SAND2014-1294P

SNL Capabilities

With a Focus on Electrical Sciences

Boeing
February 20th, 2014

Steve Glover

Electrical Sciences and Experiments Department Manager

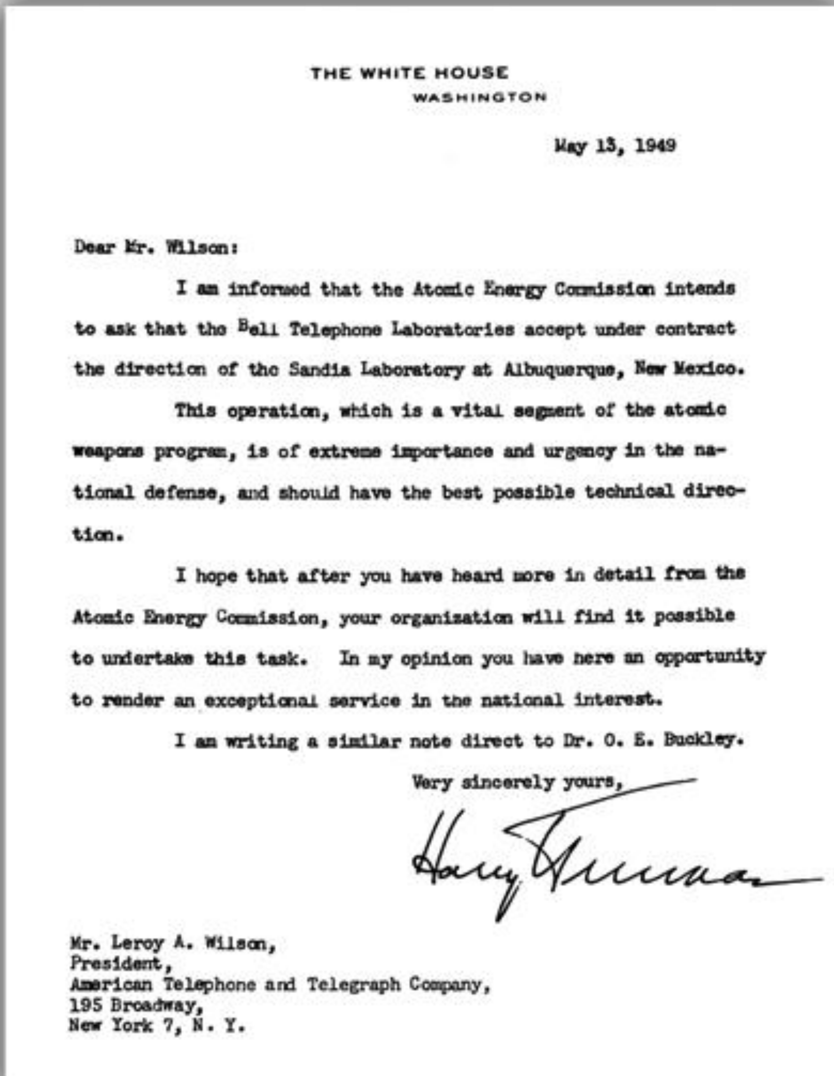
Sandia National Laboratories
Albuquerque, NM 87185

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Outline

- Sandia National Laboratories
- Electrical and Radiation Sciences
- Electrical Sciences Group
- Electrical Sciences and Experiments Department
  - Component aging
  - Counterfeit components
  - Hypersonic wind tunnel research
  - Thermal research
  - Lightning research
  - Wire insulator degradation
  - Experimental electromagnetics
  - Advanced power systems and renewable energy
- Conclusion

Sandia's History



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

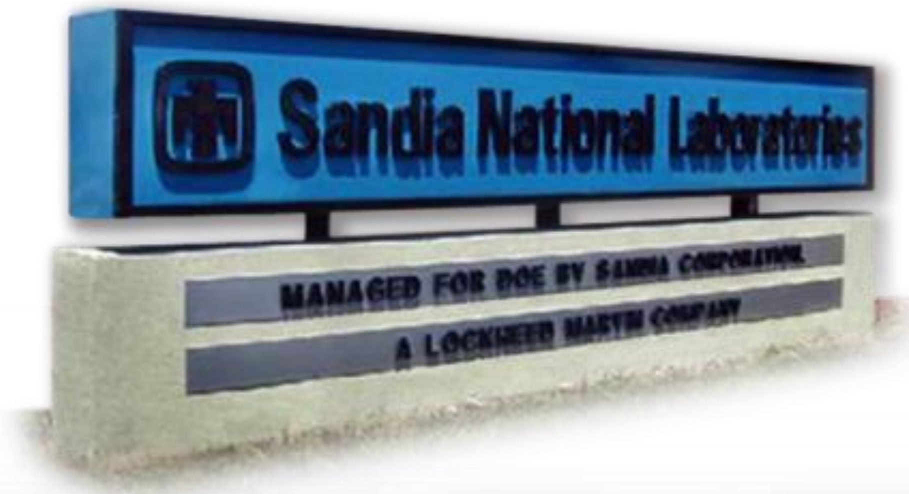
Mr. Leroy A. Wilson,
President,
American Telephone and Telegraph Company,
195 Broadway,
New York 7, N. Y.

Sandia is a Multidisciplinary National Security Laboratory

- **Sandia develops technologies to:**
  - Sustain and modernize the nuclear deterrent,
  - Prevent the spread of weapons of mass destruction,
  - Protect the national infrastructure,
  - Defend the national against terrorist threats,
  - Provide new capabilities to the armed forces, and
  - Ensure the stability of the nation's energy and water supplies.

Sandia's science, technology, and engineering help ensure that the nation maintains technological superiority and preparedness, which are critical to national defense, homeland security, and the nation's economic well-being.

Sandia’s Governance Structure



Sandia Corporation

- AT&T: 1949–1993
- Martin Marietta: 1993–1995
- Lockheed Martin: 1995–present

Government-owned contractor-operated

Federally funded research and development center

Sandia National Laboratories

Sandia's Sites

Albuquerque, New Mexico

Carlsbad, New Mexico

Tonopah, Nevada

Livermore, California

Amarillo, Texas

Kauai, Hawaii

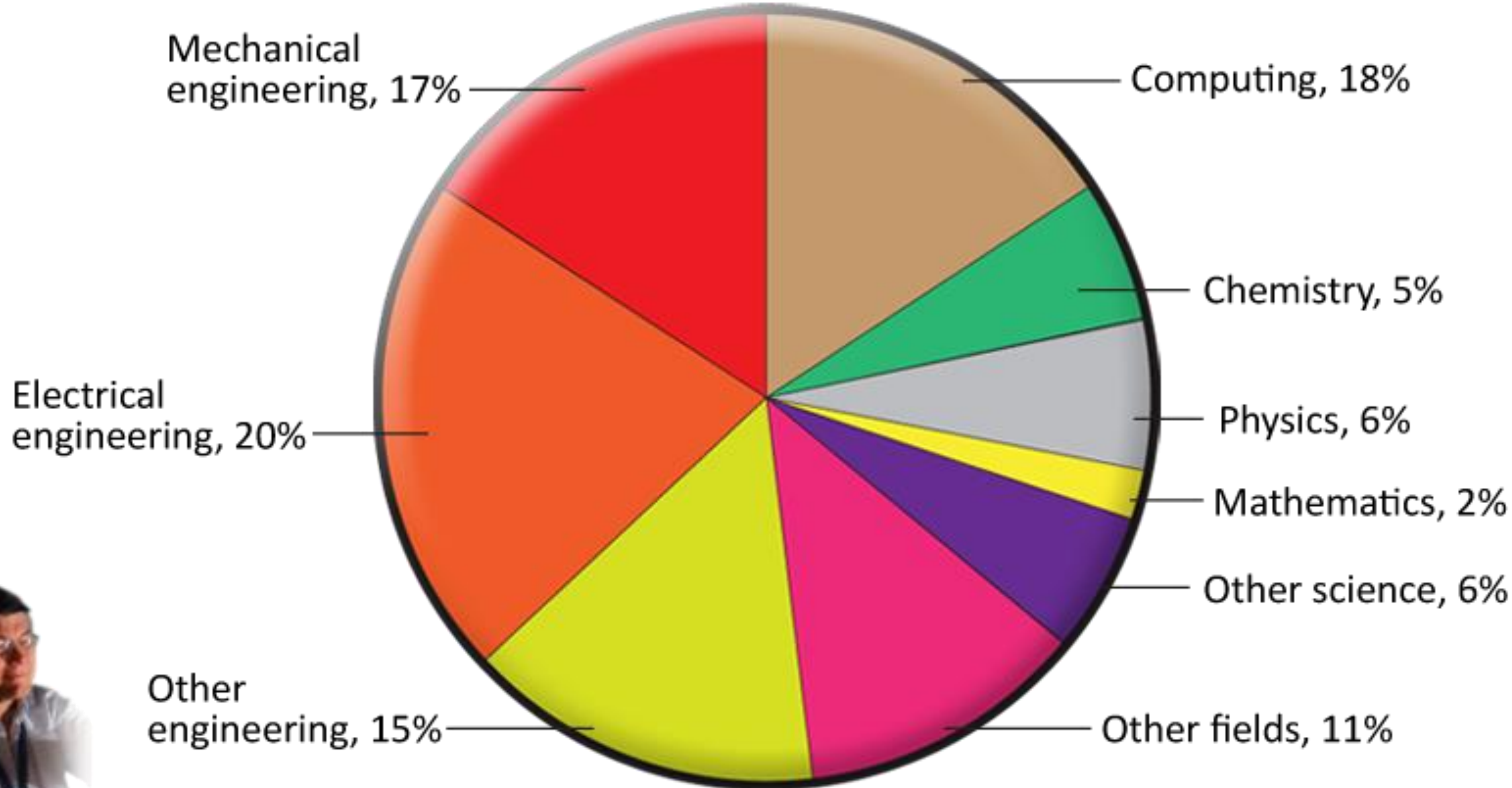
Our Workforce

~170 Purdue alumni

- **Onsite workforce: 11,711**
- **Regular employees: 9,238**
- **Gross payroll: ~$981M**

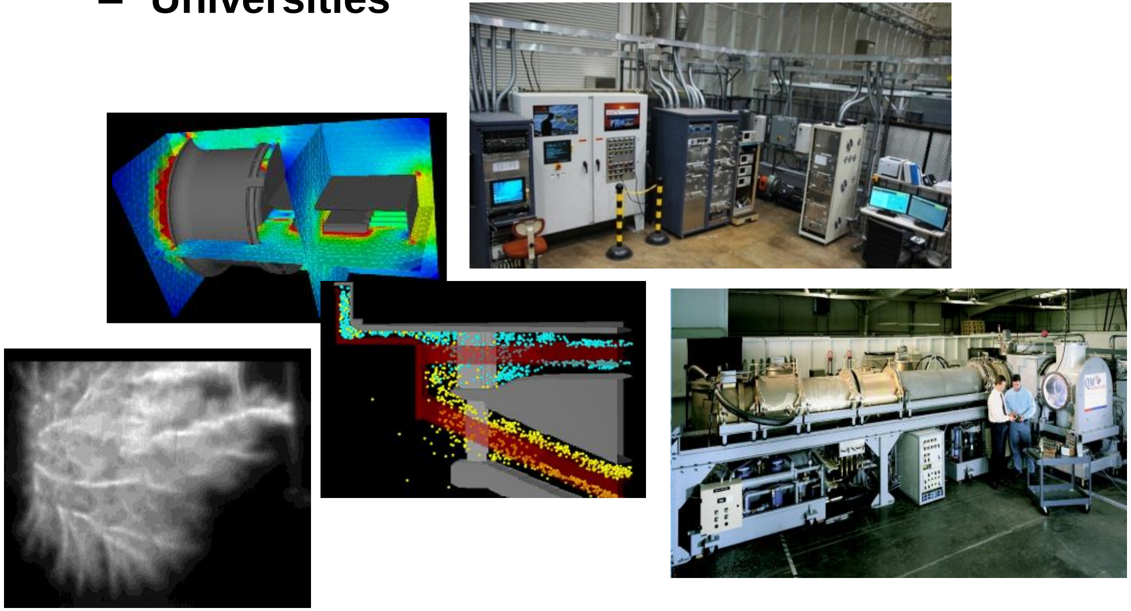
Data for FY12 through end of September

Research & Development staff(4,682) by discipline

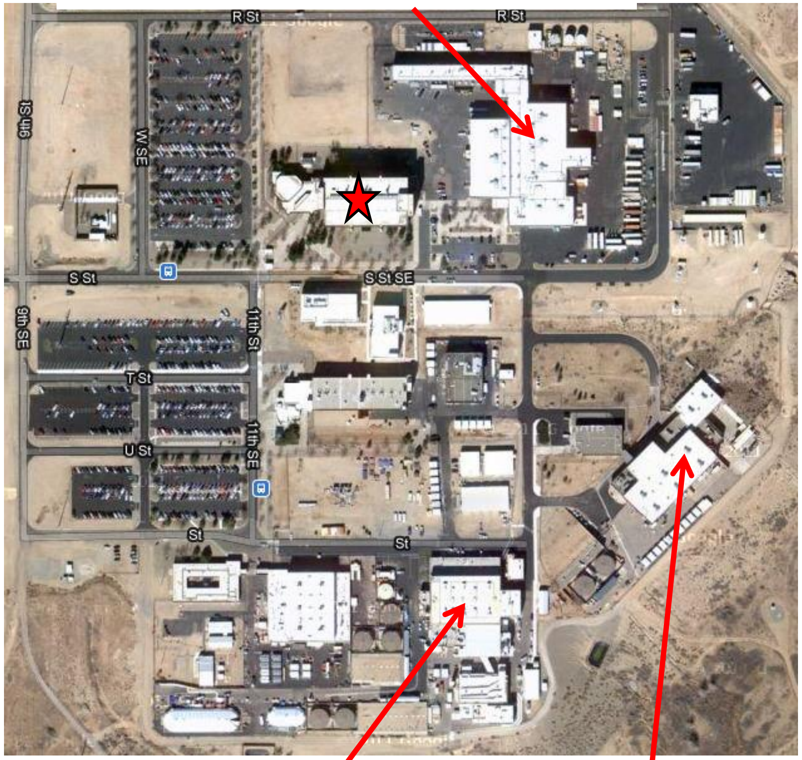


Electrical and Radiation Sciences Customers and Organization and Facilities

- **National security activities for and in collaboration with:**
  - **Department of Energy** (National Nuclear Security Administration, Office of Science, Office of Electricity)
  - **Other federal agencies** (DOD-Army/USAF/NRL, DOT-Federal Aviation Administration, DOL – Mine Safety and Health Admin.)
  - **Non-federal entities**
  - **Industry** (Goodyear, FMC, Inc., Lockheed Martin Technology Research)
  - **Universities**



HAWK
World's largest DC-like electron beam accelerator



Z Machine (350 TW, 26 MA)
World's most powerful radiation source for fusion, dynamic materials and radiation effects sciences

Hermes III
Flash x-ray source for nuclear weapons effects testing

Sandia's Electrical Sciences Group

1350
Electrical Sciences
Larry Schneider

Financial/Space: Robert Petro, 10616 manager
Financial support: Renee Sisneros, 10616
OAAs: Bev Rudys, Peggy Aragon

1352 Electromagnetic Theory — Bryan Oliver

- EMPHASIS Code Development
- SGEMP, EMP, EMR
- Electrical Breakdown
- NW System Qualification

11 SNL tech staff (9 PhD)*
1 Staff Aug
Total:12

1353 Electrical Science & Experiments — Steve Glover

- Electromagnetic Experiments
- NW System Qualification
- High Voltage Sciences
- WFO Programs

8 SNL tech staff (5 PhD)*
6 SNL technicians
7 Contractors
Total: 21

1355 Electrical Models & Simulation — Scott Hutchinson

- Xyce Code Development
- Charon Code Development
- Physics & Model Development
- Application Analysts

11 SNL tech staff (12 PhD)*
1 Staff Aug
1 Contractor
Total: 13

1356 Component & System Analysis — Steve Wix

- Device Model Development & Extraction
- Test & Characterization
- Mixed Signal Analysis

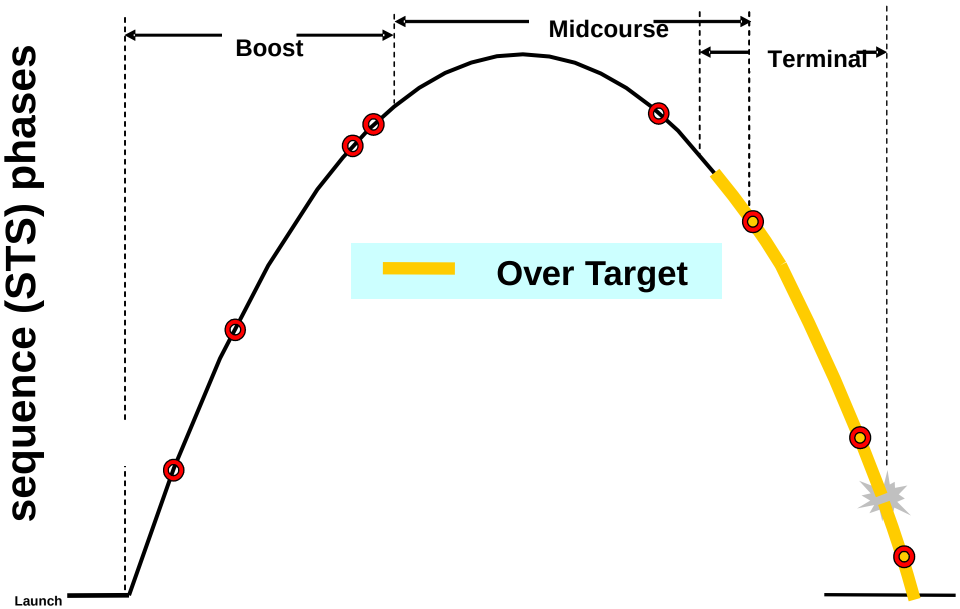
3 SNL tech staff (1 PhD)*
2 SNL technicians
2 Contractors
Total: 7

*Includes managers

Electrical Sciences Group Total:
42 SNL (34 tech staff (27 PhDs), 8 technicians)*
10 Contractors
2 Staff Aug
2 Admin
56 total

Nuclear Weapons Stockpile Responsibilities Drive Deep Expertise in Grid-relevant Science and Engineering

All stockpile-to-target-sequence (STS) phases



Physical Environments

- **Weapon storage, transportation, maintenance, storage on delivery platform, launch and in-flight path**
- **Normal Environments** (EMR, ESD, nearby lightning, degaussing)
- **Abnormal Environments** (lightning, exposure to power sources)
- **Hostile Environments** (nuclear weapon effects, directed energy weapons, high power microwaves)

System & Components

Grid-relevant Science and Engineering at Sandia

- Advanced power systems and AC/DC microgrids
- High voltage breakdown science & experiments
- Pulsed power components and systems development
- Electromagnetics theory/code development
- Electromagnetic experiments
- Systems engineering and integration

Other Capabilities include

E-beam supported wind tunnel and high heat flux research

Sandia National Laboratories

Electrical Sciences Have Been Consolidated to Strengthen Stewardship of Key NW Capabilities

Circuits, Devices, Atomistic / Sub-scale

Electrical System Modeling

Coupled EM and Full System Models, EMP

Electromagnetic Effects

EMR, EMI, EMP, HPM, ESD, Lightning

Codes: Xyce CHARON Habanero

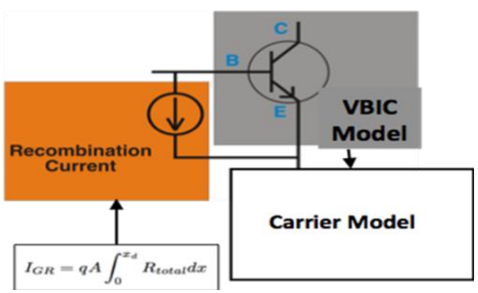
SANDIA NATIONAL LABORATORIES ELECTRICAL SCIENCES

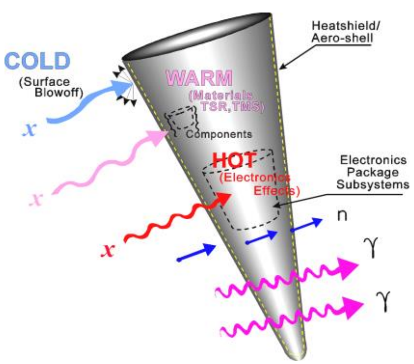
Code Suite: EMPHASIS

Qualification Alternatives without Pulsed Reactors (QASPR)

System Generated EMP (SGEMP)

Radiation Effects





Consolidates RAMSES Code Suite development in Center 1300 (NuGet, Xyce, Charon, ITS, SCEPTRE, EMPHASIS, Habanero)

Department 1356 Component and System Analysis Organization

Device Model Development

Model Extraction

Calibration/V&V/UQ

Aging

Physics of Failure Mathematical Models

Physical Simulation

Aging of Electronics

NW Component Surveillance

Part Characterization

Trust and Counterfeit Electronics

Future Growth

System-scale tools, capabilities and physical simulation (Habanero)

QASPR Engagement

Integrated Workflow

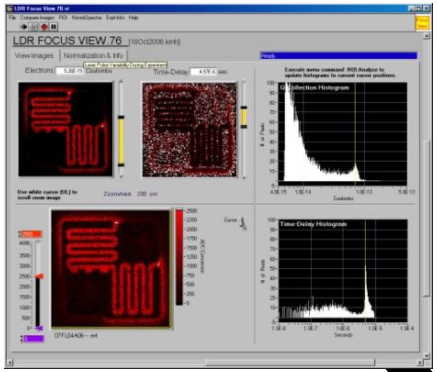
Infrastructure

Test & Evaluation Lab(862/3009)

1300/1600 Computing Resources (Design/Computational/Developer)

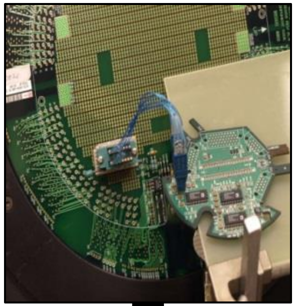
Customers include NW (W76, W88, W87, W80, B61), ASC, 1730 Components, WFO (Navy, JMP), QASPR, 1300 & 1600 Computational Community

Electrical Component Aging Behavior for Stockpile Assessment

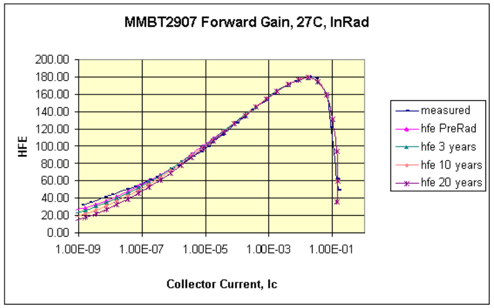


Laser Dose Rate Study

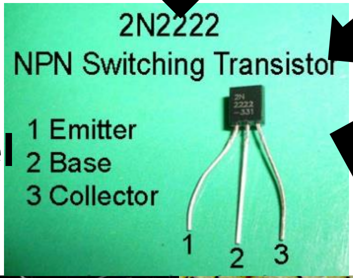
Field data

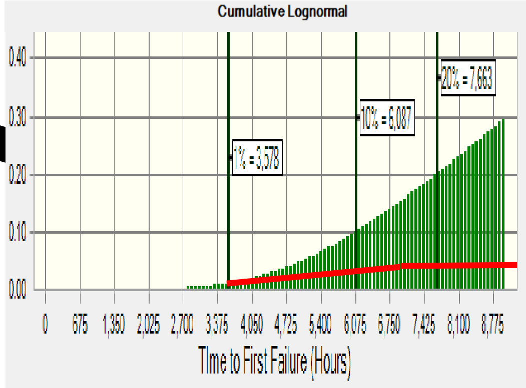


Mildly Accelerated Aging

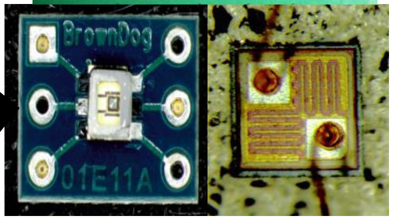


Predictive Radiation Aging Model



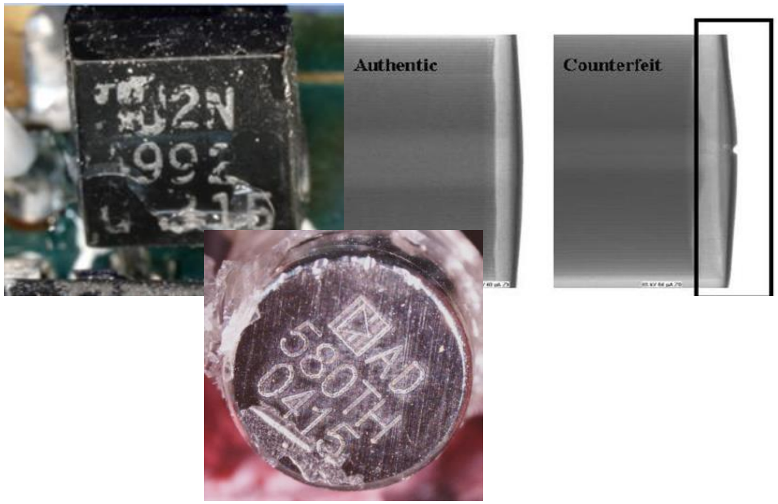


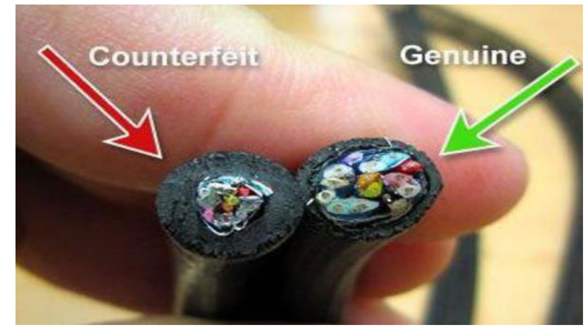
Life Model Validation



Tin Whisker Mitigation Evaluation

Department 1356 has expertise in Electrical Aging Physical Simulation





Suspect/Counterfeit Items Control: Best Practices Across Industry

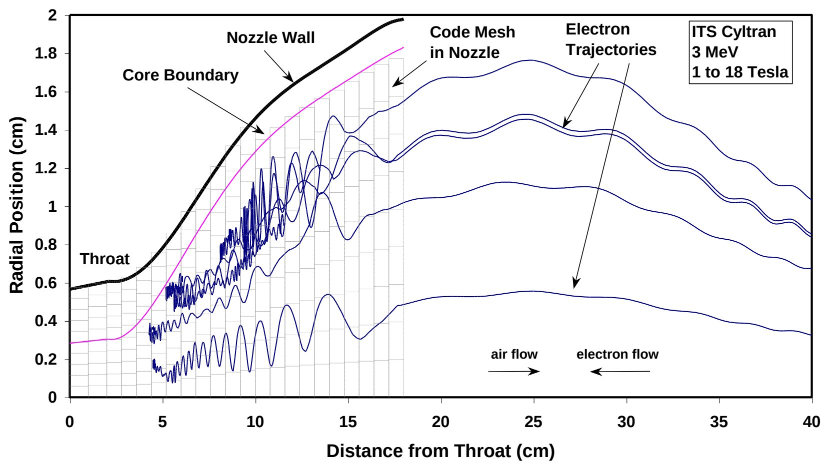
S. Wix, J. Sikkens, V. Halford and the members of the Sandia S/C Working Group

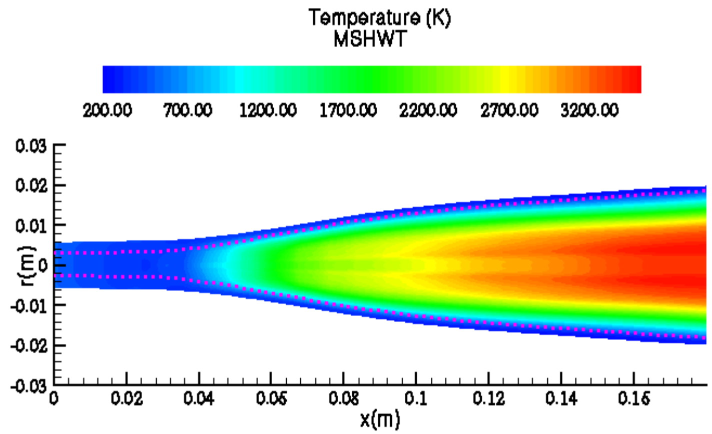
November 13, 2013

Department 1356 has expertise in Trust/Counterfeit Electronics

Modeling, analysis, validation experiments, Complex system design & integration

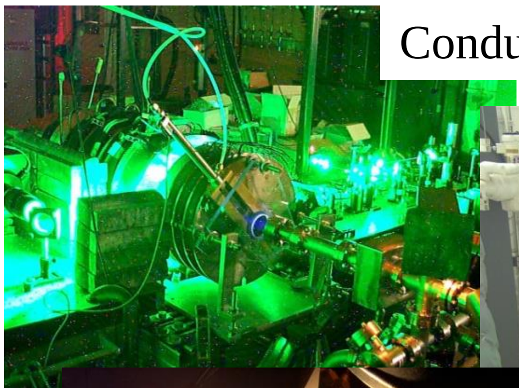
Coupled electron/photon Monte Carlo transport codes for energy addition and CFD

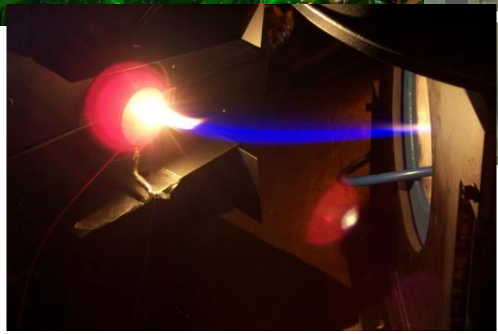




World class accelerator technology development

Conduct of complex experiments

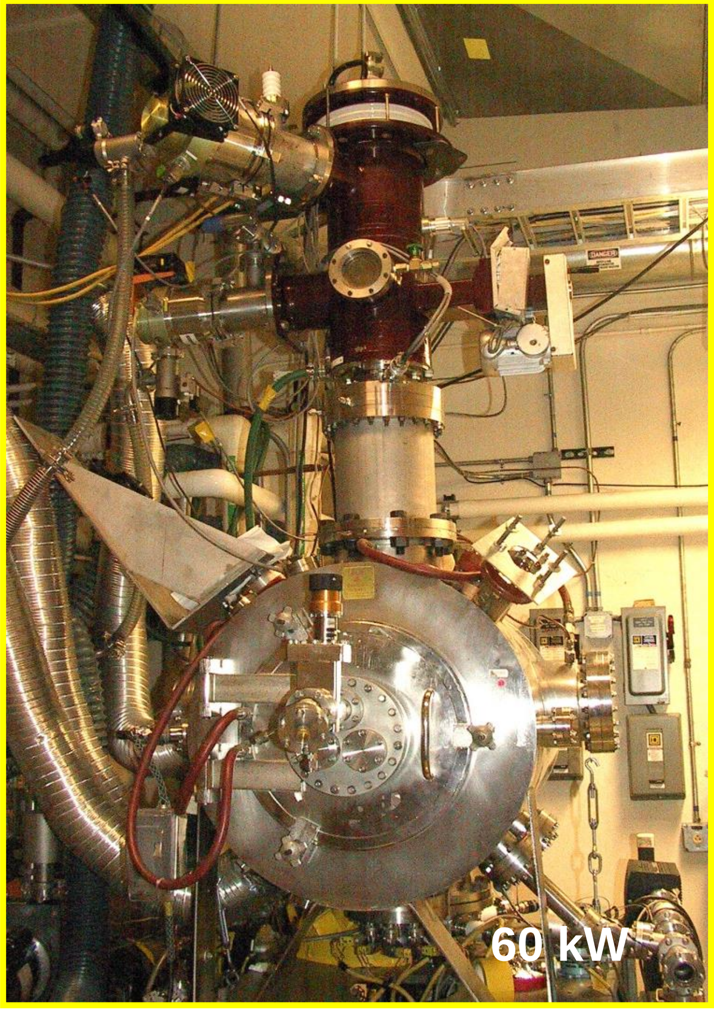




World's first large aperture vacuum window

Sandia National Laboratories

HHFF e-beams

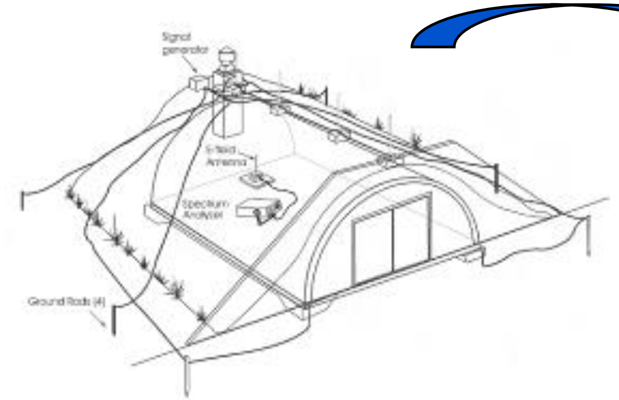


EB-1200

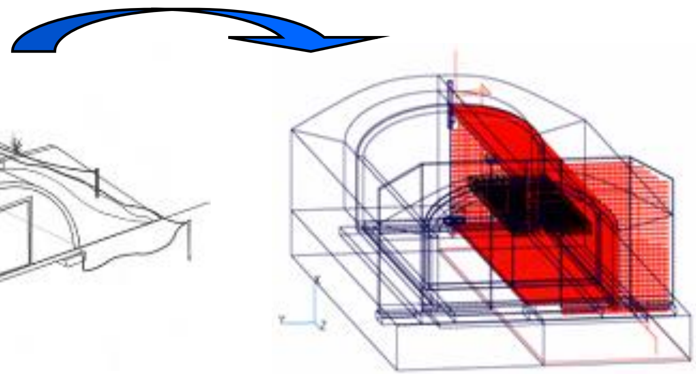
EB-60

Rigorous Lightning Protection Developed for DOE Nuclear Weapons Facilities

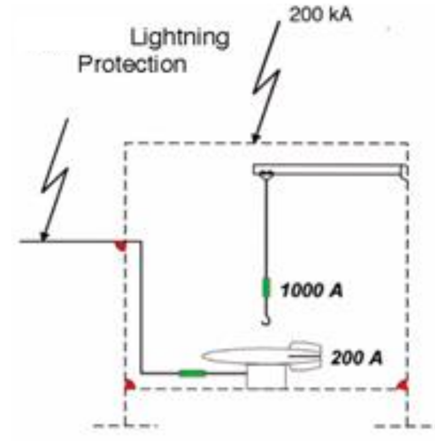
Lightning effects analysis, field transfer function measurements, engineered solutions for facility operations



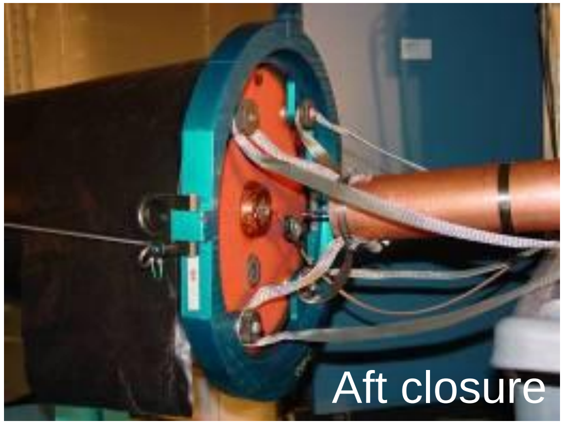
Field diagnostics/measurements



Modeling & analysis



High voltage standoff isolation



Weapons response to electrical static discharge

Past Example of Solving Problems Based on Techniques Developed for the Nuclear Weapons Complex: Mine Safety

Sago Mine -Upshur County, West Virginia

In January 2006, twelve miners perished as the result of a methane gas explosion in an abandoned mine shaft.

Report of Investigation
May 9, 2007 [1]

<u>Root cause:</u>

"Lightning was the most likely cause for this explosion with the energy transferring onto an abandoned pump cable …providing an ignition source for the explosion." [1]

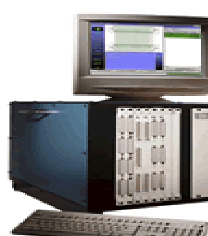
[1] R. Gates, et al., Fatal underground coal mine explosion, Mine Safety and Health Administration, Office of the Administrator, ID No. 46-08791, May 9, 2007.

In January 2006, twelve miners perished as the result of a methane gas explosion in an abandoned mine shaft.

Sandia-developed techniques and diagnostics demonstrated a first-ever link between a mine explosion and indirect coupled lightning.

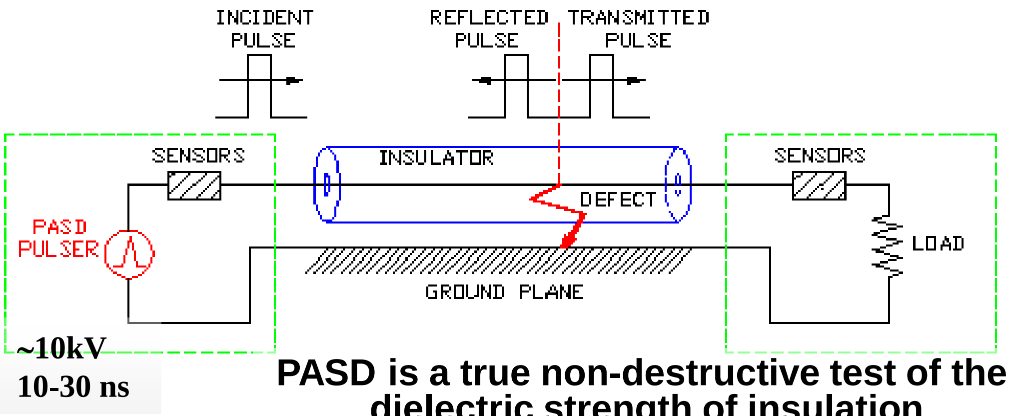
Sandia National Laboratories

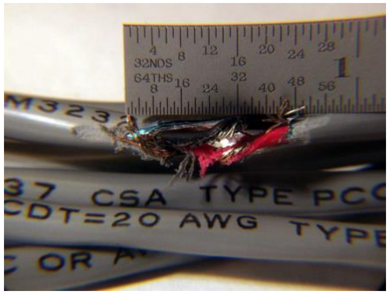
Wiring test bed developed for the evaluation of wiring diagnostics for commercial aircraft

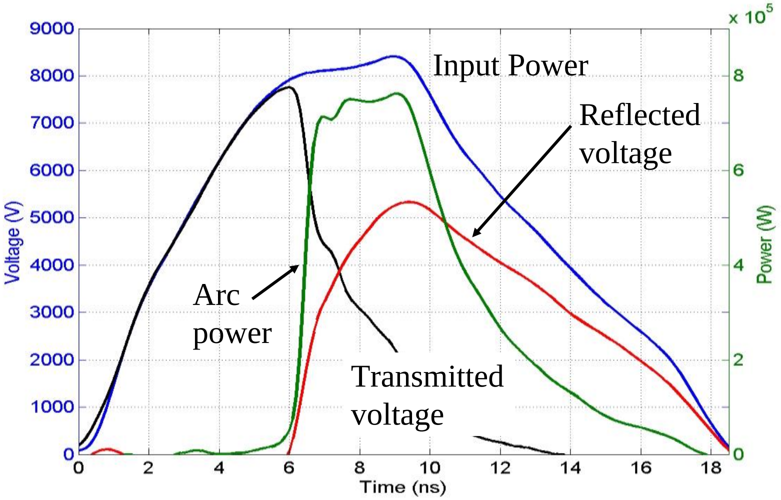


Another Example of Solving Problems Based on Techniques Developed for the NW Complex: Wiring Diagnostics

PASD can find and locate what no others can see – from pin-holes in the dielectric to crushed, but fully functional cables, waiting for a disaster to occur.



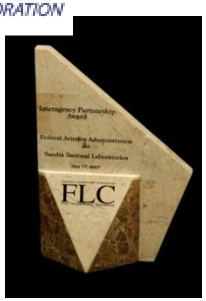




PASD is a true non-destructive test of the dielectric strength of insulation

Commercialized by

ASTRONICS CORPORATION

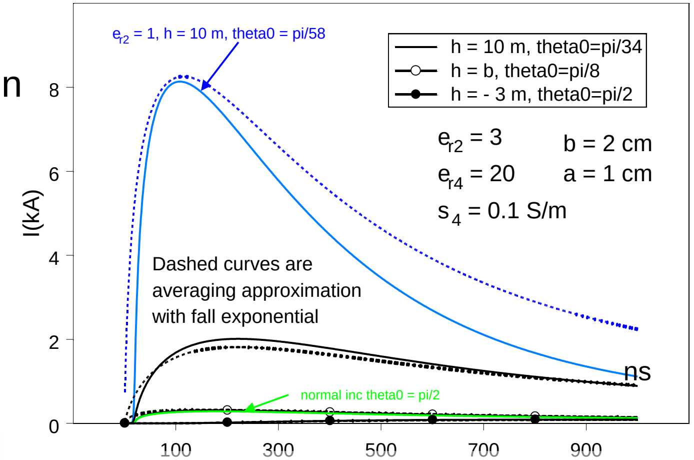


- Winner of Federal Laboratories Consortium Award for Interagency Partnering

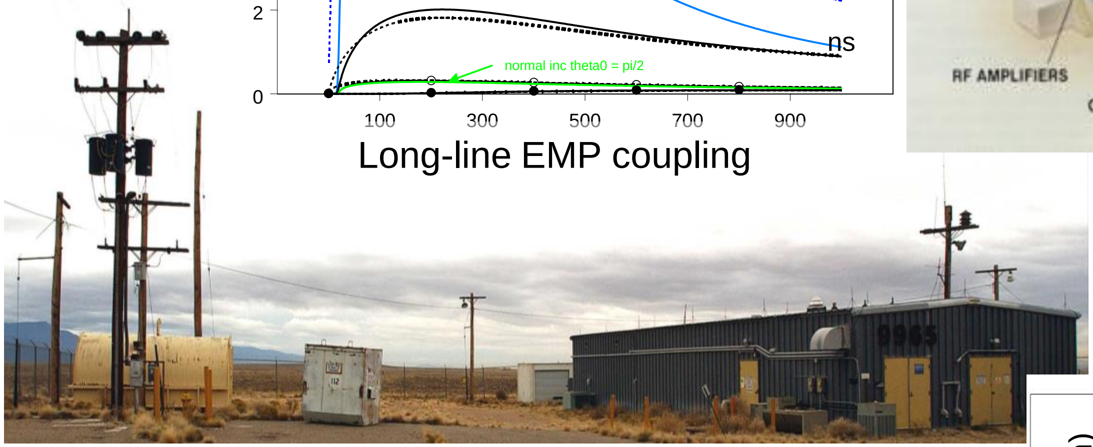
- Winner R&D 100 Award from R&D magazine

Support to the Congressional Commission on the impact of Nuclear ElectroMagnetic Pulse energy on power systems

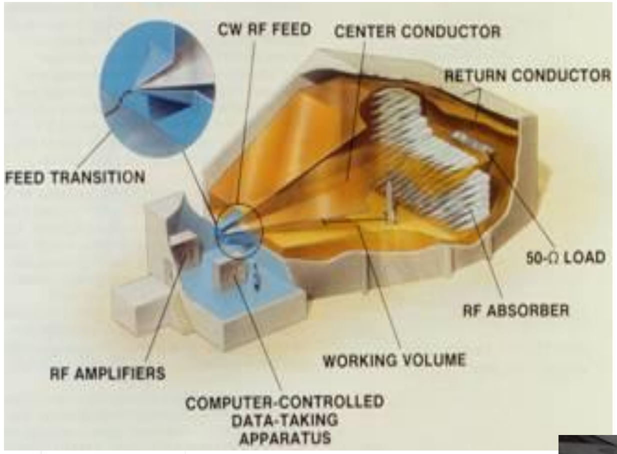
Warne / Chen

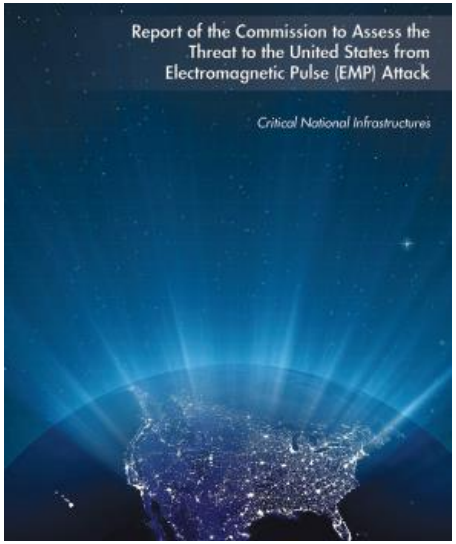


Long-line EMP coupling



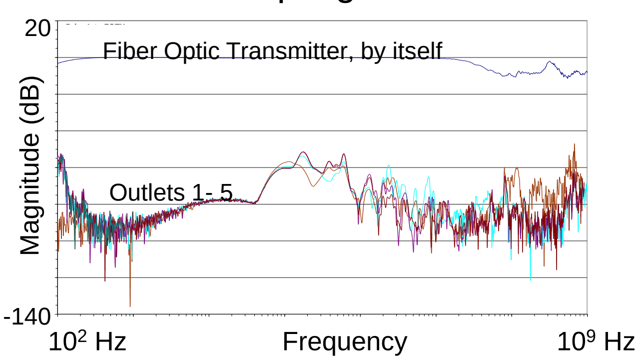
Large scale TEM cell with full threat EMP capabilities



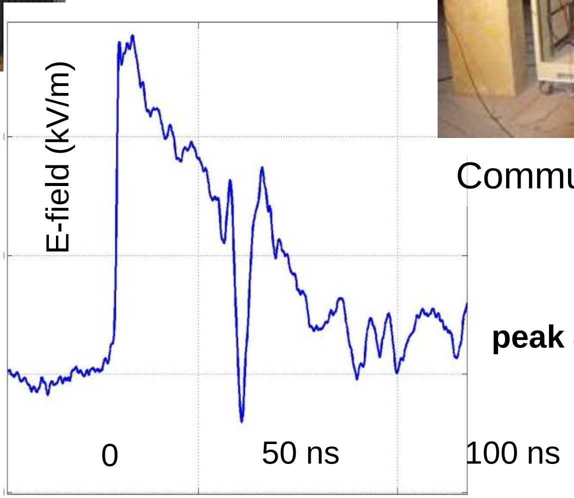


Communication Equipment

EMP coupling into facilities

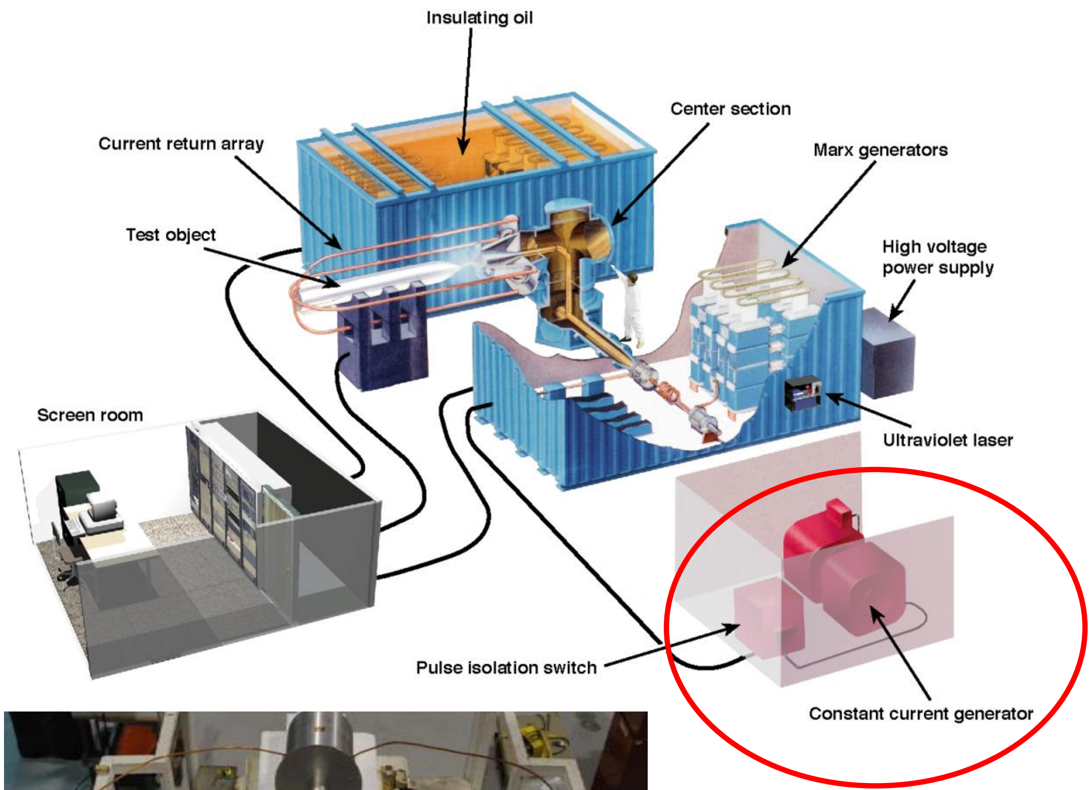


Typical EMES EMP waveform

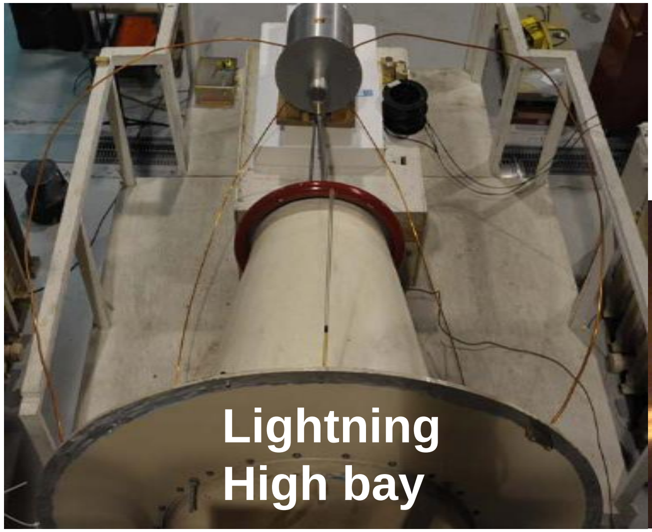


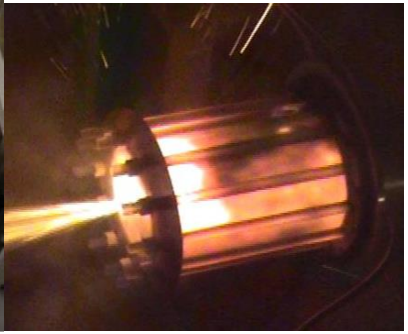
peak 30 – 250 kV/m

The SLS (building 888) simulates full-threat lightning with continuing current



CCG replacement in progress





Test volume:

- Bombs, RV/RBs or similar sizes

Environments:

- Full-threat lightning (direct-attach and nearby lightning)
- Dual-stroke, with or without continuing current

Specs:

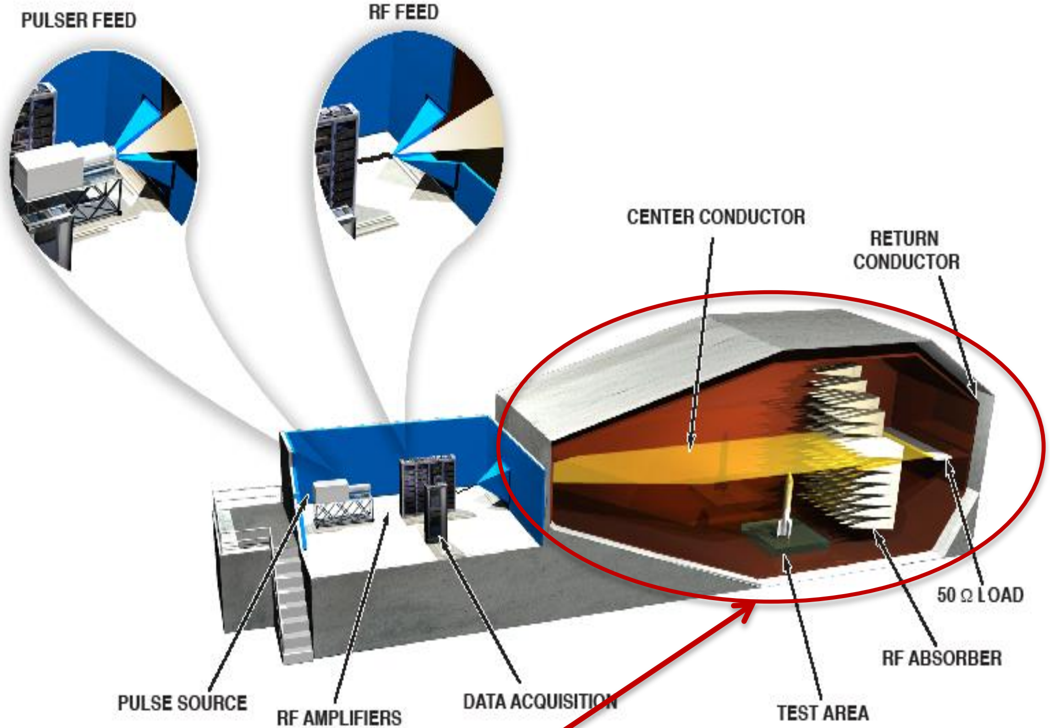
- Peak current – 200 kA (99th percentile)
- Min current – 30 kA
- Current rise time: 1 to 5 μsec
- Current rate of rise: 200 kA/μsec, max
- Pulse width (@50% level): 50 to 500 μsec (dependent on load impedance)
- Number of pulses: 1 or 2
- Variable pulse interval
- Continuing current 100s A for up to 1 sec

Capacity:

- 4 test/day (Max capability)
- 20/day (nominal)

ROM cost for small test series: $40K

EMES (building 871)



Test volume:
- 4x5x11 m

Environments:
- High altitude EMP: 30 to 250 kV/m
- Plane-wave RF (CW): 100 kHz – 100MHz at 125 V/m
- Rolls off to 100 V/m at the upper freq. limit of 250 MHz.

EMP Capacity:
- 2 shots/day (Max voltage)
- 4 shots/day (nominal)

ROM Cost for simple frequency scan: $5K

EMES was built in the 1970's and requires replacement of:
- **RF absorbers ($1.4M)**

Or, preferred:
- **Entire test cell ($3.4M)**

EMES Test area

Mode-Stirred and Anechoic Chambers can be operated up to 40 GHz (extension to 50 GHz TBD)

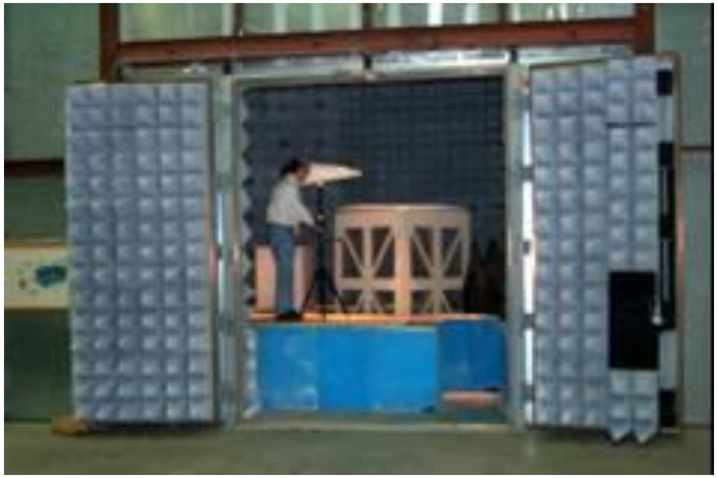
Mode Stirred Chamber

Test volume:
- 3x6x10 m (approx.)

Environments:
- Reverberant chamber, Q ~ 1,000,000,
- Statistical RF environments (modes, incidences, polarizations)
- Frequency range: 150 MHz to 40 GHz
  Field Strength:
    ~ 3000-9000 V/m peak, 220 MHz - 18 GHz
    ~ 600 V/m peak, 18 - 40 GHz

ROM cost of simple sweep: $5K

Anechoic Chamber

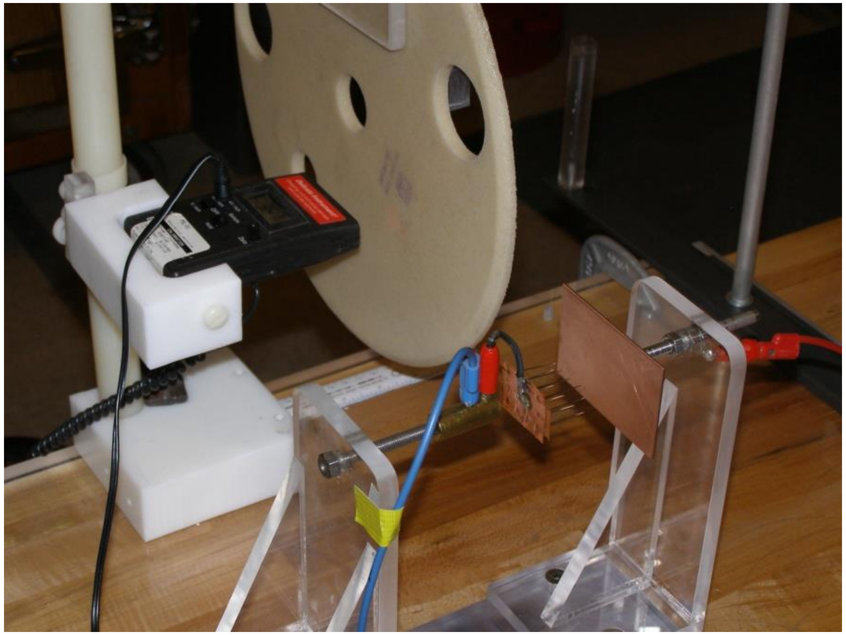


Test volume:
- Chamber: 5x7x10 m
- Turntable diameter: 2 m

Environments:
- RF, CW and Pulsed, 500 MHz – 40 GHz
- Turntable, with pan/tilt for objects < 70 lb
- Transmitter power:
    1kW, 500 MHz - 18 GHz
    40W, 18 GHz - 40GHz

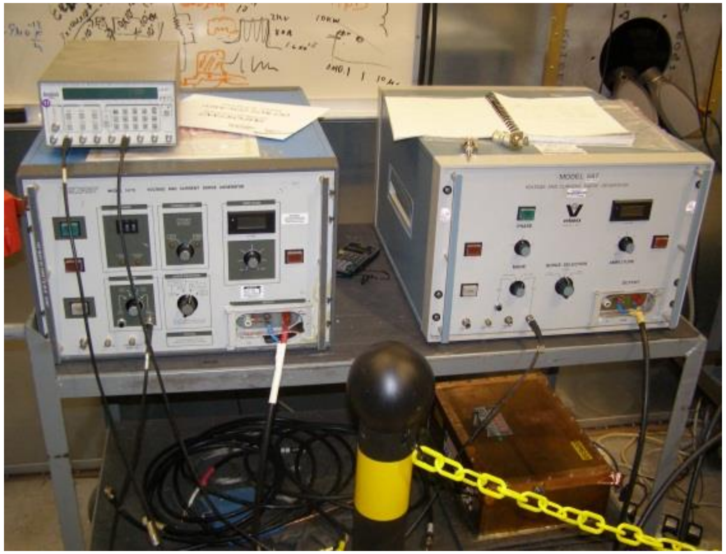
ROM cost of simple sweep: $5K

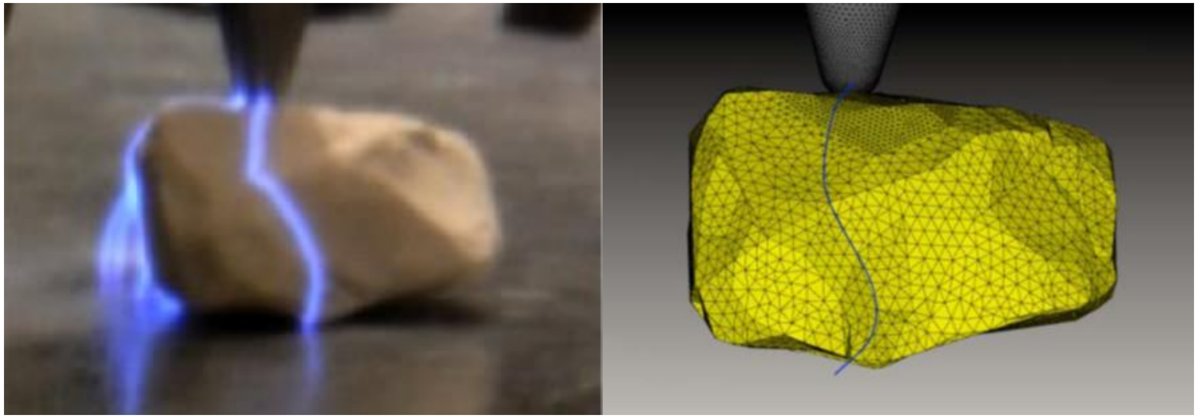
Electrostatic Discharge (ESD) Lab



Environments:
- Generally low energy and power
- ESD:
  - Generation, storage, and charge transfer effects
  - Can also perform field measurements
- Low-level lightning effects (1 or 2 pulse)
- Injected HV pulses and CW
- Humidity-controlled chamber
- Combined electrical/high-temperature environments for small objects

ROM costs for straightforward tests: $5-10K

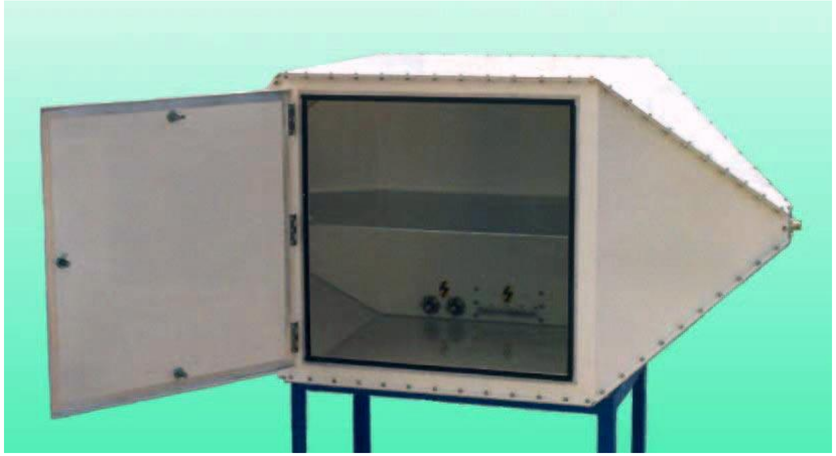




Odds and Ends in Building 963

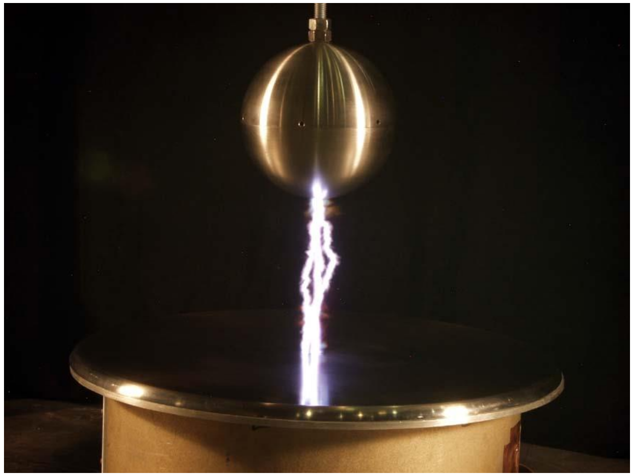
TEM cells for EM test and experimentation with small objects

- **Small TEM cell:**
  - **8 inch septum**
  - **DC – ?**
- **Medium TEM:**
  - **24 inch septum**
  - **DC – 125 MHz**
- **Medium GTEM:**
  - **0.75 m septum**
  - **DC to 18 GHz**



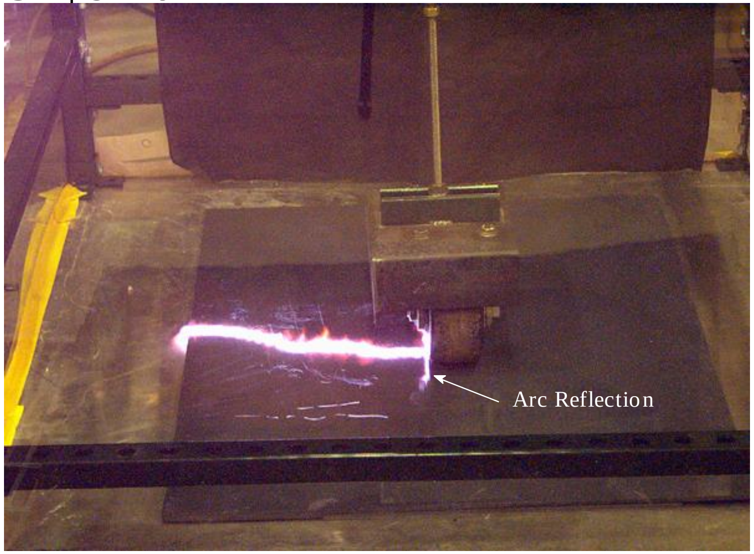
Magnetic fields from nearby lightning (dI / dt slightly low)

High Voltage Lab – DC and Impulse Testing



Capability:
- High voltage lightning standoff testing with DC and pulsed voltages
  - DC up to 200 kV
  - Impulse testing from 130 kV – 400 kV
- Certify components such as lifting straps, task hoses

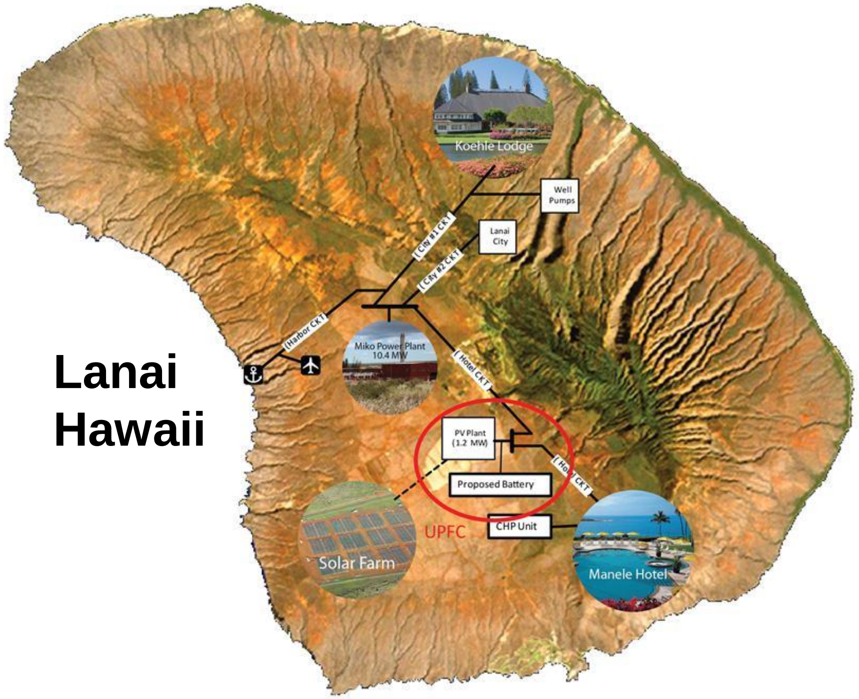
ROM cost for test series: $5-10K

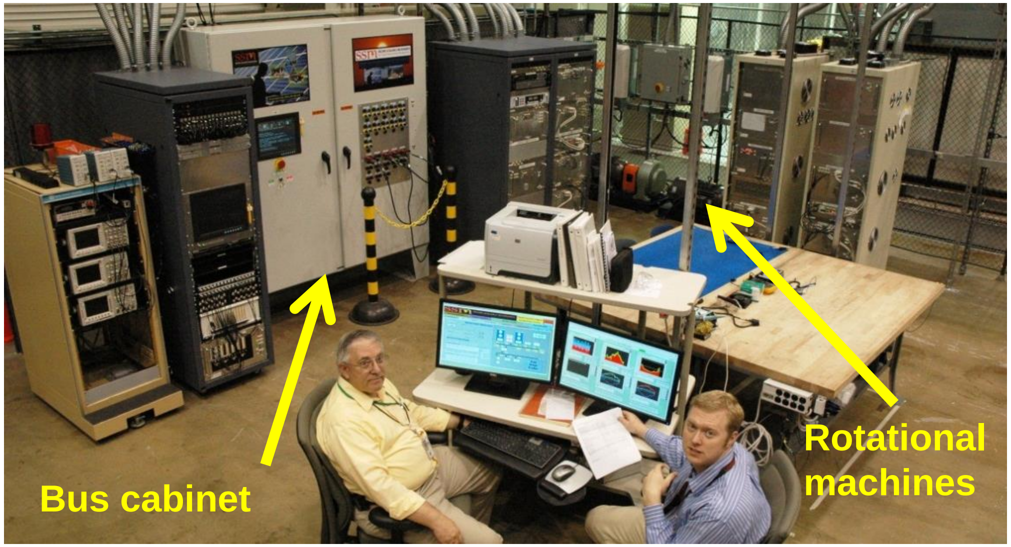


Networked, secure, scalable microgrids (SSM ™) enable high-penetration renewables and improved operations

- Ground breaking nonlinear control theory, informatics, and hardware.
- Tools are being developed for networked microgrids spanning from conventional to 100% stochastic generation.
- Potential impact:
  - **Unlimited use of renewable sources**
  - **Lower-cost provisioning at a given level of renewables**
  - **Reduction in centralized fossil fuel based sources**
  - **Self-healing, self-adapting architectures**
  - **Microgrids as building blocks for larger systems**
  - **Optimized network architecture with optimal energy storage**

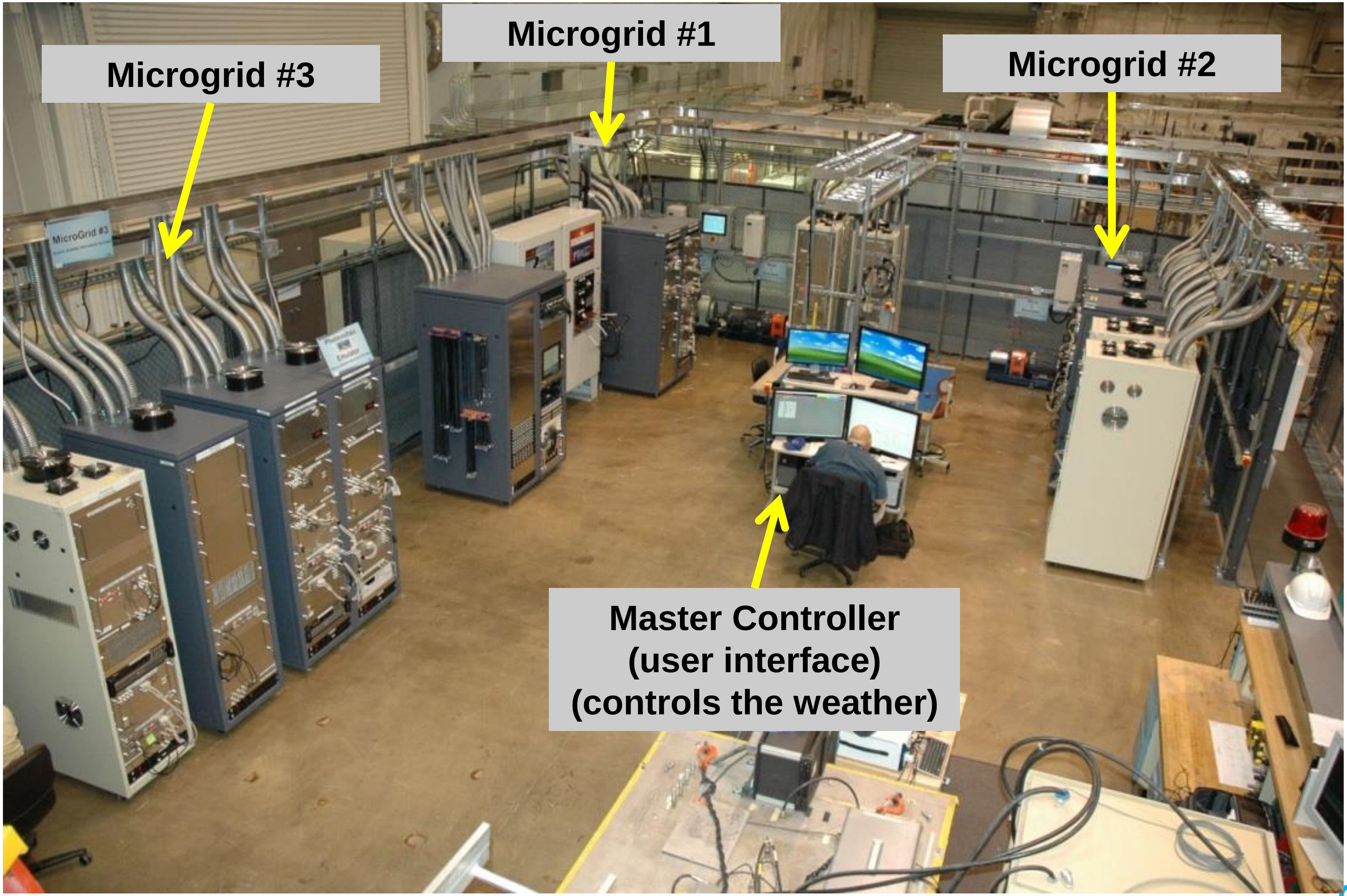
Lanai Hawaii



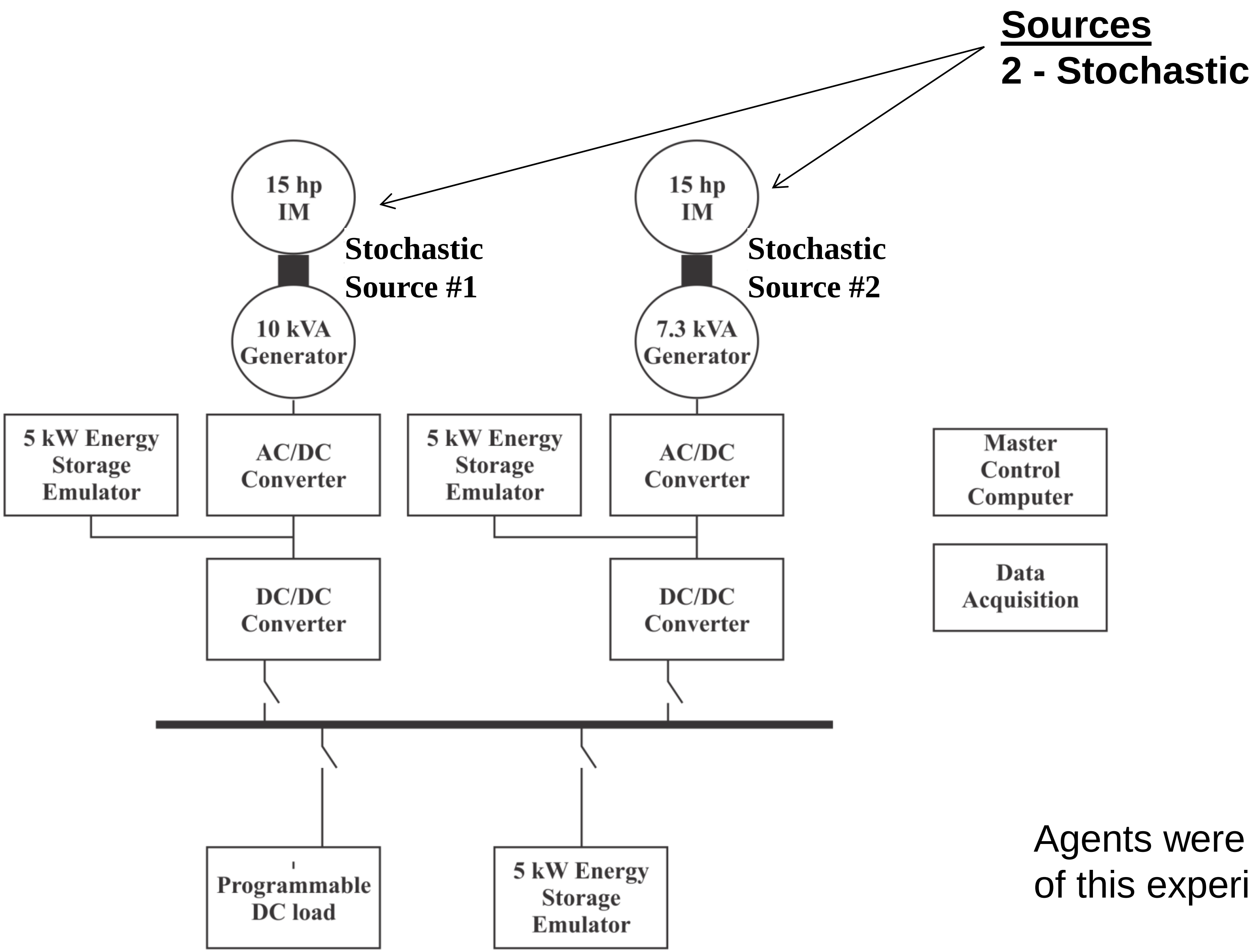


SSM test bed

Networked microgrid test bed is a national resource



Demonstrated Performance with 100% Stochastic Generation and Load is Enabled Through Controls and Storage

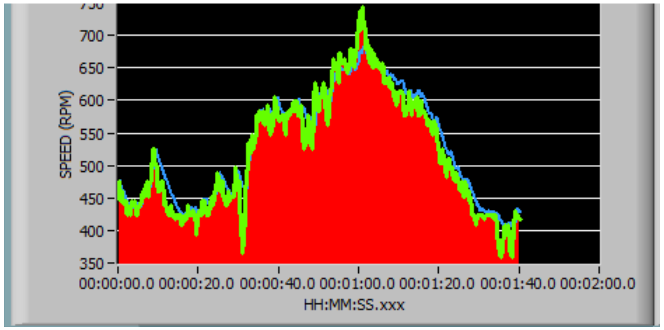


Agents were not part of this experiment.

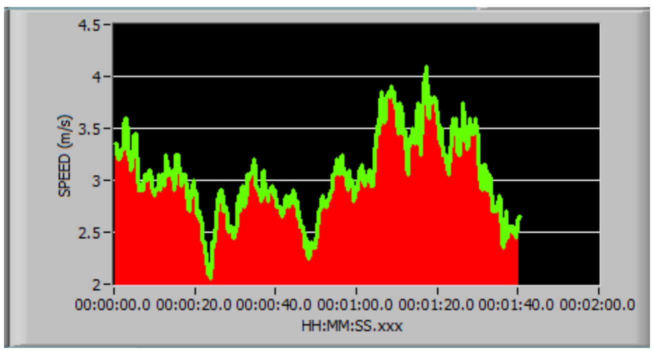
Hamiltonian Based Control Approach with Full State Control – Reduces Bus Voltage Transients

Source and load profiles

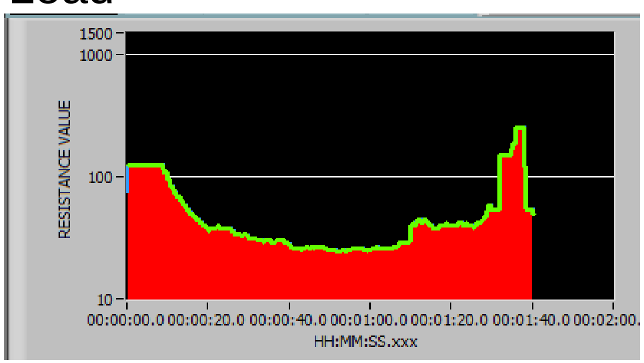
Stochastic source #1



Stochastic source # 2

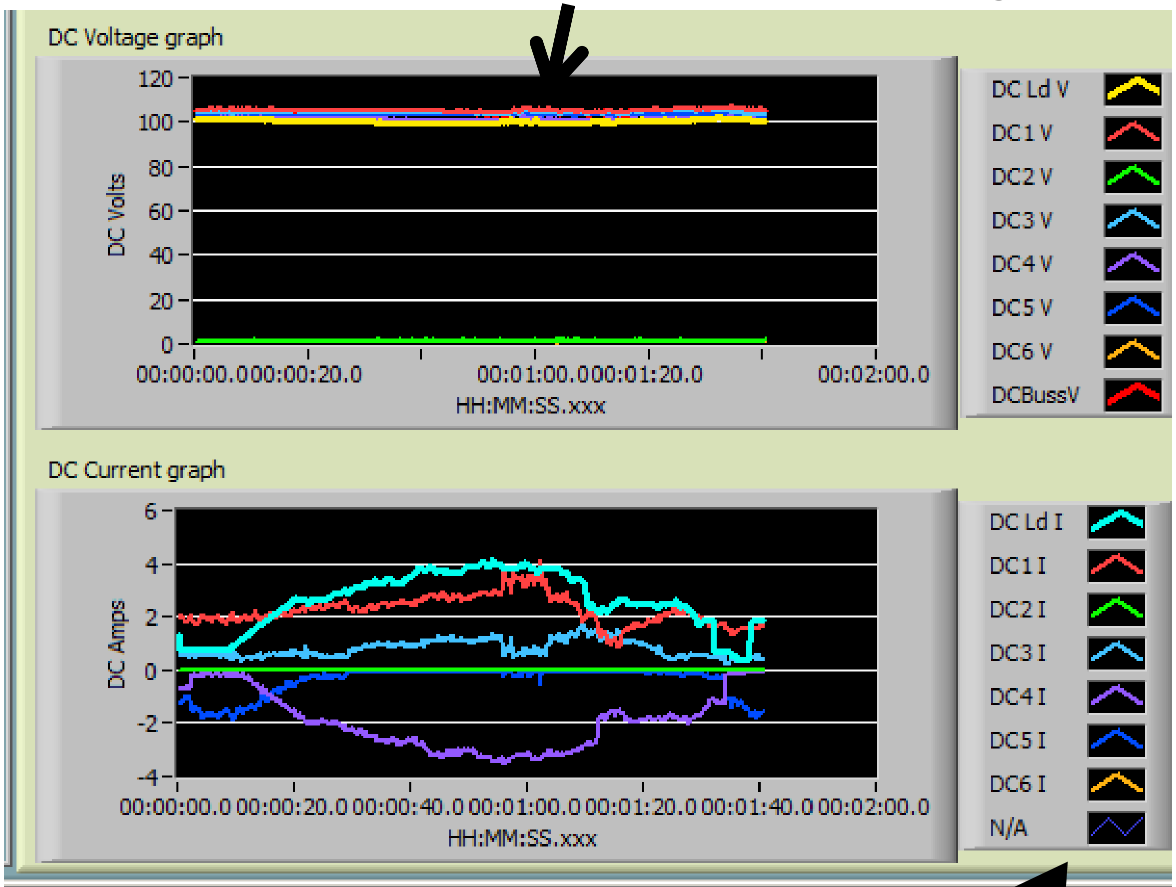


Load



Green – commanded profile
Blue – actual profile
Red – indicates progress in time

Transients are not evident in the bus voltage



Cyan – load current
Red – diesel current
Light blue – wind current
Purple – load current
Dark blue – Bus energy storage current

Water Power Program

UNIQUE CAPABILITIES

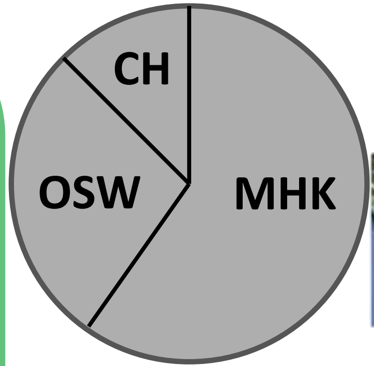
- SEAWOLF laboratory/field oscillatory-flow sediment transport testing
- Sandia Lake Facility – TRL 6 appropriate for wave testing
- MHK-capable environmental circulation and performance code (SNL-EFDC)

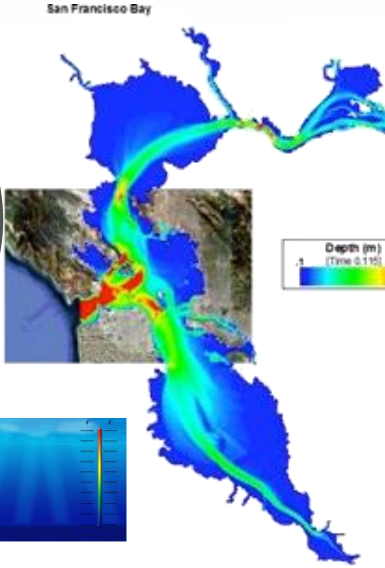
COLLABORATIVE PROJECTS

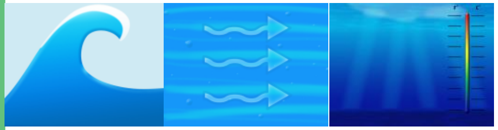
- Technical Industry FOA Support
  - Ocean Renewable Power Company, Ocean Power Technologies, Snohomish PUD
- SNL-EFDC Technology Transfer to
  - Free Flow Power, NOAA, FERC, BOEM, Verdant, ORPC

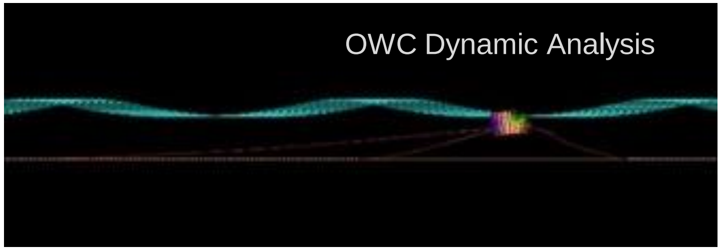
IMPACT EXAMPLES

- Leading the techno-economic report to be given to Congress this fall detailing how significant penetration will be possible and what steps need to be taken to ensure the growth of the WEC industry.
- Reference model generation and evaluation to set industry cost of electricity baselines and cost reduction pathways
- Renewable-appropriate composite structural materials and anti-biofouling coatings evaluation
- Fundamental code development for current and wave devices
- Water turbine acoustic signature prediction and measurement
- Large HAWT rotor blades, novel VAWT designs, and structural health monitoring for offshore wind devices







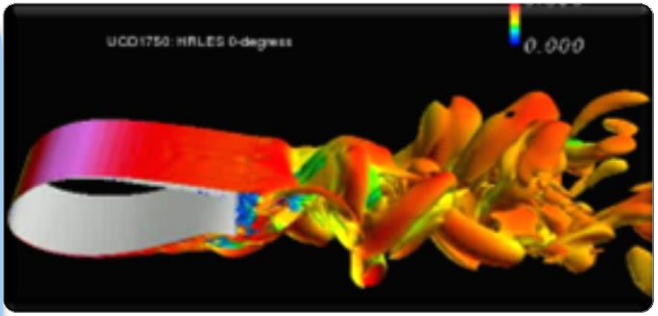


Sandia National Laboratories

Wind Program

UNIQUE CAPABILITIES

- Wind-turbine blade design and modeling, and wind system reliability
- Test facilities for scaled blade testing and turbine-to-turbine interaction studies (SWIFT test site, Lubbock, TX)



COLLABORITIVE PROJECTS

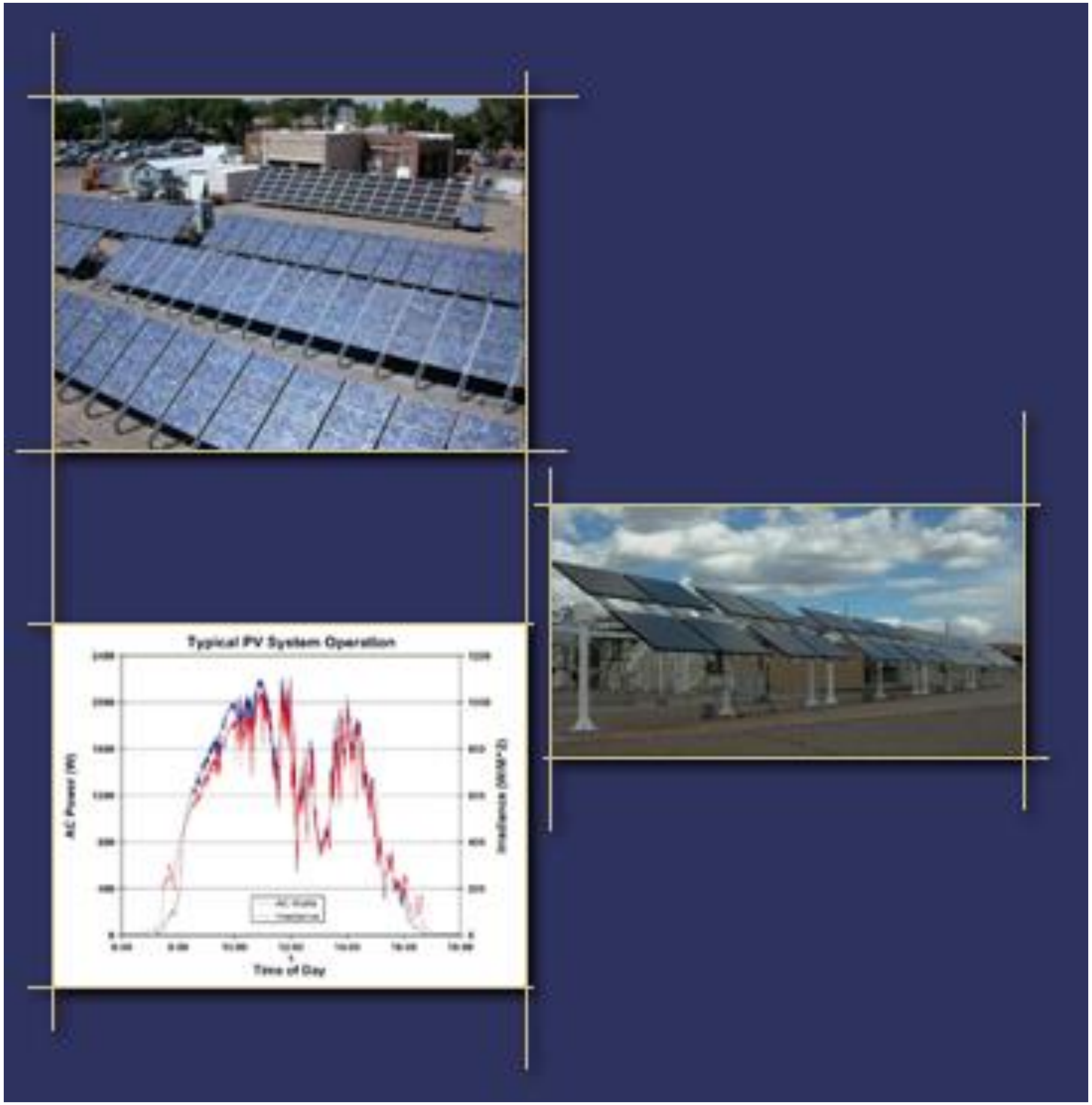
- GE, Vestas, Texas Tech University – complex wind flow; active controls; scaled wind farm testing
- MIT Lincoln Lab – wind turbine radar interference
- Montana State University – blade material testing
- NREL – systems engineering, wind farm planning, blade testing

IMPACT EXAMPLES

- The SWIFT facility being built at TTU will allow turbine and farm testing at approximately 1/20th of full scale cost
- Evaluation of methods for mitigating radar interference
- Reliability data base and analysis
- Development of tools for wind turbine design & modeling
- Blade testing and materials analysis to improve efficiency

Solar Program

- Solar collection
- Energy storage
- Power distribution
- Standards and policies



In Summary: We have a history of diverse impact on national security

- US ground beef safety in response to 1993 Jack-in-the-box O157:H7 e-coli outbreak 1997
  - Radiation pasteurization technology and contingency planning for major US and foreign beef producers, process development and validation experiments.
  - High dose-rate irradiation of ground beef for sensory panel evaluation.

- Introduction of radiation processing technology into tire manufacturing 1997-98
  - Irradiation of green and cured elastomers to determine impact on wide range of properties and applications. Led to tailoring of compounds for targeted effects.

- Mach 8-12 US hypersonic ground test facility R&D. (US Army/USAF) 1998 - ongoing
  - Concepts and proof-of-principle technology demonstrations, physics validation experiments.

- Response to Hart building anthrax attack (US Postal Service) 2001
  - Electron beam irradiation efficacy, process reliability, impact on mail content including volatile organic chemical release, national irradiation facilities planning.

- Wiring diagnostics for the Aging US Aircraft Fleet (DOT/FAA, Industry) 2005-07
  - PASD - World's first effective aging wiring diagnostic for commercial aircraft fleet.
  - *2007 R&D 100 Award.*
  - *2007 Federal Lab Consortium Interagency Partnering Award.*

- Sago Coal Mine accident investigation (DOL/Mine Safety & Health Administration) 2007
  - First-ever demonstrated link between a lightning ground strike and deep mine explosion. Led to changes in mine safety requirements.

- *Next: the Secure Scalable Microgrid*
  - *Integration of informatics, nonlinear distributed control, communication, and hardware for the development of power system design and analysis tools.*

In Summary

- Sandia Electrical Sciences research is addressing a wide range of power system challenges
  - Controls, stability, protection, and susceptibility
- Sandia's Energy Surety Microgrid research is addressing reliability and resiliency of DoD and commercial microgrids through near term technologies
- Sandia's Secure Scalable Microgrid research is integrating:
  - Informatics theory (including cyber security),
  - Hamiltonian based controls,
  - Communication theory,
  - and flexible experimental capabilities
- Scalable approaches to networked microgrids support the building block concept
- DC system control approaches are being migrated to AC systems

In Summary

- Sandia research is addressing a wide range of technical challenges
- Electrical Sciences includes
  - Modeling
  - Simulation
  - High voltage sciences
  - Electromagnetics
  - Advance power systems

- Not mentioned
  - Modeling
  - Simulation
  - HV switch development
  - Material science

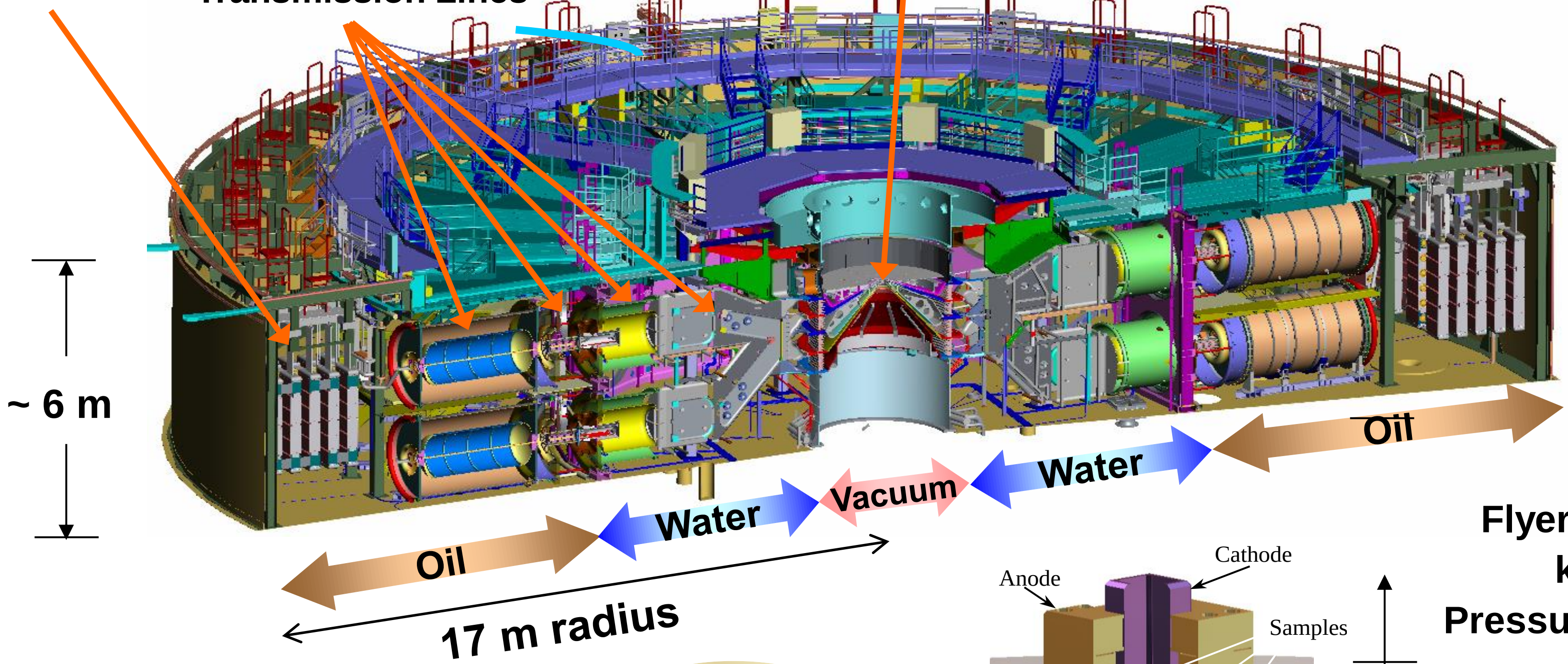
BACK UP SLIDES

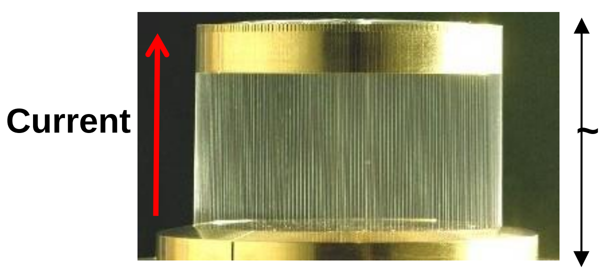
BACK UP

Z Represents the Core of Pulsed Power Sciences

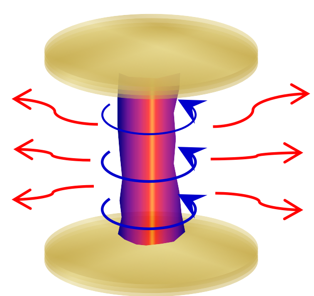
Pulse Forming Section:
- Intermediate Storage Capacitors
- Laser triggered gas switches
- Pulse Forming Lines
- Transmission Lines

Experiment Load Region

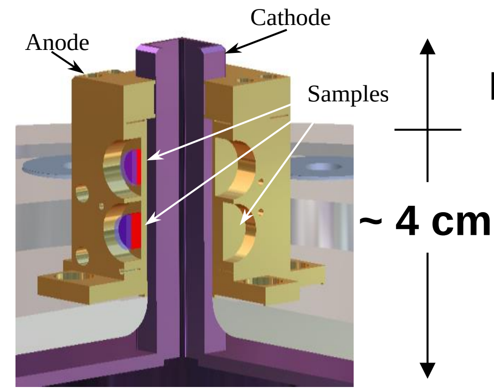




Wire-array z-pinch load for radiation effects and inertial confinement fusion

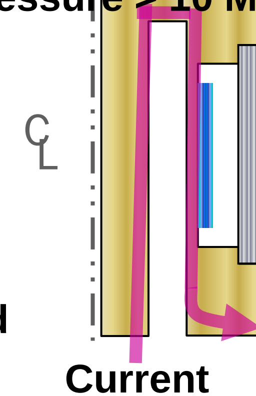


Implosion/stagnation 300 TW, 2 MJ x-ray



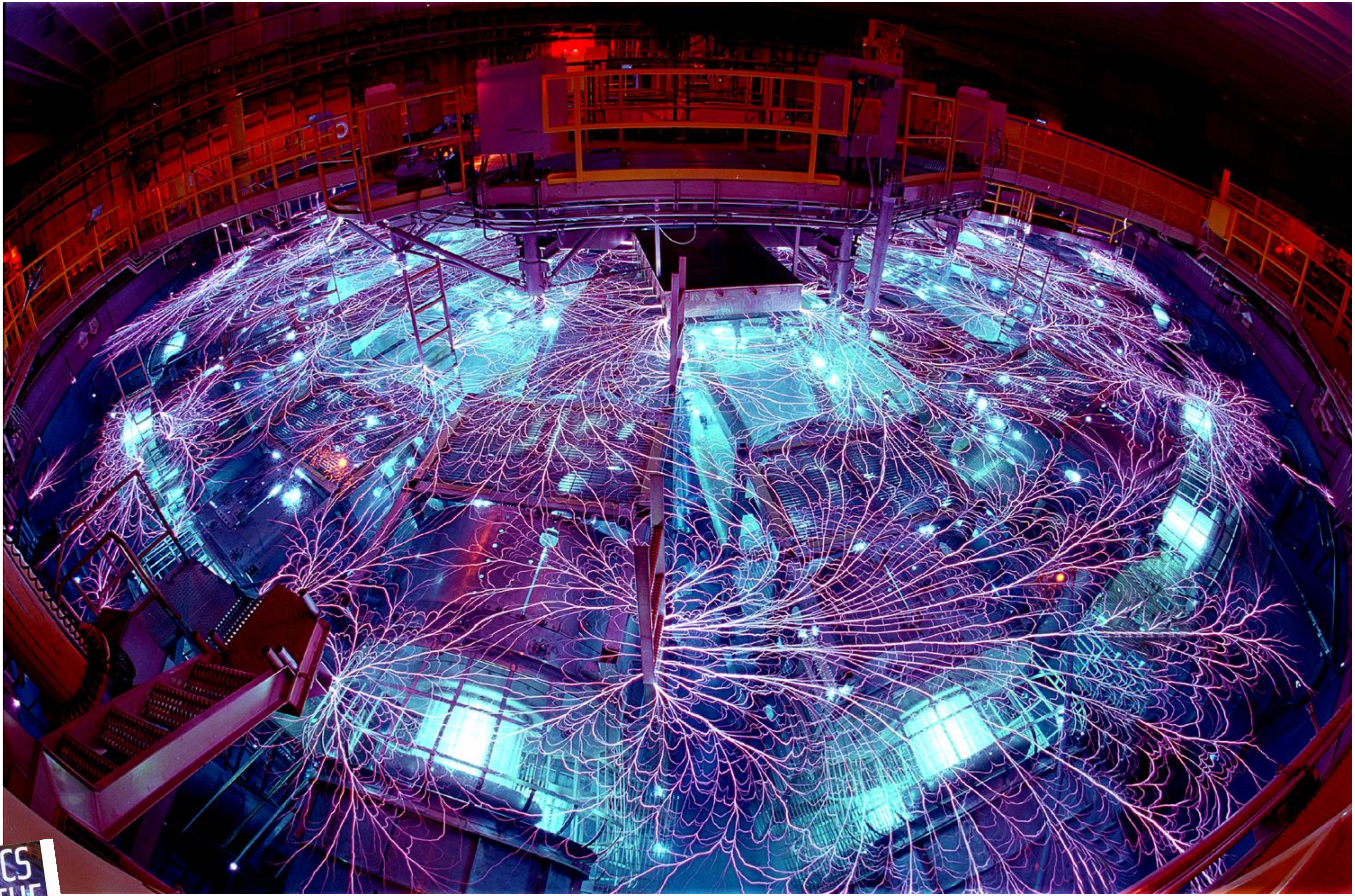
Magnetic compression load for dynamic materials experiments

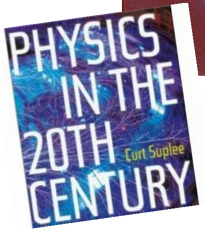
Flyer plate > 40 km/sec
Pressure > 10 Mbar



22 MJ stored energy, 26 MA peak current, 100-600ns rise times

Z Machine in Operation

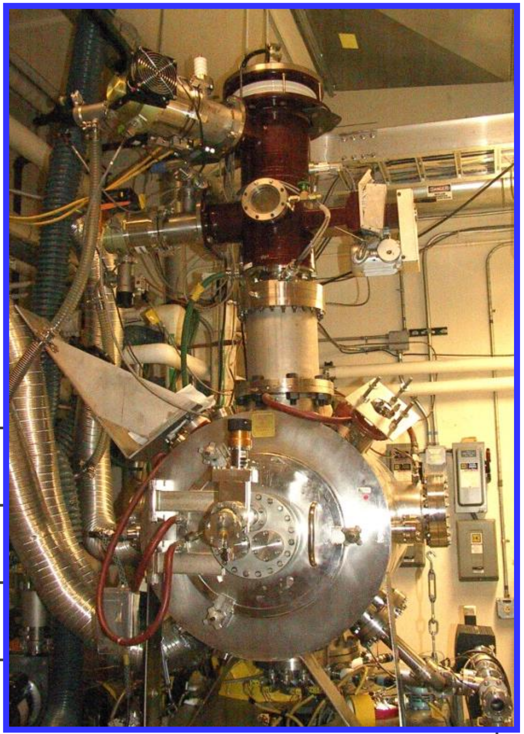




Arcing on the surface of the water and gas switch closure can be seen during operation of an older version of Z. These features disappear within a microsecond.

- **e-beam testing gives <u>complete</u> access to the heated surface for optical, IR and pyrometry measurements**
- **low thermal conduction losses**
- **requires 10 mTorr or better vacuum**
- **RGA, OES and LIF possible**
- **Fiberscopes, borescopes**

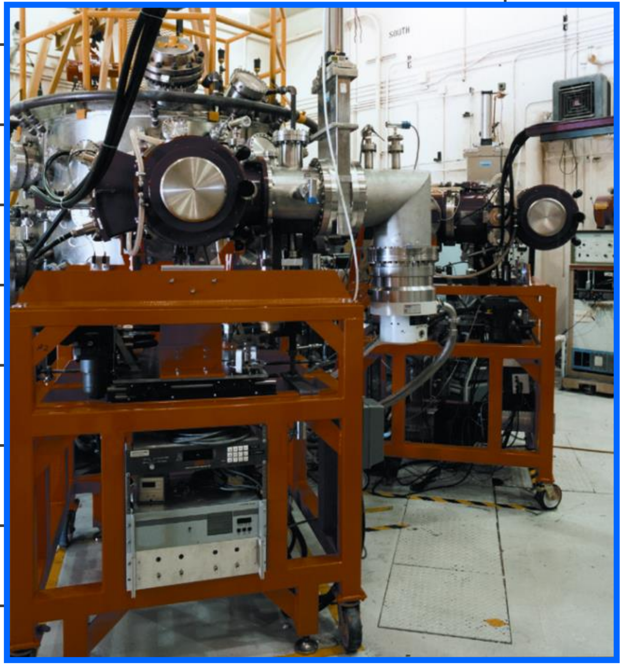
EB-60



Beam power	60,000W (60kW)
Accelerating voltage	30,000V (30kV)
Beam current	2A
Beam spot	2mm FWHM at target plane
Target area	0.1-10,000mm^2
Pulse length	From 2ms to continuous
Chamber pressure	~6 x 10^{-4} Pa, cold-trapped diffusion pump
Gun pressure	~1 x 10^{-6} Pa, turbopump

EB-1200

Beam power	0-0.6MW(cw) each gun; 0-1.2MW(cw) total
Accelerating voltage	0-40,000V (40kV)
Beam current	0-15A each gun
Magnetic lenses	2 coils
Spot diameter at 600kW, 1.5m	12mm
Magnetic deflection	2 yokes(orthogonal)
Max raster frequency	10,000Hz (10kHz)
Max. angle beam deflection	±7°, 10kHz; ±30°, <200Hz
Max. heat flux (unrastered)	>1000MW/m^2
Max. heated area at 10kHz	370mm x 370mm at 1.5m
Heat flux at maximum area	8.7MW/m^2
Max. pressure in chamber	<3Pa
Cooling water consumption	2.2m^3/h



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