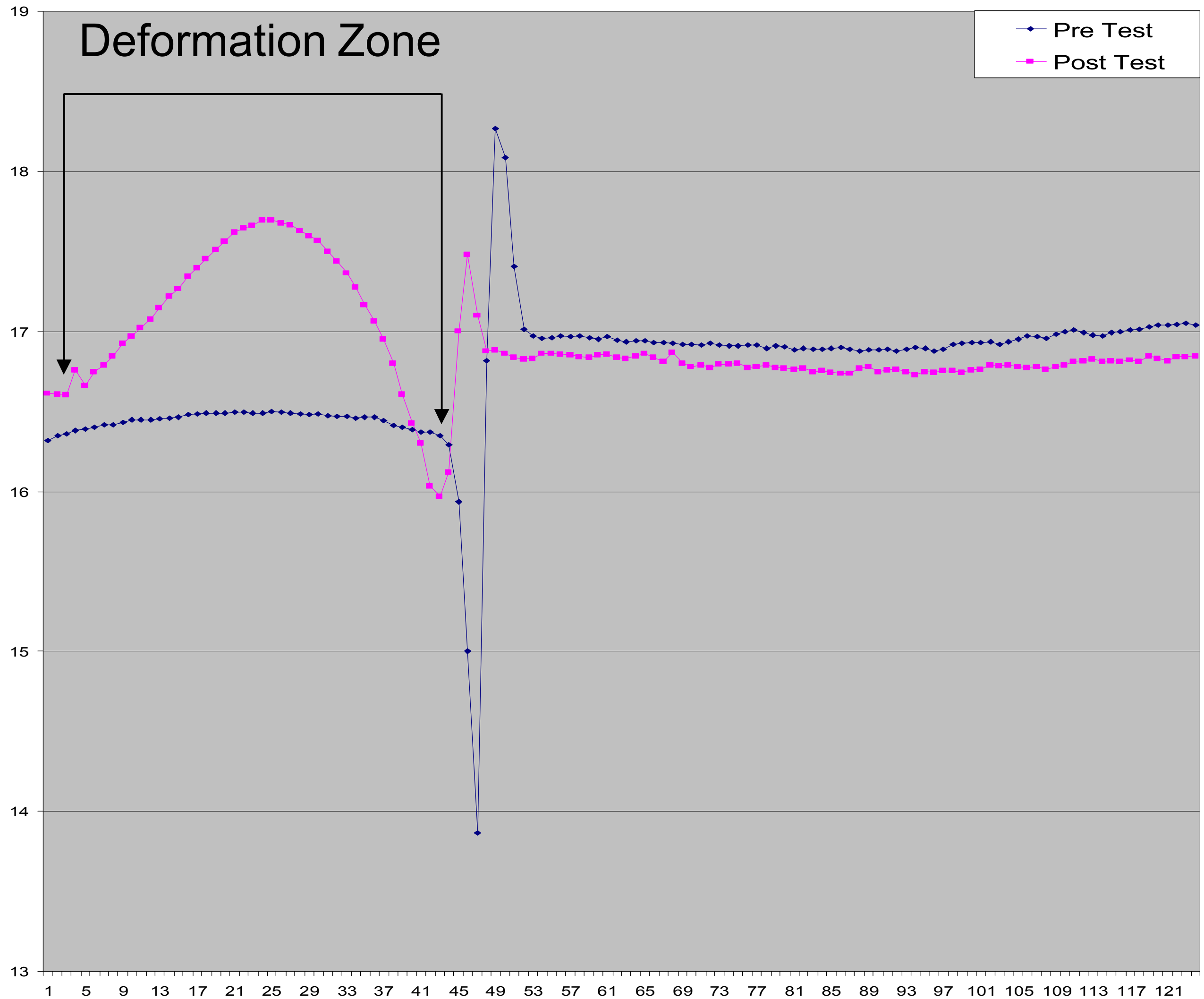








Before and After Shock Testing



Fragmentation Characterization

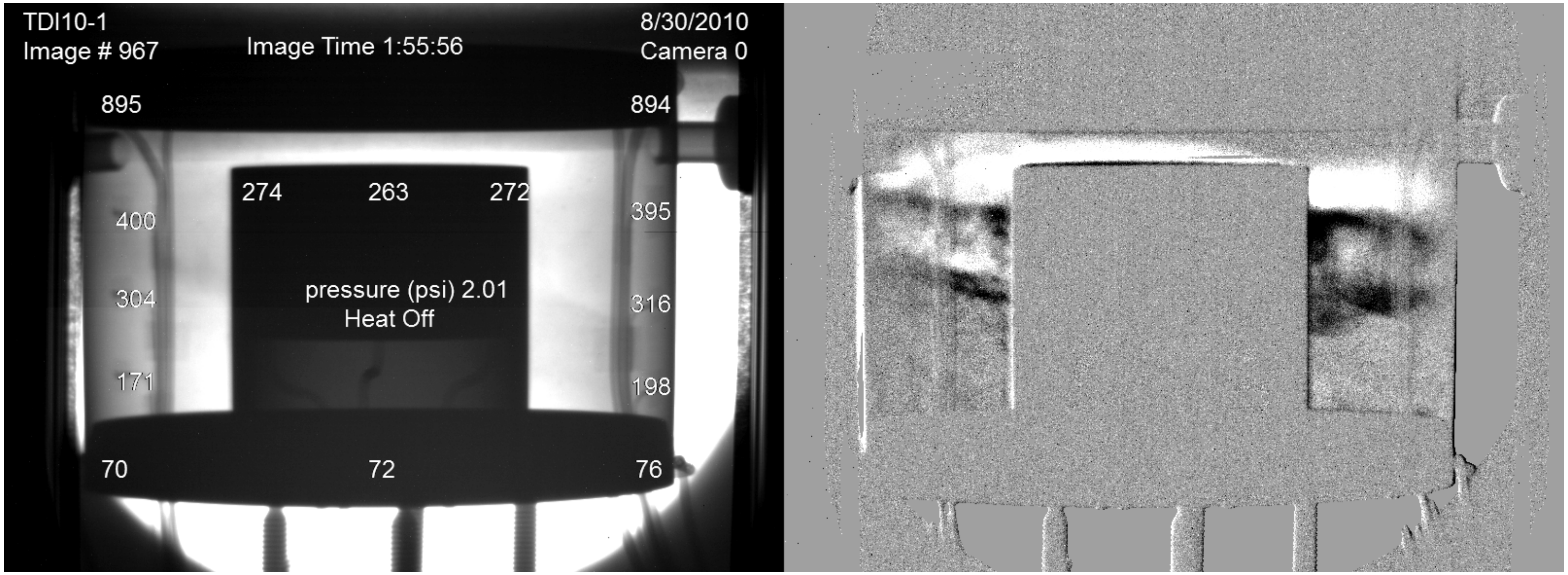
- Interested in measuring fragment size, velocity, and direction of travel
- Utilize flash x-ray
- Previous measurements were inaccurate

The image cannot be displayed. Your computer may not have enough memory to open the image, or the image may have been corrupted. Restart your computer, and then open the file again. If the red x still appears, you may have to delete the image and then insert it again.

The image cannot be displayed. Your computer may not have enough memory to open the image, or the image may have been corrupted. Restart your computer, and then open the file again. If the red x still appears, you may have to delete the image and then insert it again.

Realtime Radiography

- Image foam decomposition as it is exposed to intense heat
- Set up at Sandia's Thermal Test Complex
  - Remote x-ray operations

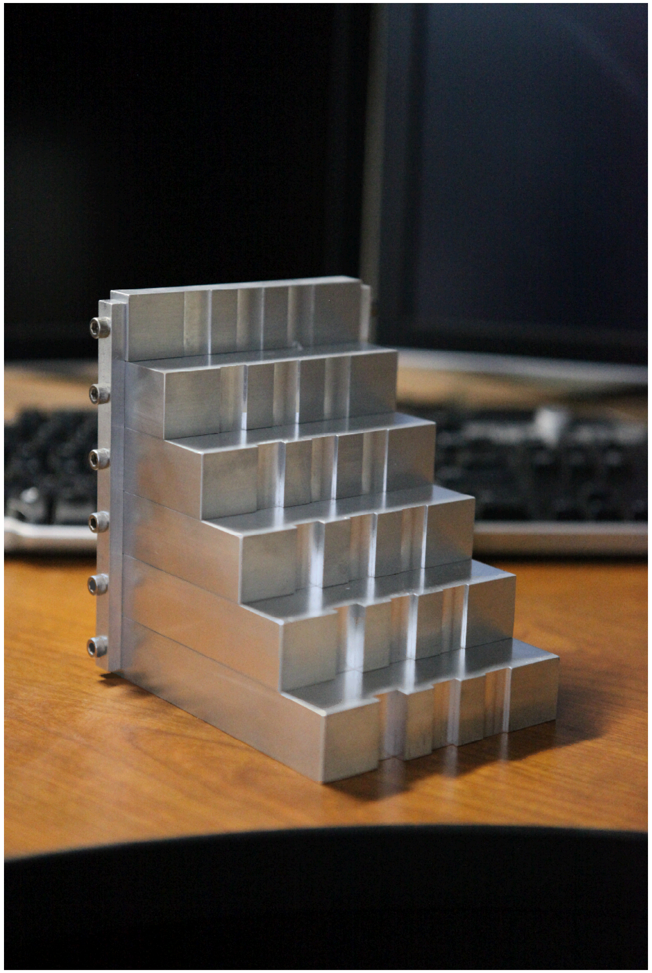


Research Projects

- Stereo X-ray Calibration
  - Map two systems into 3D space
  - Accurately measure out of plane movement
- Nano-focus CT
  - Characterize metallic structure deformation at grain boundaries
  - Interrogate internal surfaces of small energetic materials
- Million frame per second x-ray imaging
  - Extension of Stereo X-ray Calibration project
  - High speed, continuous x-ray imaging of dynamic events
  - See through smoke, flame, and debris
- Characterization of digital radiography systems at high energies
  - Determine SNR, CNR, Spatial Resolution
- Model Validation using CT Data

Contrast Sensitivity Step Wedge

- Calculate contrast-to-noise ratio and contrast sensitivity in digital x-ray images for varying material thicknesses
- Grooves are 1%, 2%, 4% of step thickness
- Can I see a 1% groove, 2% groove, etc?
- $CNR = \frac{A-B}{\sigma}$
  - A = Average Intensity outside of groove
  - B = Average intensity inside groove
  - σ = noise in A



Questions