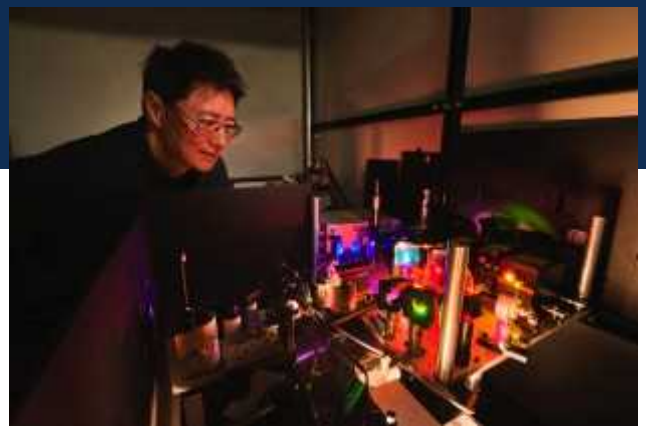
SAND2015-10424C

Exceptional service in the national interest

Sandia National Laboratories


Securing Trusted Rad-Hard Electronics for the Future

Rich Dondero
Microsystems Assessments I
rdonder@sandia.gov

with Bruce Draper, draperbl@sandia.gov & Paul Dodd, pedodd@sandia.gov

Sandia National Laboratories
DMSMS 2015
December 3, 2015

U.S. DEPARTMENT OF ENERGY | NNSA

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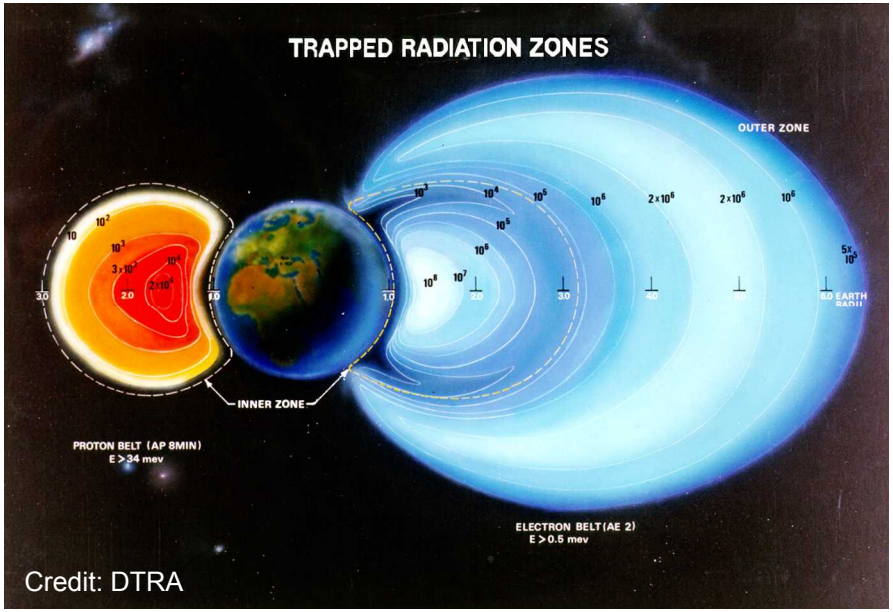
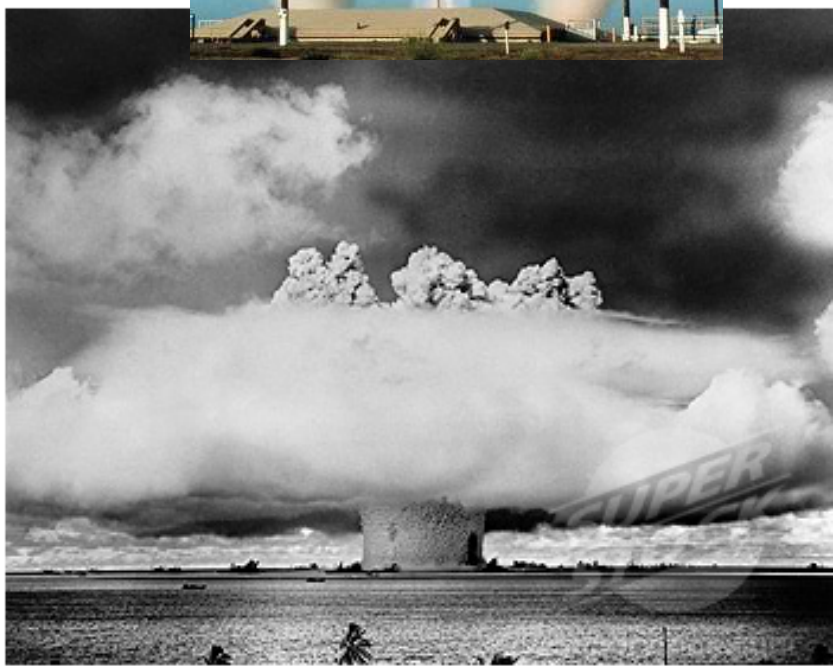


Microelectronics

Sandia National Laboratories

Safe
Secure
Effective

Trust versus Trustworthiness

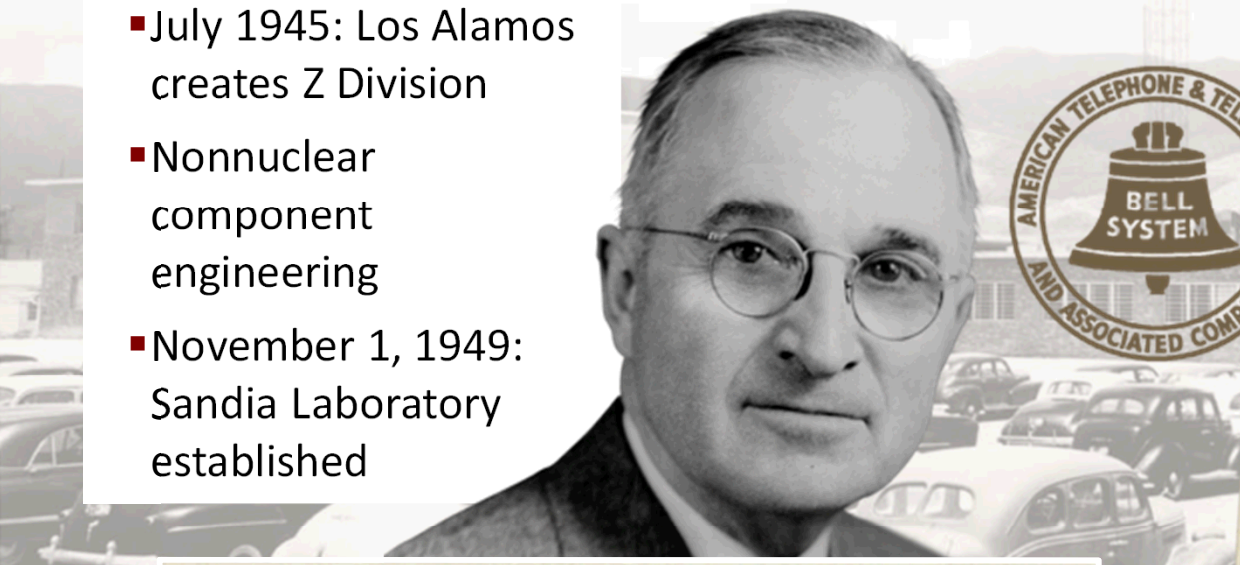


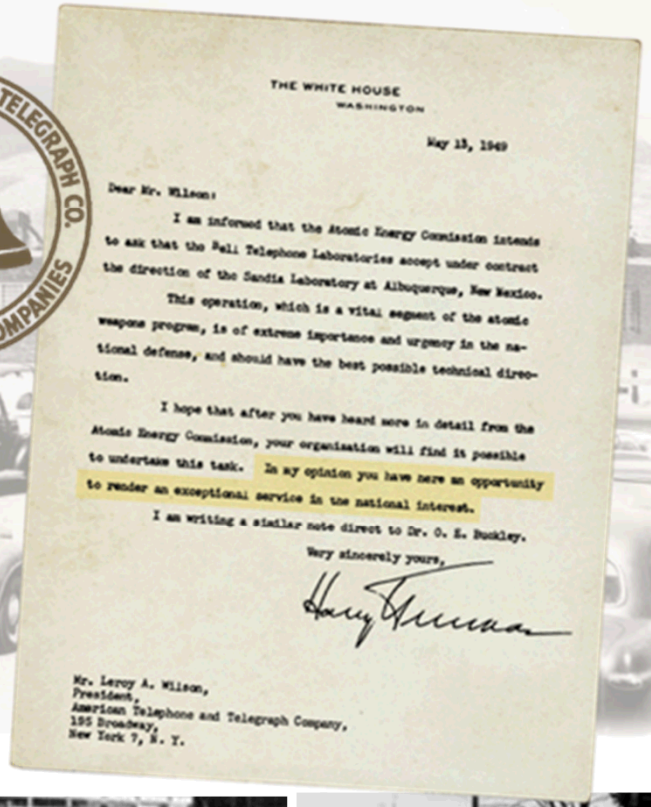
http://www.superstock.com/stock-photography/Atomic+blast+military

Sandia's History

Exceptional service in the national interest

- July 1945: Los Alamos creates Z Division
- Nonnuclear component engineering
- November 1, 1949: Sandia Laboratory established





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 the Sandia Laboratory at Albuquerque, New Mexico.

This operation, which is a vital segment of the atomic weapons program, is of extreme importance and urgency in the 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.

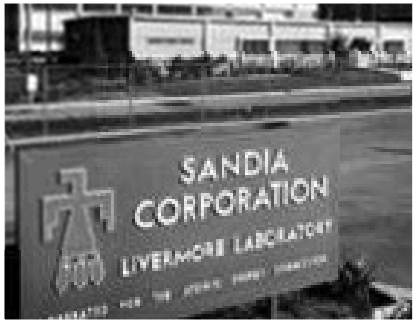
I am writing a similar note direct to Dr. O. E. Buckley.

Very sincerely yours,

Harry Truman

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

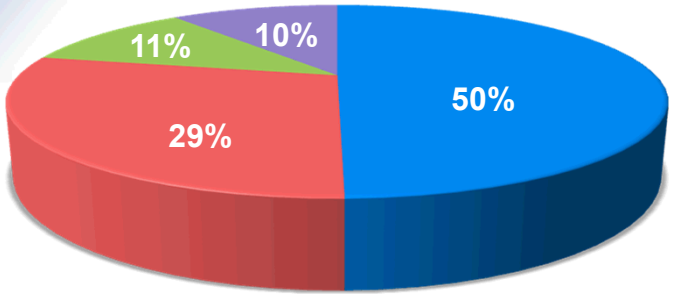
to undertake this task. In my opinion you have here an opportunity to render an exceptional service in the national interest.



Sandia National Laboratories

- Total Sandia Workforce: 12,609
- Regular Employees: 10,330
- Advanced Degrees: 5,790 (56%)

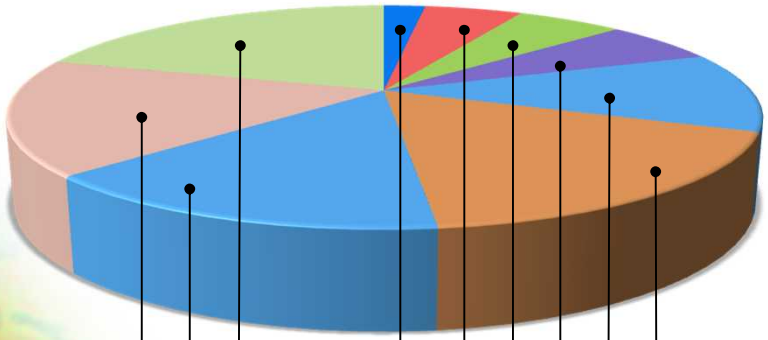
FY14 Operating Revenue
$2.7 billion



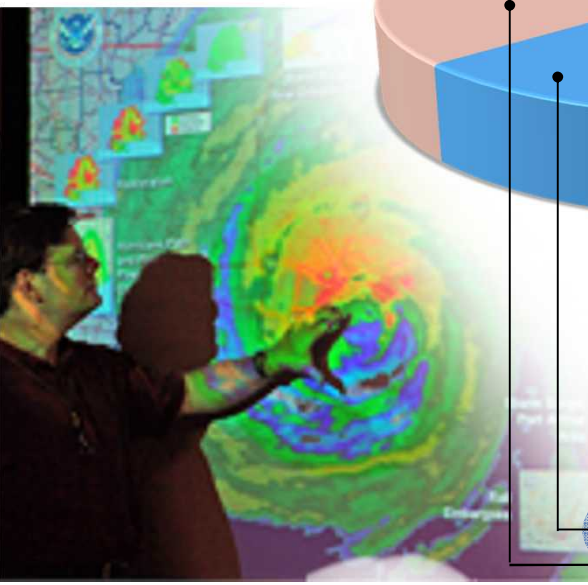
(Operating Budget)

- Nuclear Weapons
- Defense Systems & Assessments
- Energy, Climate & Infrastructure Security
- International, Homeland, and Nuclear Security

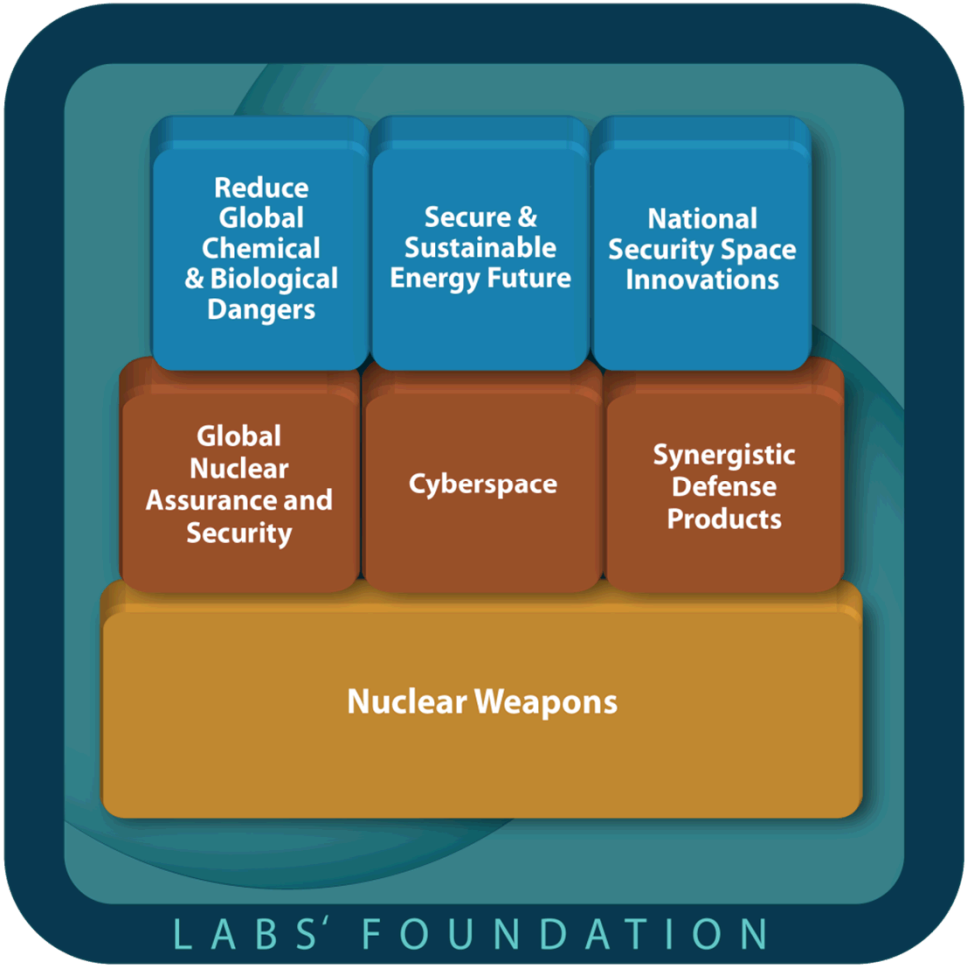
Technical staff (5,046) by discipline



- Computing 17%
- Other Fields 12%
- Other Science 6%
- Physics 6%
- Chemistry 5%
- Math 2%
- Electrical Engineering 20%
- Mechanical Engineering 17%
- Other Engineering 15%



Seven National Security Mission Areas



Sandia accomplishes tasks that are integral to the mission and operation of our sponsoring agencies by:

- Anticipating and resolving emerging national security challenges
- Innovating and discovering new technologies to strengthen the nation's technological superiority
- Creating value through products and services that solve important national security challenges
- Informing the national debate where technology policy is critical to preserving security and freedom throughout our world

Microsystems and Engineering Sciences Applications (MESA): 400,000 Sq-ft Complex with >650 Employees

Sandia National Laboratories

Silicon Fabrication

- Trusted Digital, Analog, Mixed Signal & RF Integrated Circuits Design & Fabrication
- Custom IC Design
  - Secure microcontrollers
  - Sensor Readout ICs
  - Analog/Digital/RF
  - IBM Trusted Foundry
  - Tamper Resistant
- Micromachining
- RAD Effects and Assurance
- Failure Analysis, Reliability Physics
- Test & Validation
- 3-D Integration Features

Compound Semiconductor Fabrication

- Compound Semiconductor Epitaxial Growth (UV-THz)
- Photonics: Si & III-V
- MEMS, VCSELs, Plasmonics
- Specialized Sensors, FPAs
- Materials Science, Graphene
- Nanotechnology, Chem/Bio
- Heterogeneous-Technology Integration & Processing
- III-V Semiconductor Devices
  - Neutron-Immune HBT
  - Rad-hard Optical Links
  - Solid-State RF Devices
  - GaN Power Electronics

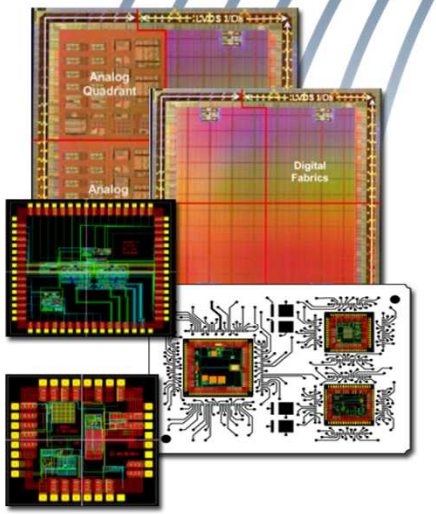
- Advanced Computation
- Modeling & Simulation
- COTS Qualification
- Advanced Packaging
- Custom Electronic Components
- System Design & Test

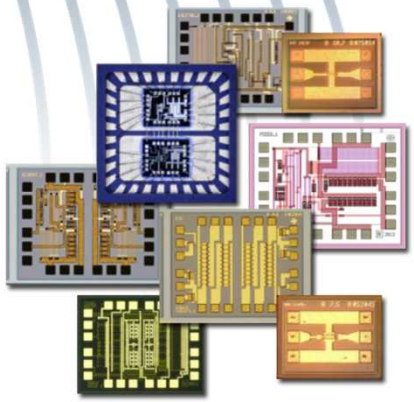
Materials Research

MESA is an FFRDC-based development and production facility for any microsystem component or technology that cannot or should not be obtained commercially.

MESA Manufactures Strategic Rad-Hard Trusted Components for Nuclear Weapons

Sandia National Laboratories





Rad-Hard ASICs
- >25,000 deliveries

Rad-Hard III-V Microelectronics
- >150,000 deliveries

Trust Environment (NW, DMEA)

Strong Failure Analysis, Reliability

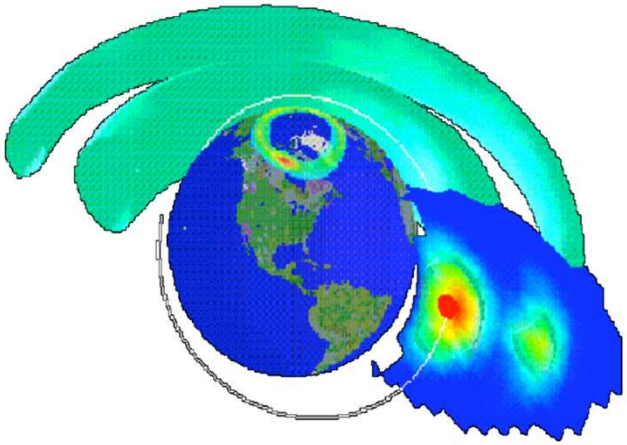
Table of Contents

- Radiation Environments
- Rad-Hard Solutions for Space
- Nuclear Weapon Radiation Environments
- Strategic Rad-Hard Solutions
- Trust
- Trust Solutions Today
- Trust Solutions Tomorrow
- Trust & Strategic Rad-Hard Futures
- Heterogeneous Solutions
- Supporting Framework

Space Radiation Environments

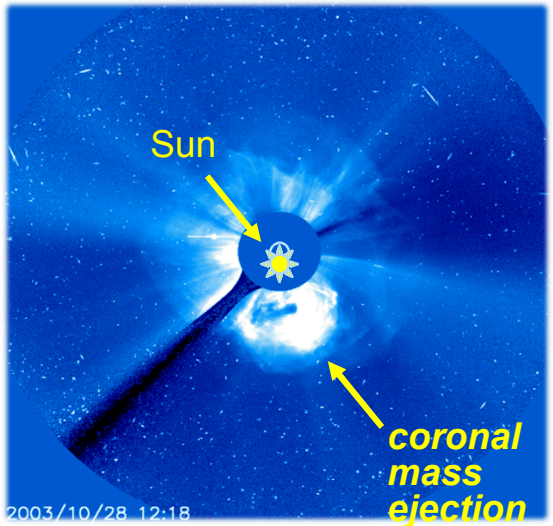
- The natural space radiation environment consists of trapped particle belts, solar events (flares and coronal mass ejections), and galactic cosmic rays
- Radiation can produce temporary malfunctions in electronics (e.g., single-event upset, single-event functional interrupts) or permanent degradation/failure (e.g., total ionizing dose, displacement damage, latchup/burnout)
- The impact of these effects can range from data corruption to instrument malfunction to mission failure

Trapped Particle Belts



J. Barth, 1997 NSREC

Solar Particle Events



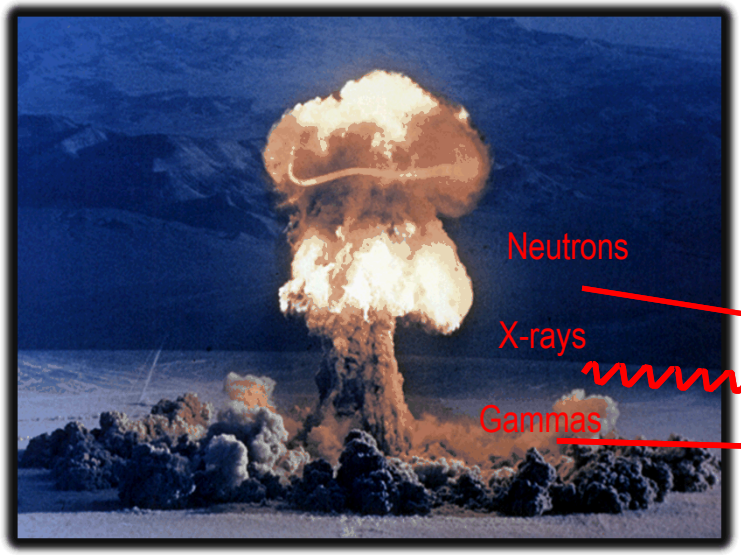
SOHO (ESA & NASA)

Galactic Cosmic Rays

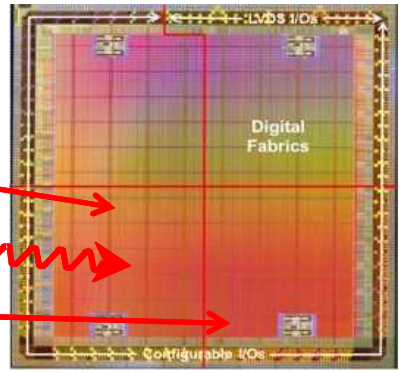
Pierre Auger Observatory

Nuclear Weapon Radiation Environments

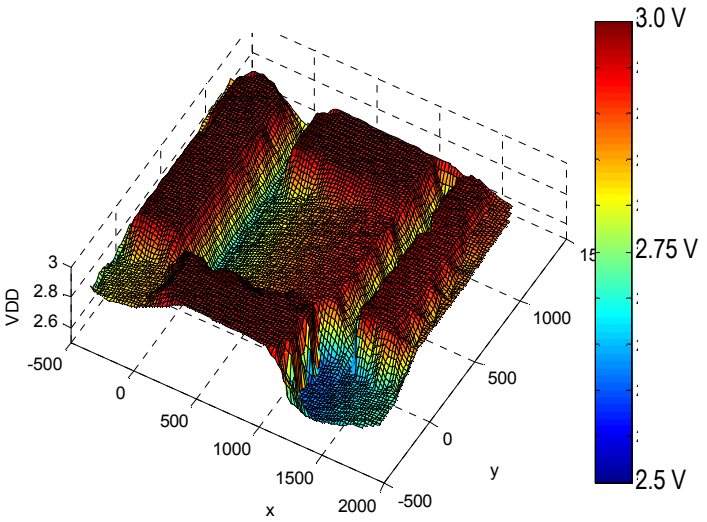
- The radiation environment near a detonated nuclear weapon contains large numbers of x-rays, gammas, and neutrons
- Some effects of this environment are similar to those of the natural space environment but different in scale (e.g., displacement damage effects in bipolar transistors), while others are unique to this extreme environment (e.g., dose-rate upset in integrated circuits)
- Detonation of nuclear weapons in space can also affect operation and longevity of critical space assets (commercial and military)



Rad-Hard IC

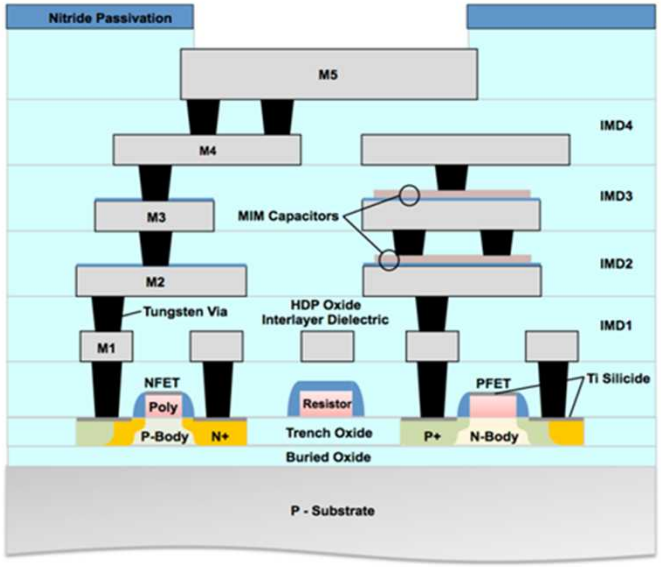


Simulated Rail Droop at High Dose Rate



Rad-Hard Solutions

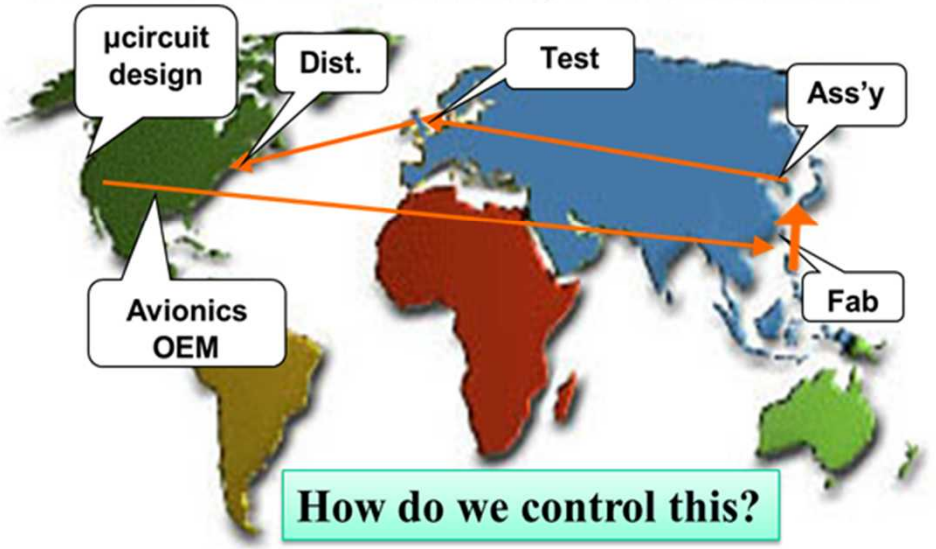
- Rad-Hard by Process (RHBP)
  - Honeywell: SOI CMOS at the 150-nm node, Rad-Hard products for satellite programs
  - ST Micro: Large portfolio of rad-tolerant products
- Rad-Hard by Design (RHBD)
  - Championed by Boeing, USAF, DTRA, and others
  - Provides radiation tolerance at the expense of density
  - Most RHBP technologies use some RHBD techniques
- Upscreening of COTS
  - Aeroflex/Cobham
- The solutions depend on the requirements
  - "Strategic" means different things to various customers
  - Strategic space vs. strategic nuclear weapons
  - Some hardness can be leveraged from space solutions, but additional techniques are required for some applications
- RHBP + RHBD
  - The total solution is usually a combination of both techniques
- Generally the solution space is small
  - Honeywell, BAE Systems, Boeing Design Kit, Sandia National Laboratories, Northrop Grumman



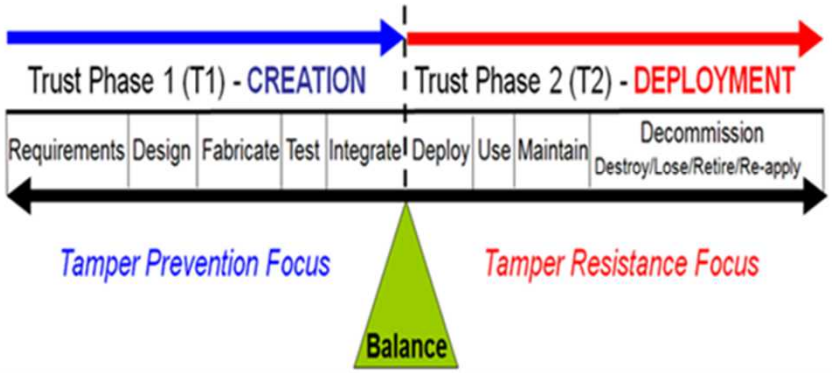
Sandia's SOI CMOS7 Rad-Hard Technology

Trust: The Issues

- Counterfeit parts are big business - Legacy parts
- Cloning is becoming a serious threat – not easy to detect
- The rise of malicious intent: denial of service, kill switches, and inclusion of hidden communications ports
- Circuitous supply chain – where is the chain of custody



Syd Pope (ODUSD/IP), GOMAC 2009

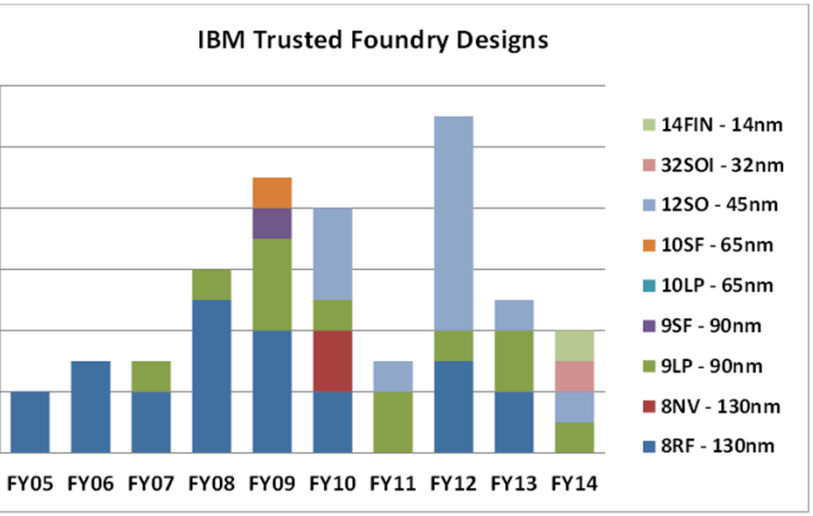


Verification, Validation, Certification

Cradle to Grave Protections

Trust Solutions Today

- DMEA Accredited Trusted Foundry
  - Global Foundries US 2
  - Formerly IBM TF: 52 Designs
  - Trusted Access Program Office (TAPO)
- DMEA Accredited Trusted Suppliers
  - Design through package parts
  - Roughly 63 accredited suppliers
- Legacy Parts – know your supply chain
  - SRI, Lansdale Semiconductor
- Counterfeit Detection – Verification/Validation
  - Several government and commercial services
  - Fairly straightforward methods
  - Counterfeiters adapt to detection techniques
    - Cloning detection – challenging



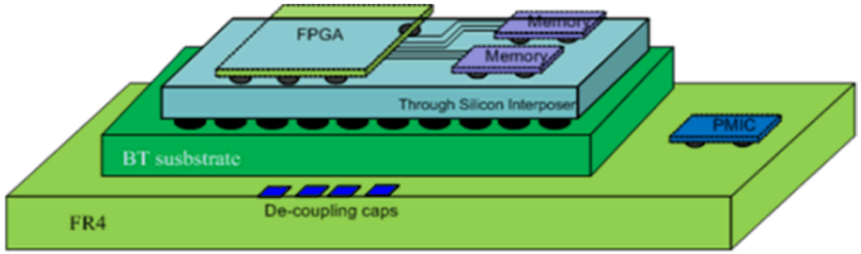
Trust Solutions Tomorrow

- DMEA accredited, Trusted Microsystems suppliers will continue
  - In a challenging environment manufacturers continue to move off-shore or shut down
  - Manufacturer consolidation increases foreign ownership
  - Access to trusted state-of-the-art microelectronics is in jeopardy
- State-of-the-art moves off-shore or is foreign owned – How to mitigate?
  - IARPA – TIC: Split BEOL/FEOL manufacturing flow
  - SHIELD: Provide a secure hardware root-of-trust which co-packaged with an electronic component
  - CRAFT: Significantly increase reuse of integrated circuit elements (IP)
  - Diverse and Accessible Heterogeneous Integration: Manufacturing a device across multiple commercial locations while concealing its functionality
- Areas of Opportunity
  - Trust Metrics – when to use what
  - Trust Resiliency
  - Obfuscation Techniques
  - Fast Assurance Techniques

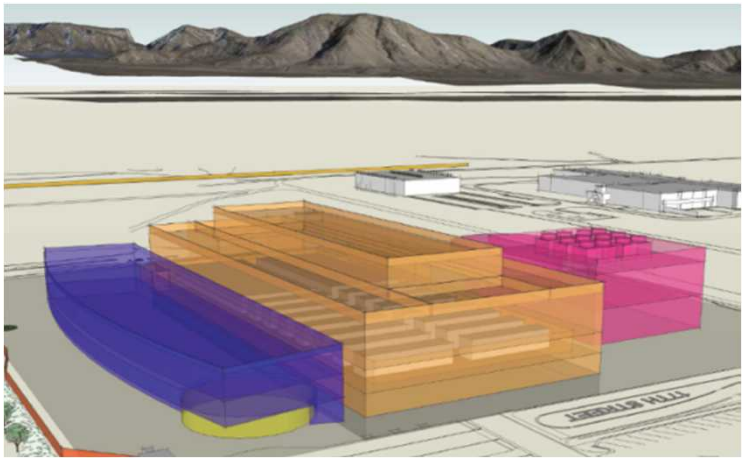
Sandia's Trust & Strategic Rad-Hard Futures

- Developing 180/150nm Technology
  - Based on BAE's technologies, but on SOI
  - Upgrading our silicon fab to process 200mm wafers
  - Strategic hardness with improved speed and density
- Planning a Future Capability
  - Can CMOS be strategic rad-hard at 90nm?
    - Sweet spot identified by customers for both analog and digital applications
    - Tradeoffs in cost, yield, and performance need to be addressed
  - Includes CMOS fab, advanced packaging, design, and test
  - Should it be scalable to 300mm?
    - Possibly for split-fab back-end-of-line
  - Expanded R&D capabilities
  - Heterogeneous Integration

MESA Complex



Stacking & Heterogeneous Integration



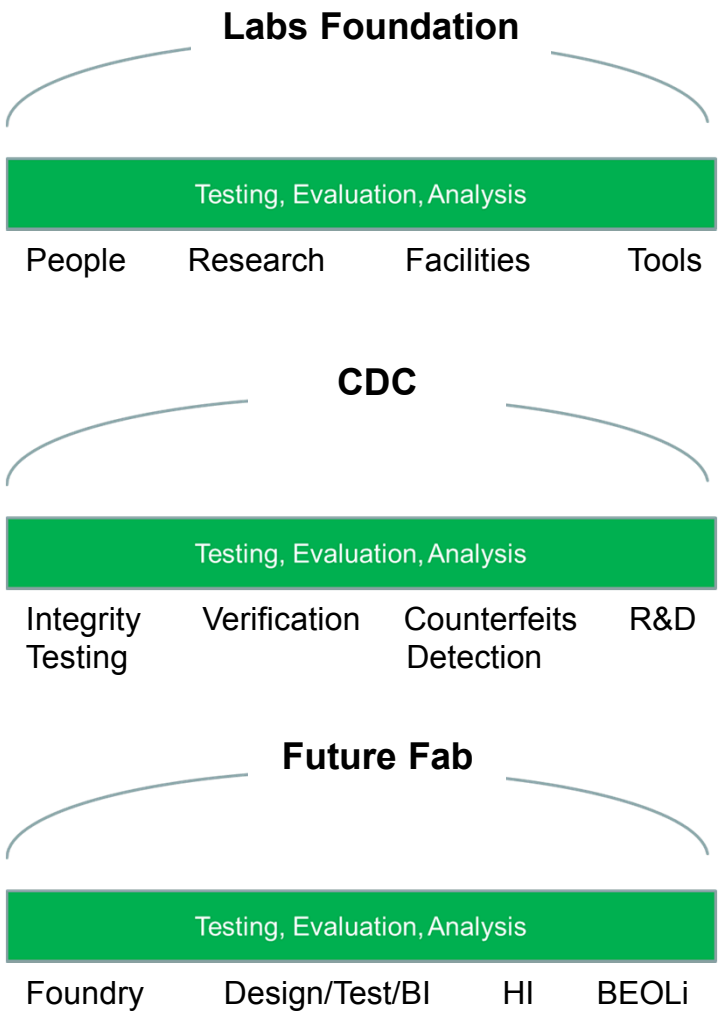
Next Generation Facility

For NW, Trusted Services Alone is Not the Answer

- A holistic approach is required for microelectronics
  - Fortification of the Supply Chain - Pedigree
  - Verification & Validation that the part does nothing more and nothing less than intended reliably
  - Assurance that what you designed is what you get - ASIC
  - Deterrence of Malicious intent – through attribution, policy
  - Cradle to Grave verification
- Research & Development, Advanced Capabilities & Talent are necessary
  - RHBD techniques
  - New RHBP methods
  - Materials
  - Imaging Techniques
  - Data Processing
  - Packaging
  - Assessments
  - Software Engineering
  - Red Teaming

Counterfeit Detection Center (CDC)

- An R&D facility that deals with counterfeit detection supporting SNL mission areas



R&D Enables and Sustains Sandia's Rad-Hard Microelectronics/Microsystems Capability

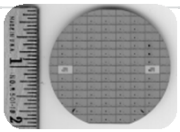
Sandia National Laboratories

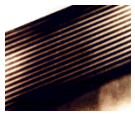
Impact

Research

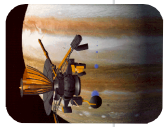
Facilities


Establishment of Research Program (1956)

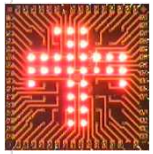

Radiation-Hardened CMOS (1975)

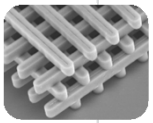

Strained Superlattice (1982)


B83 (1982)

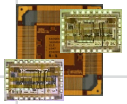

Design/Build Galileo ICs (1985)


5-Level MEMS (1995)

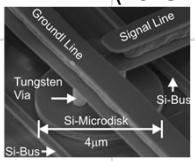

VCSEL (1995)


Photonic Lattice (1998)

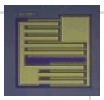

Burst Detection (2004)


RH ASICs for W76-1 & W80 (2005)


Ion Trap (2005)

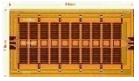


Si Phot (2009)


W80 HBT (2006)

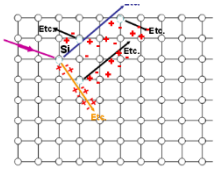

ViArray (2009)


MEMS W80 JTA (2011)


GaAs, InP uElect (2013-2021)

RH uelectronics (2013-2021)


Laminar Flow Clean Room (1960)



Ion-Implantation Science (1970s)

First RH Lab (1972)

SDL Fab (1976)

CRM (1983)

CSRL (1986)

MDL Si Fab (1988)

MESA Micro Fab (2006)

MESA Si Tools (2005)


Trusted Foundry (2009)

Si Fab Revitalization (2012-2018)

RH Foundry/CHIP² (2027)

Product Deliveries & R&D for 40 years
>370 Active Patents
42 R&D 100 Awards
Commercial Spinoffs
Seminal Rad-Hard Microelectronics & Photonics Contributions

1958 1970 1980 1990 2000 2010 2020 2030

MISSION: Invent and mature integrated circuit and microsystems technologies that provide differentiation and impact for NW and other national security missions

Summary

- Electronics must withstand radiation to minimize the possibility of malfunction in both space and nuclear weapon environments
- Solutions include Radiation-Hardened By Process and Radiation-Hardened By Design, sometimes both
- Solution space is small
- The supply chain is circuitous, therefore raising concerns about the integrity of parts
- There are many rad-hard trusted foundries, although the solution also includes design, supply chain and manufacturing
- There is ongoing R&D to ensure the creation of trusted circuits and a secure supply chain
- We propose to define foundational techniques for supporting analysis of trustworthiness, and for improving trust through diversification.
- The future of trusted rad-hard technologies is uncertain, however, Sandia is engaged in creating solutions
- Measuring and engineering trust presents difficult research problems with national-scale impact. Sandia is ideally suited to address these complexities due to its long history of developing highly reliable systems and understanding nation-state threats

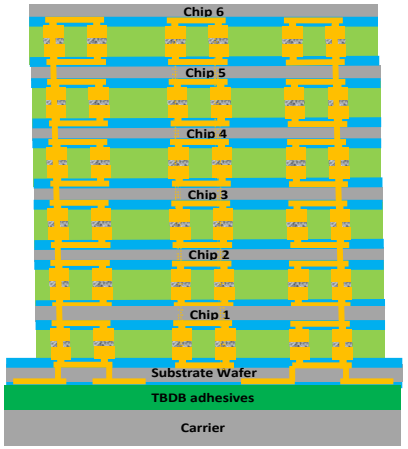
Extra Slides

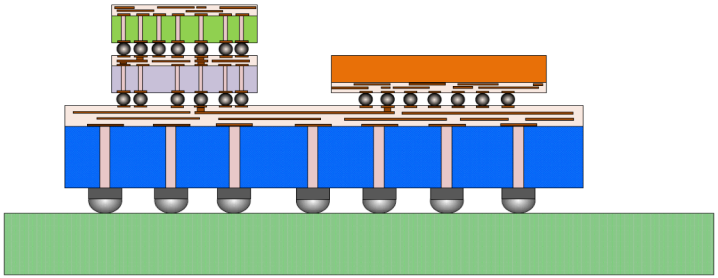
Sandia National Laboratories

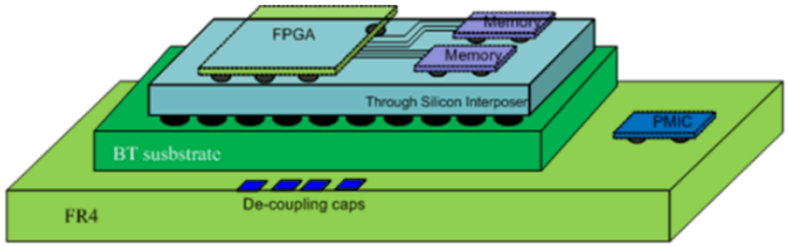
2.5-D and 3-D Solutions

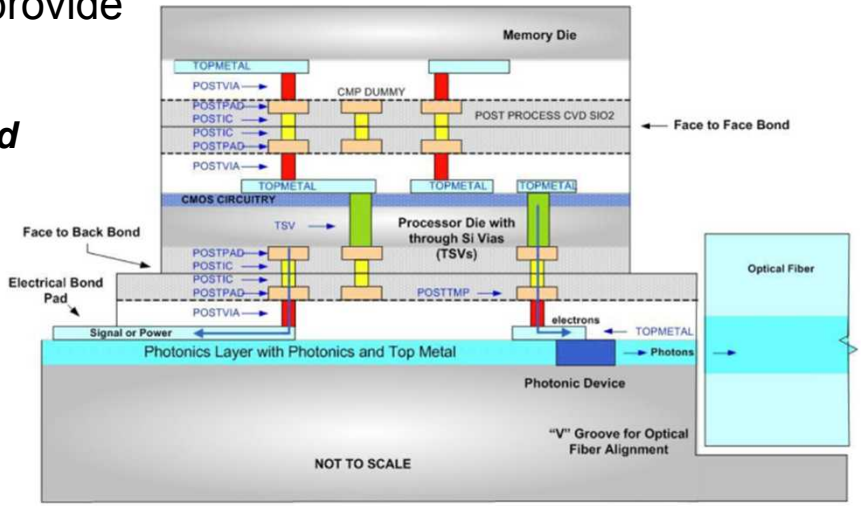
- Chip stacking can be used to increase the effective areal density. For example, stacking multiple rad-hard CMOS chips manufactured at the 180-nm node could provide the same or better functionality and footprint compared to a single chip manufactured at the 32-nm node, but at reduced production cost.
- 2.5-D integration combine disparate technologies on a single substrate.
- 3-D heterogeneous integration can be used to combine traditional rad-hard ICs with photonics, compound semiconductors, and MEMS components to provide new functionality.

All of these techniques can be used to create trusted systems out of untrusted components.









Schematic of a potential 3D stacked photonics, processor, and memory structure

Sandia Addresses National Security Challenges

Sandia National Laboratories

Sandia's Mission: Our unique mission responsibilities in the nuclear weapons (NW) program create a foundation from which we leverage capabilities, enabling us to solve complex national security problems.

1950s	1960s	1970s	1980s	1990s	2000s	2010s
Nuclear weapons	Development engineering	Multiprogram laboratory	Missile defense work	Post–Cold War transition	START Post 9/11	LEPs Cyber, biosecurity proliferation
Production and manufacturing engineering	Vietnam conflict	Energy crisis	Cold War	Stockpile stewardship	National security	Evolving national security challenges

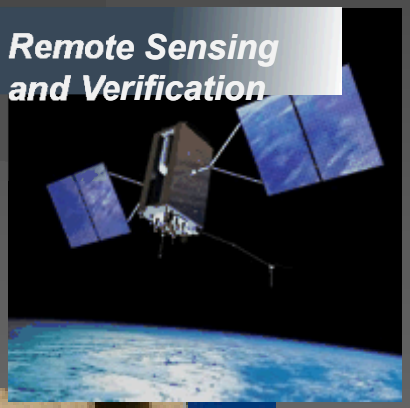
Defense Systems & Assessments Programs

Sandia National Laboratories

Information Operations

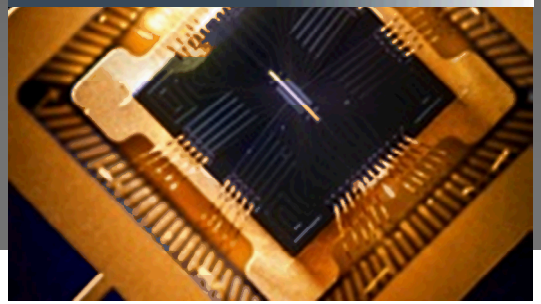
Surveillance & Reconnaissance

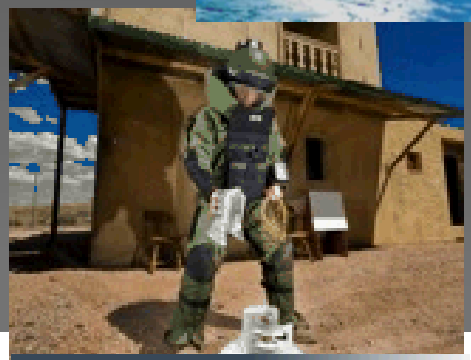
Remote Sensing and Verification



Space Mission

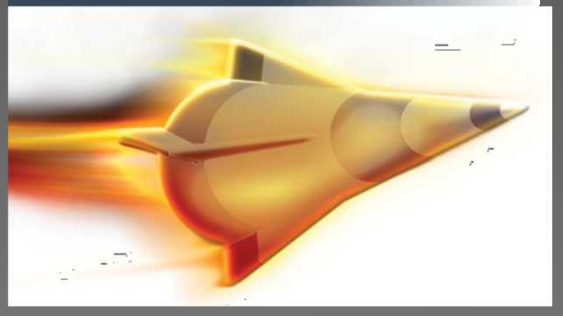
Science & Technology Products





Proliferation Assessment

Integrated Military Systems



Counterfeit Detection Center

- Expertise in Si CMOS, III-V, MEMS, and Optoelectronics
  - Component and now board-level
- Sandia developed techniques now industry standards (LIVA, TIVA, SDL, etc.)
- Deprocessing, and build analysis capabilities
- Support through entire product life cycle
- Extensive reliability & FA capabilities, equipment, tools, & techniques