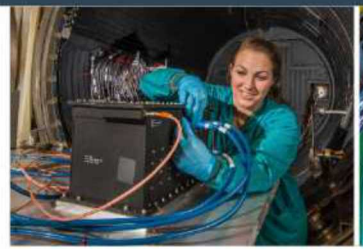
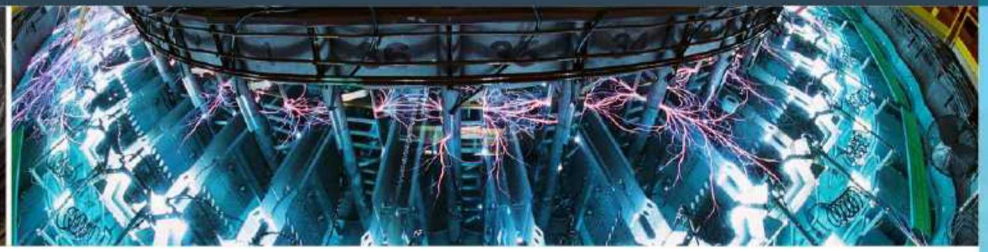
SAND2020-2729C

Sandia National Laboratories

Labs Strategic Priority 6

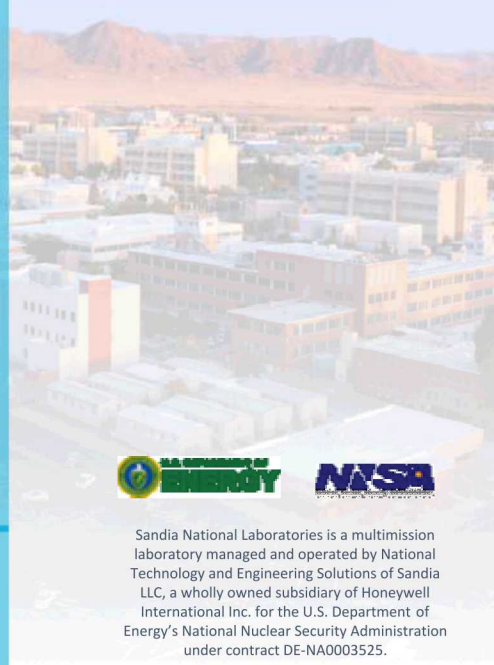




March 4, 2020

Gil Herrera, Laboratory Fellow

CRO External Advisory Board



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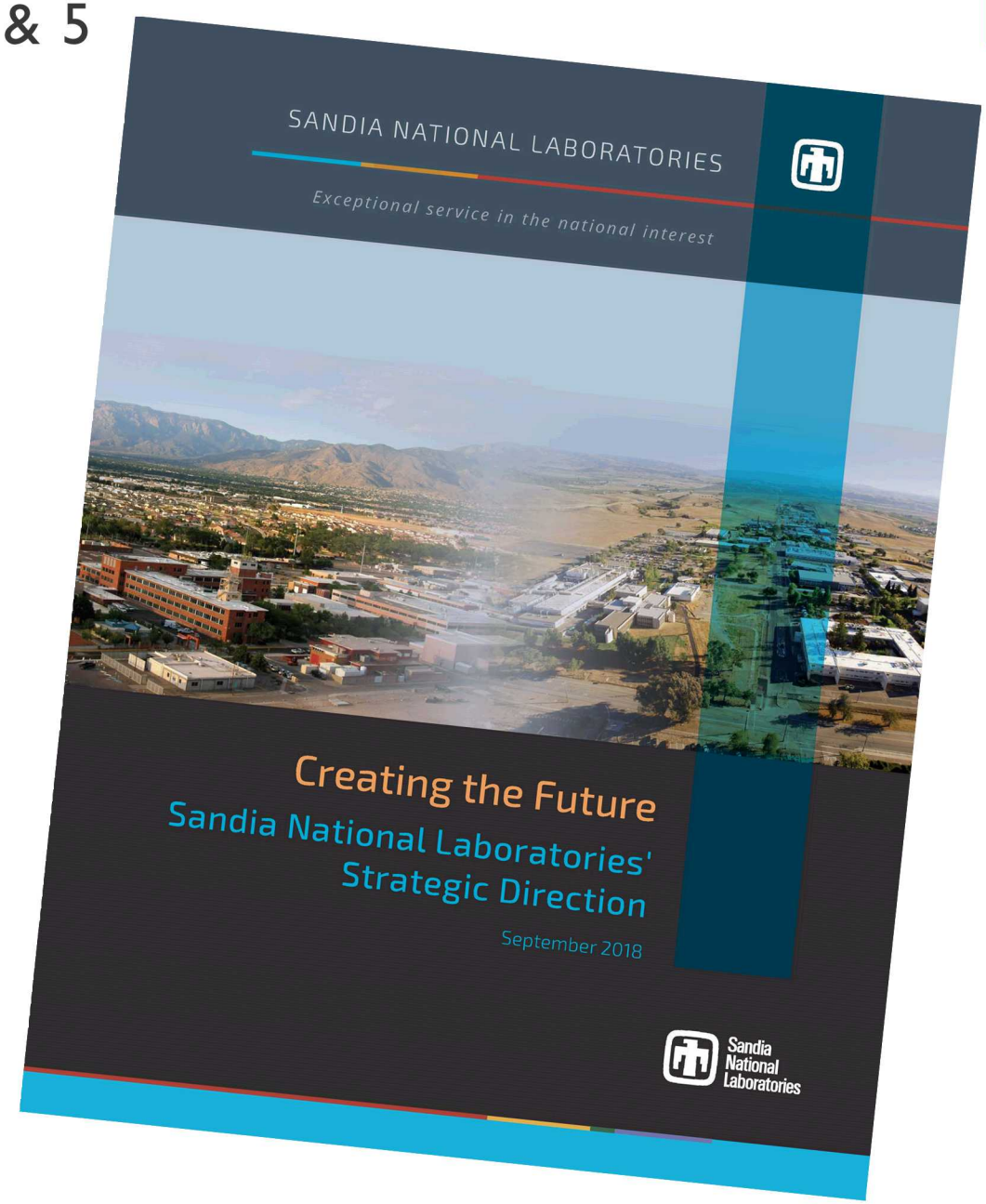
Labs Strategic Priority 6 Team – Phases 4 & 5

- Gil Herrera (lead)
- Brad Aimone
- Pat Brady
- Igal Brener
- Phil Dreike
- *Rebecca Horton*
- Bob Hwang
- Mike Keifer
- Keith Matzen
- Bill Miller
- *LeAnn Miller*
- Reno Sanchez
- Joel Sikora
- *Kathy Simonson*
- Anup Singh
- Hy Tran
- Karla Weaver (facilitator)

Italics = Did not continue into Phase 5
Underline = Added in Phase 5



Context

- NTESS initiated a new Lab Strategy in 2017
  - Deploy outstanding engineering, science, and technology to our missions – Priority 6
    - Sandia's ability to deliver on our missions relies on a strong foundation in outstanding engineering, science, and technology. With origins in our original nuclear weapons program, this core has expanded over decades to meet a variety of special national security needs. Outstanding engineering, science, and technology is about pursuing impossible discoveries. It leverages a breadth of capabilities that are healthy, cutting edge, forward thinking, and ready to be used at a moment's notice.
- First three phases have led to LDRD program improvements, changes to the CRO structure, and increased emphasis on peer review and scientific integrity.
- Phase 4-5 refocused by Steve Younger, tasking the team to deliver 2-5 candidate visionary research themes with potential to dramatically enhance Sandia's national security impact over the next 20-30 years.

Priority 6 – Deploy outstanding engineering, science, and technology to our mission

The goal of this priority is to deliver 2-5 candidate visionary research themes with potential to dramatically enhance Sandia's national security impact over the next 20-30 years.

TRACK 1: Candidate Visionary Themes

- 2-5 visionary themes
- Cast a broad net for ideas
- Vetting criteria and prioritization methodology

TRACK 2: Artificial Intelligence and Autonomy

- Near term exemplar
- Builds upon significant work and energy in phase 3
- Research agenda

Vetting Criteria

- **Emerging existential threats to/opportunities for national security**
- **"Sandia-Hard" problems, requiring discovery science and ultimately ground-breaking engineering**
- **Extends capability, existing capability or capability we can create or acquire via partnerships**
- **Institutional in nature, with participation from multiple Divisions and Centers**
- **Inspirational and can motivate and recruit top-level talent**
- **Path to future sponsorship by the DOE, DoD, IC, or other agencies**
- **Sandia is exceptionally suited to perform this work as judged by ourselves and our sponsors**

Visionary Research and Engineering to Solve Emerging and Future National Security Challenges

Track 2 (AI/Autonomy)

Artificial Intelligence and Autonomy R&D whitepaper recommended areas for action:

- AI R&D Quality: We must ensure that our AI research and development (R&D) is world class in technical validity, relevant, and appropriately scoped.
- Coordination of AI R&D: We must take steps to ensure that our AI R&D can be maximally leveraged across the laboratory and is adequately balanced between stakeholders.
- Ensure a balanced emphasis of applied and foundational AI R&D: We must establish mechanisms to ensure that cross-cutting AI research that is foundational to many Sandia missions is supported and encouraged.

Concept Whitepapers

- ~~**10-Day Energy Storage for the US** – Pat Brady, Bob Hwang~~
  - ~~Making the grid resilient by transitioning it from a resistor to a capacitor.~~
- **Assessing the Impact of Geoengineering** – Pat Brady, Bob Hwang
  - Sandia as the Assessment Science Lab for Geoengineering; scoring positive efforts to manage the impact of climate change, and detecting deleterious efforts by adversaries to use geoengineering as a climate weapon.
- **Inherently Safe, Resilient, Modular Nuclear Weapons** – Reno Sanchez, Greg Ten Eyck
  - A research through systems agenda for Nuclear Weapons in the 2050's and beyond.
- **Human Augmentation** – Hy Tran, Anup Singh, Brad Aimone
  - An ethical R&D agenda for human augmentation research for ~~both offensive and~~ defensive purposes.
- **Mission Impact of Z-Next Beyond NW** – Keith Matzen
  - Assuring institutional participation and benefit from the proposed Z-Next Facility.
- **Non-Nuclear Strategic Weapons** – Mike Keifer
  - Providing the President with options for strategic strike without using nuclear weapons.
- **From Bits to Brilliance** – Brad Aimone, Bob Hwang
  - Creating a computing ecosystem that is ubiquitous and integrated across our missions and at all scales of the computing technology stack, but utilizing emerging and undiscovered technologies and architectures to meet mission needs in a post-CMOS, post-Moore's Law environment.

Not presented; whitepaper insufficiently visionary

Modified from original; did not advance past SLT

Assessing the Threat of Geoengineering

Geoengineering will be applied by someone if climate reaches a tipping point – mounting sea level rise, repeated extreme temperatures, large-scale economic disruption, etc. It may be applied by an adversary to disrupt our economy or otherwise harm our country.

Lowering temperatures can be done rapidly and inexpensively but with unknown unintended consequences (see figure).

Sandia Geoengineering scope:

- National security implications
- Margins and uncertainties
- Scientific tools and models needed to assess/monitor

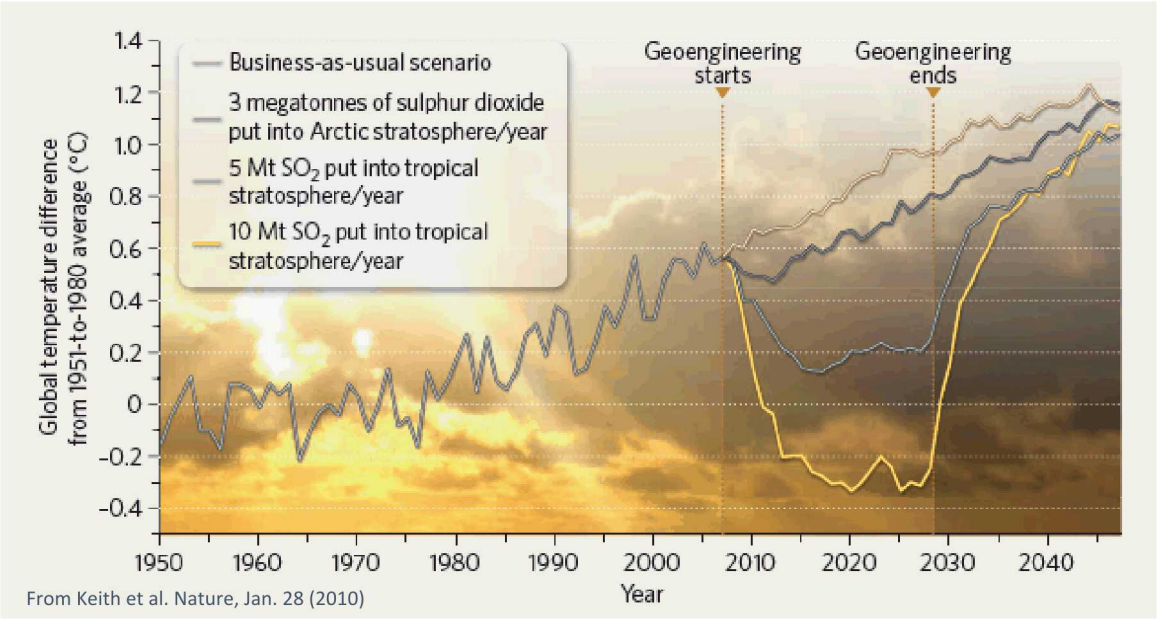
Partner scope:

- University partnerships in foundational R&D
- IC partnerships
- DoD partnerships for high TRL work, DOE, State

Technical Challenges:

- Accurate models
- UQ, risks, tails, QMU
- Critical measurements
- Assessing security consequences

Key Sandia Personnel
8800, 8700, 1400, 6800



From Keith et al. Nature, Jan. 28 (2010)

Inherently Safe, Resilient, Modular Nuclear Weapons

- A research through systems agenda for Nuclear Weapons in the 2050's and beyond.

Defending Against Adversary Human Augmentation

The use of new technologies to augment humans (physically, cognitively, genetically) is accelerating rapidly, creating emerging national security challenges

R&D needed to assess development of new technologies, look for signatures of developing programs, develop countermeasures to defend against augmented adversaries

For example:

Nanoparticles injected into eye allowed mice to see infrared as green light

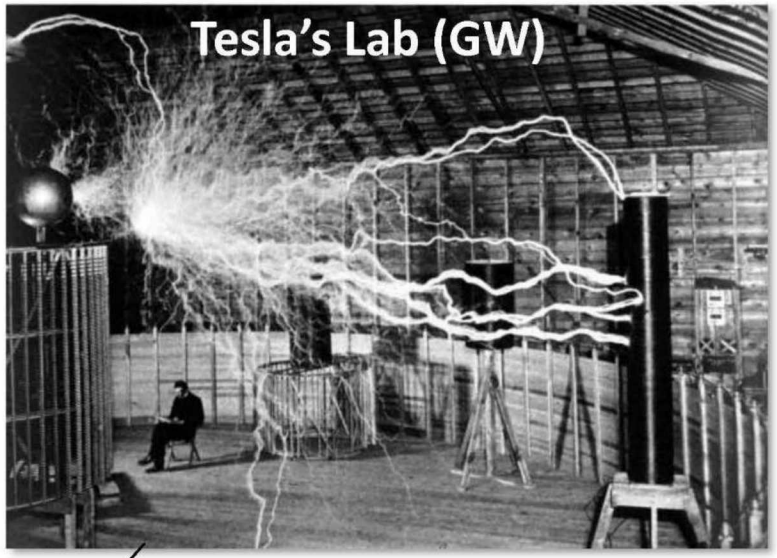
"Xue says that his technique could have several applications, including giving people 'super-vision'. Seeing infrared light could help people to see at night, by detecting infrared wavelengths emitted by, or reflected off, people and objects in the environment. This could be useful for military and security operations, for example."
***Nature*, February 28, 2019**

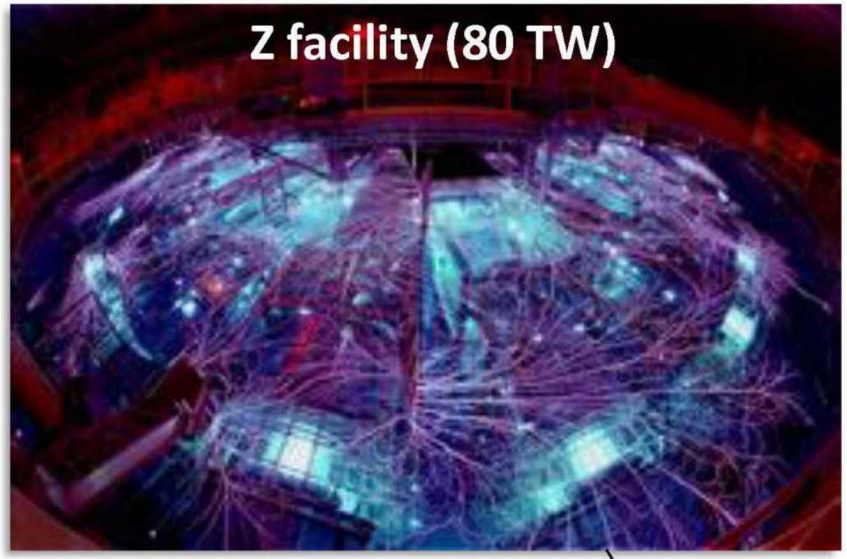
Sandia scope:
- Complex systems analysis
- Detect wearable and embedded augmentations
- Detect enhanced capabilities
- Develop countermeasures

Partner scope:
- University partnerships in foundational R&D, including, as appropriate, evaluation of technologies such as subject testing
- IC and DoD partnerships for higher TRL work

Technical challenges and internal R&D capabilities:
- Human augmentation encompasses numerous technologies and domains (sensors, power sources, electronics, nanoscience, robotics, cognitive science, biosciences, human-system interactions…)
- Cross-Sandia engagement - capabilities need are multi-center, multi-division, engage multiple PMUs
- Cross-strategy engagement - alignment with strategies 2, 3, 4, 5, and 7

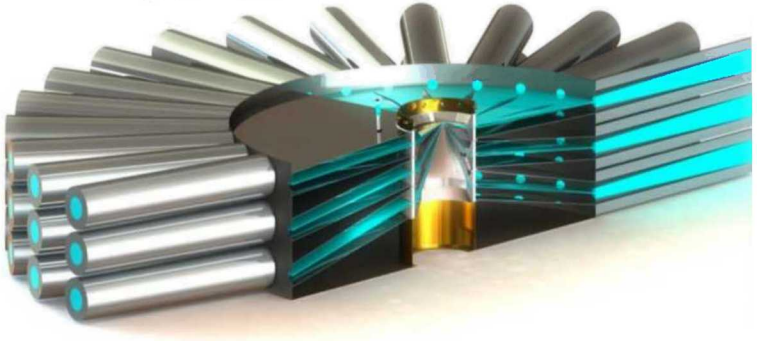
Mission Impact of Z-Next Beyond NW





Pulsed power has been evolving for over a century!

1900 1920 1940 1960 1980 2000 Z-Next (1000 TW) 2032



Increasing the electrical power by another order of magnitude would enable the U.S. to close gaps (present & future stockpile) in nuclear survivability and nuclear explosive package physics

Discussion with representatives from all Sandia mission areas revealed potential applications for all of these technologies; the need to reliably store, release, and deliver energy is widespread

- Capacitors
  - Enabling technology for multiple mission areas and customers
  - High reliability, higher capacitance/energy density, ultra-fast energy release, unconventional form factors, science basis for qualification
- Precision timing, triggering, and switching
  - “Operate through”, ultra-short time response, precision navigation, fuzing, micro robotics, advanced automated sensing, persistent atomic clock precision
- Insulator performance
  - Energy flow management (bi-directional) for multiple applications
- Advance materials
  - Applications in all mission areas
  - Materials discovery, synthesis, rapid prototyping, production, qualification
- Improved system architectures
  - SWaP (compact systems) needed for all mission areas
- Improved diagnostics
  - “Core enabler to study fundamental physics with the ability to capture actionable phenomenology”; need to collect right data at right scales
- Multiple applications in ND systems (e.g., NGs, firing set, radars, fuzing options

Non-Nuclear Strategic Weapons

- Providing the President with options for strategic strike without using nuclear weapons.

ES&T Strategy Phase 5 Transition to FY20

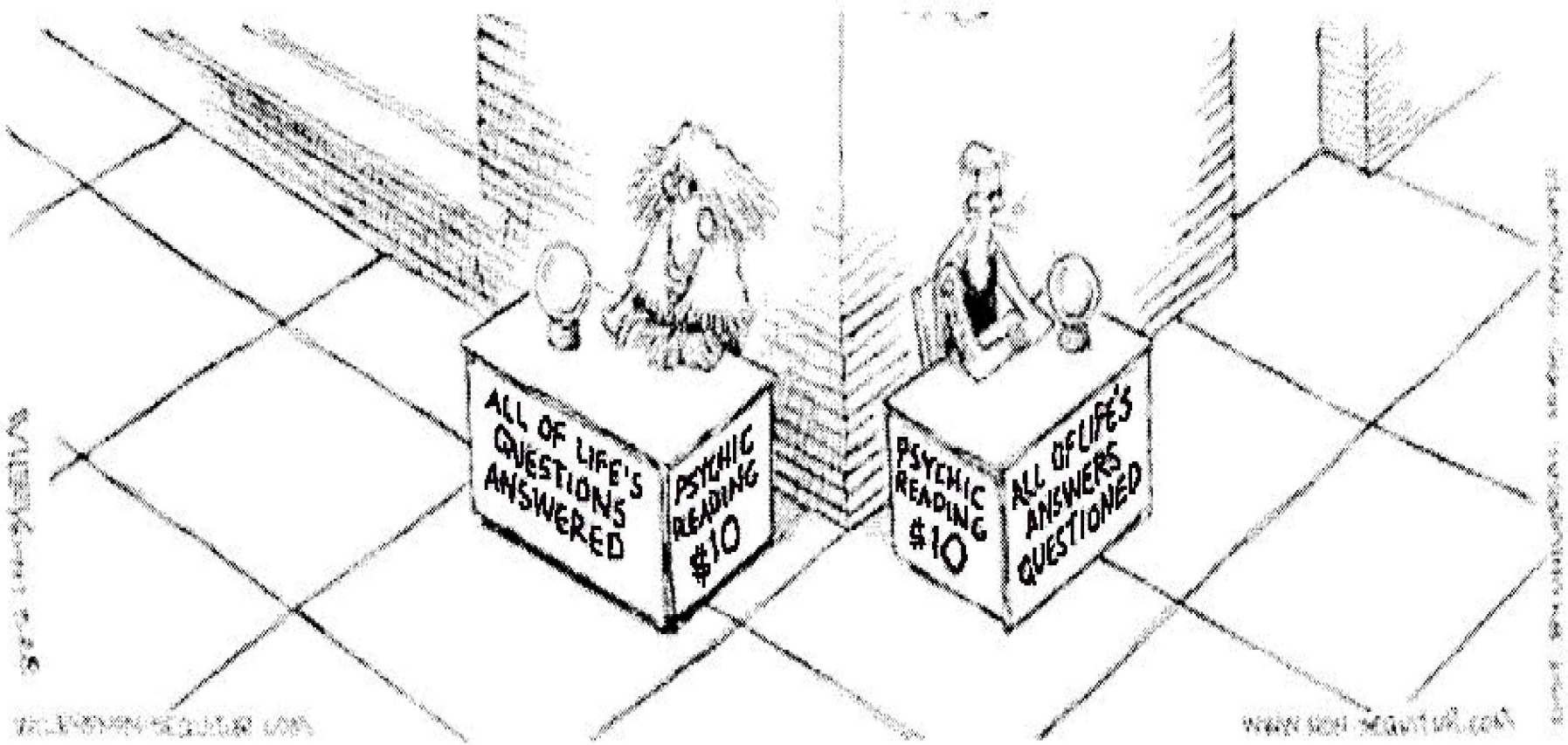
- **SLT makes decision on which themes will be "adopted". This means the "adopting" ALD agrees to own the theme which includes:**
  - Provide staffing to execute on white papers using DS or other means under their control
  - Mature the white paper into an executable business strategy
  - Support the development of proposals to fund the activity (more detail on next slide)
  - Supports competency development and enhancement
    - Develop new competencies and support existing competencies
      - Hiring and personnel actions
      - Capital equipment and space allocation prioritization
      - LDRD and other funds
  - Supports partner engagement
    - Partnership creation
    - Partnership agreements and project execution

- **AS&T enables and supports the development and maturation of the themes:**
  - LDRD
  - WS&T interface
  - SC interface
  - Partnerships office

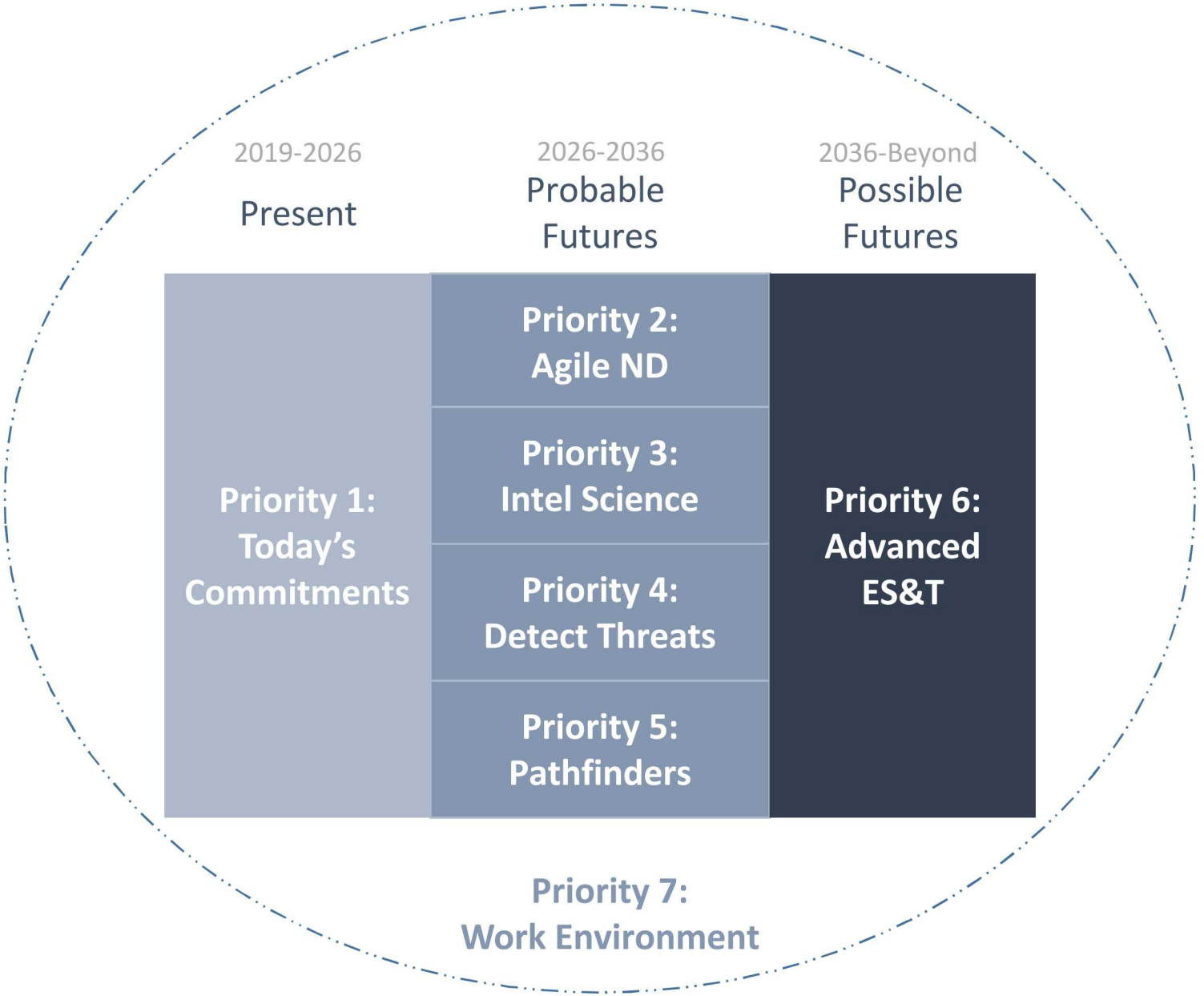
FY20 Accomplishments

- **Non-Nuclear Strike**: A formal proposal written by Mike Keifer to be presented to a sponsor by Dennis Helmich
- **Inherently Safe, Resilient, Modular Nuclear Weapons**: Scott Holswade and Gil Herrera are developing an execution strategy to present to Steve Girrens and Susan Seestrom
- **Geoengineering**: Lori Parrott is maturing the idea using D8000 customer engagement investments
- **Bits to Brilliance and AI & Autonomy**: Concepts appeared in the FY21 Computing & Information Science LDRD Call for Ideas
- **Impact of Z-Next Beyond NW**: Considerable activity continues around NGPPF; activities identified in the whitepaper have not yet begun

Questions?


ALL OF LIFE'S QUESTIONS ANSWERED
PSYCHIC READING $10
PSYCHIC READING $10
ALL OF LIFE'S ANSWERS QUESTIONED

Our View of How the Priorities Work Together



ES&T Strategy Phase 5 Transition to FY20

- **Potential Proposal Funding Mechanisms**
  - **LDRD**
    - New Mission Campaign
    - Refocus Mission Foundation
    - Grand Challenge sponsorship
  - **NNSA**
    - Map into existing engineering and science campaign work
    - Work to create a new campaign element
  - **DOE**
    - Map into existing DOE program
    - Work with DOE to create a new program
  - **OFA**
    - Develop proposals in response to existing or emerging BAA's
    - Work with existing or new federal sponsors to create new programs

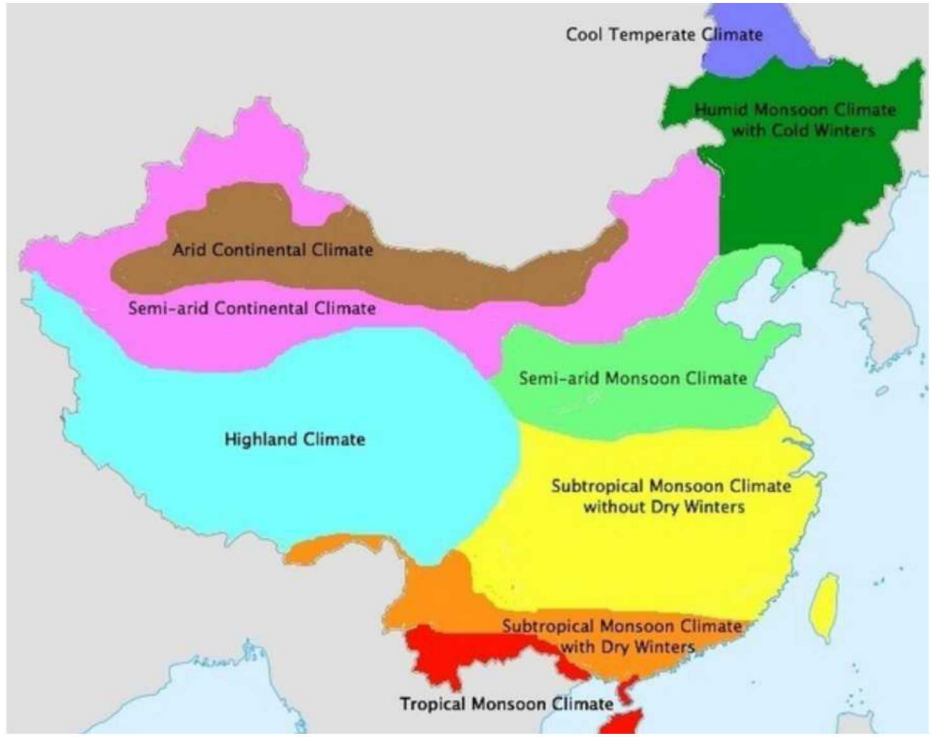
Sandia Responds to Geoengineering in 2030

"Look, in 15, 20 years, China's going to start geoengineering and they're unlikely to ask permission" Presidential Candidate Andrew Yang to *Business Insider*, Sept. 6, 2019.

Scenario: China does geoengineering unilaterally to prevent a second failed monsoon and large agricultural losses caused by climate change.

Sandia-developed tools detect and quantify its implementation early.

Sandia-developed models predict who wins/who loses,
- Whether it will succeed and by how much,
- What are unintended consequences of the new, designed climate,
- Direct and indirect impacts on US security.

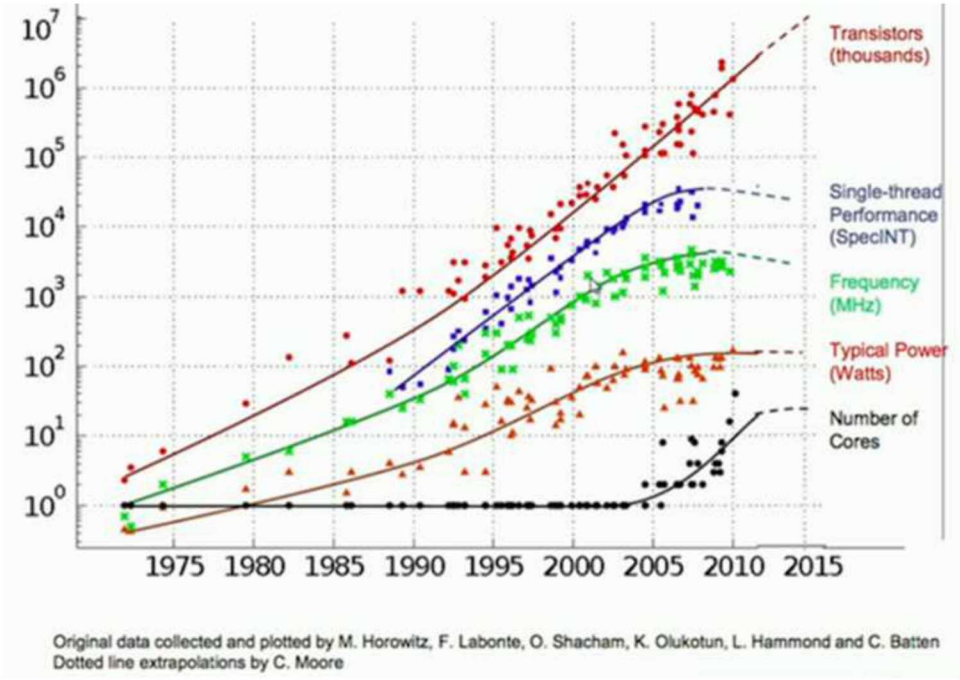


From Bits to Brilliance

- Despite slowing of Moore's Law, computing is becoming ubiquitous, compact, more diverse, and smarter every day

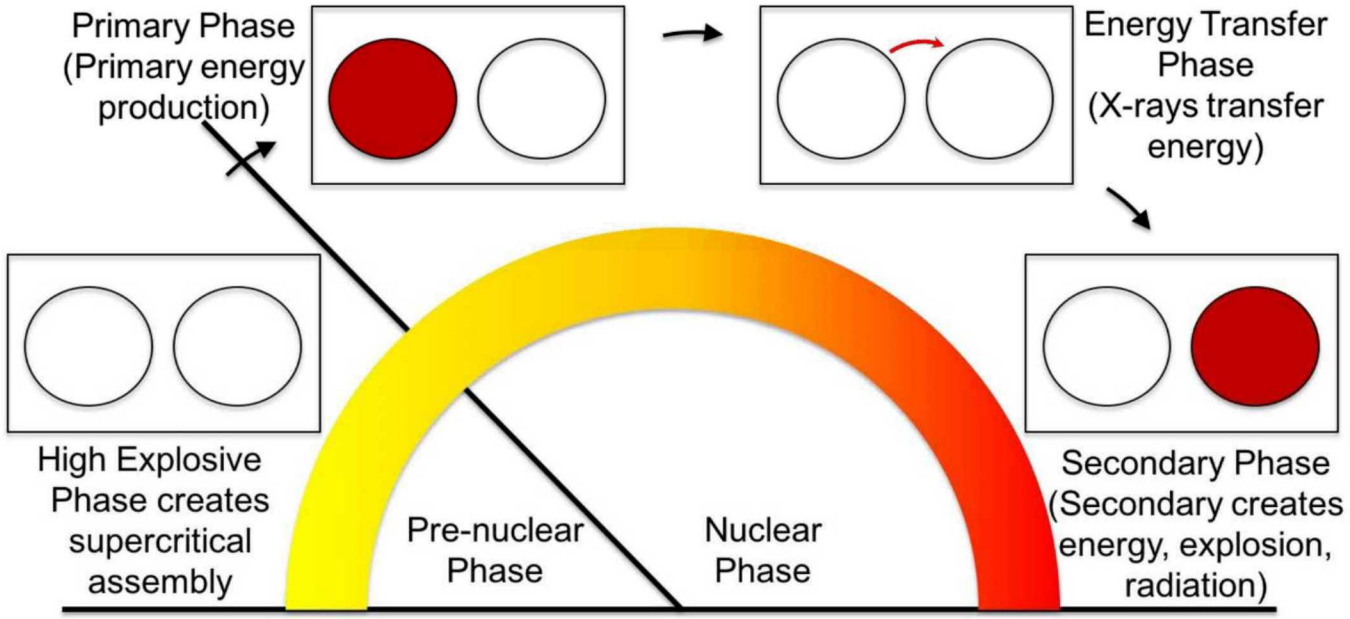
Sandia ASCI Red 1.3 TFLOP/s

≈10 iPhone XRs



- Our missions increasingly require advanced and specialized (e.g., low-power) computing solutions; pushing physical limits of foreseeable technologies
- Sandia should *embrace* this heterogeneity, rather than fighting it
  - Opportunity to redefine how computing impacts our missions
  - Make our mission robust to upcoming shifts in computing technology due to end of useful scaling laws

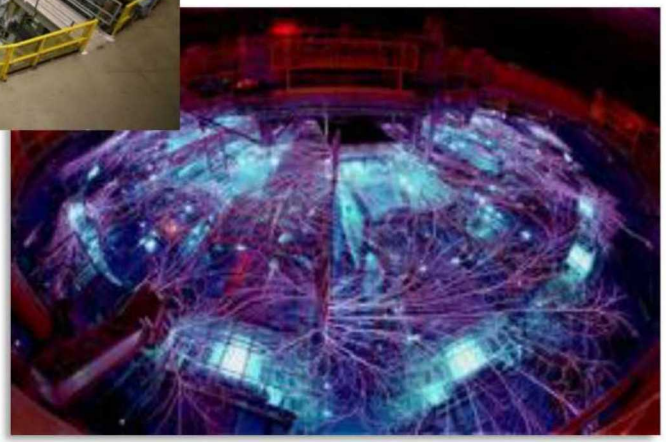
The majority of the yield of our nuclear weapons occurs from matter in the High Energy Density state, which can be studied using underground test, large lasers, or large pulsed power facilities



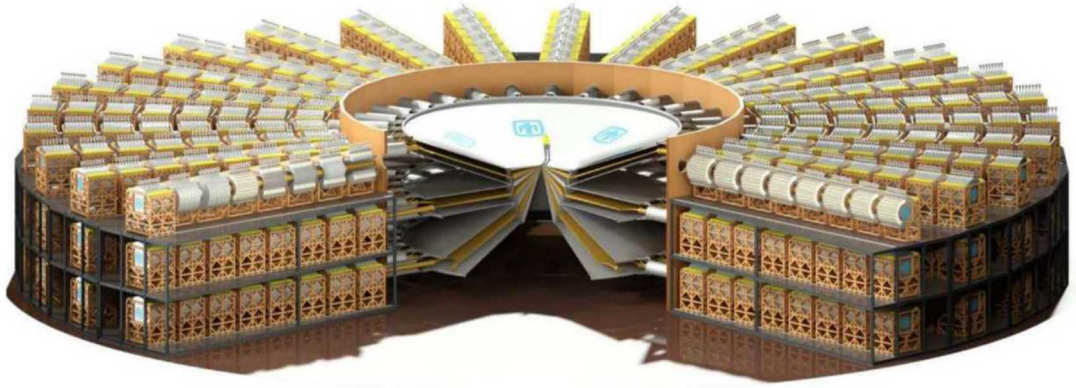
- X rays for hostile environment survivability research
- Neutrons for transient electronics studies
- Platforms for high pressure dynamic materials testing
- New platforms for primary and secondary assessments
- Thermonuclear burn in the laboratory
- Hardened diagnostics
- Avoid technological surprise
- Grand challenge problems that attract future stewards

China is rapidly developing their pulsed power capabilities

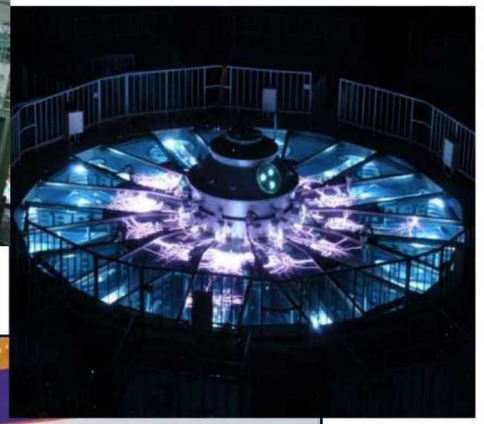
Z (2007)

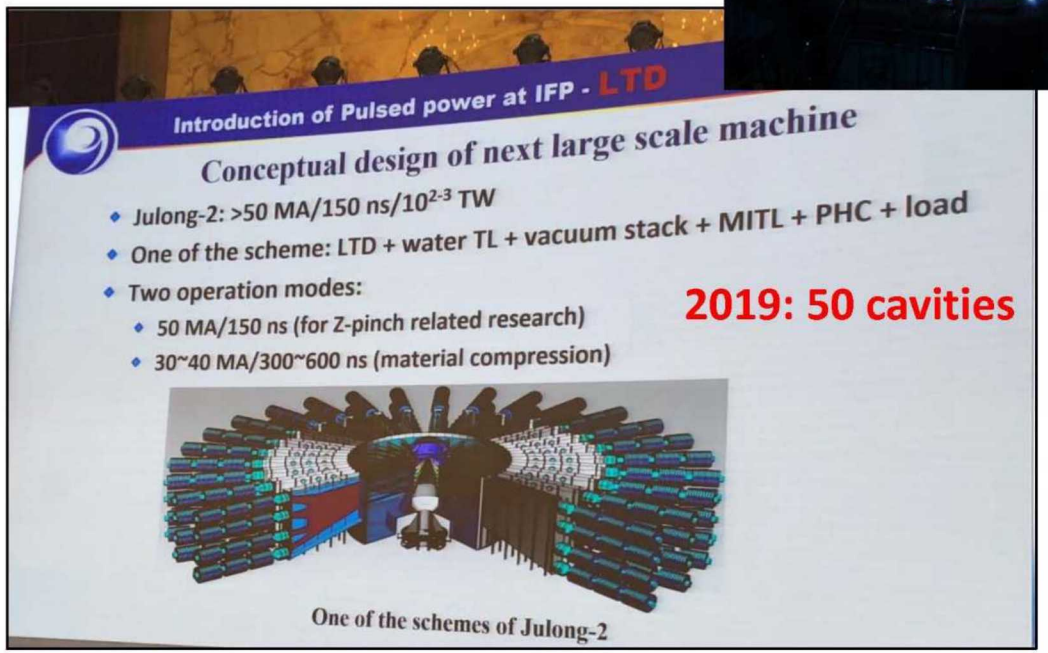


2019: One cavity

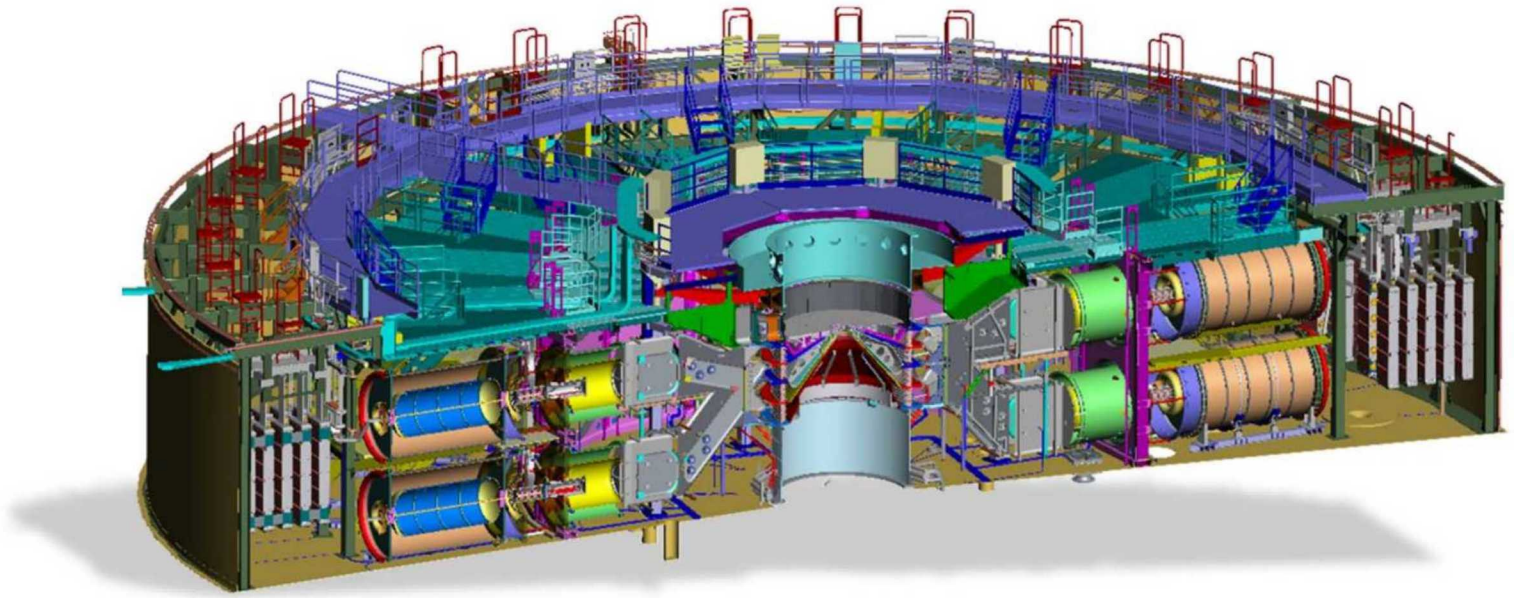


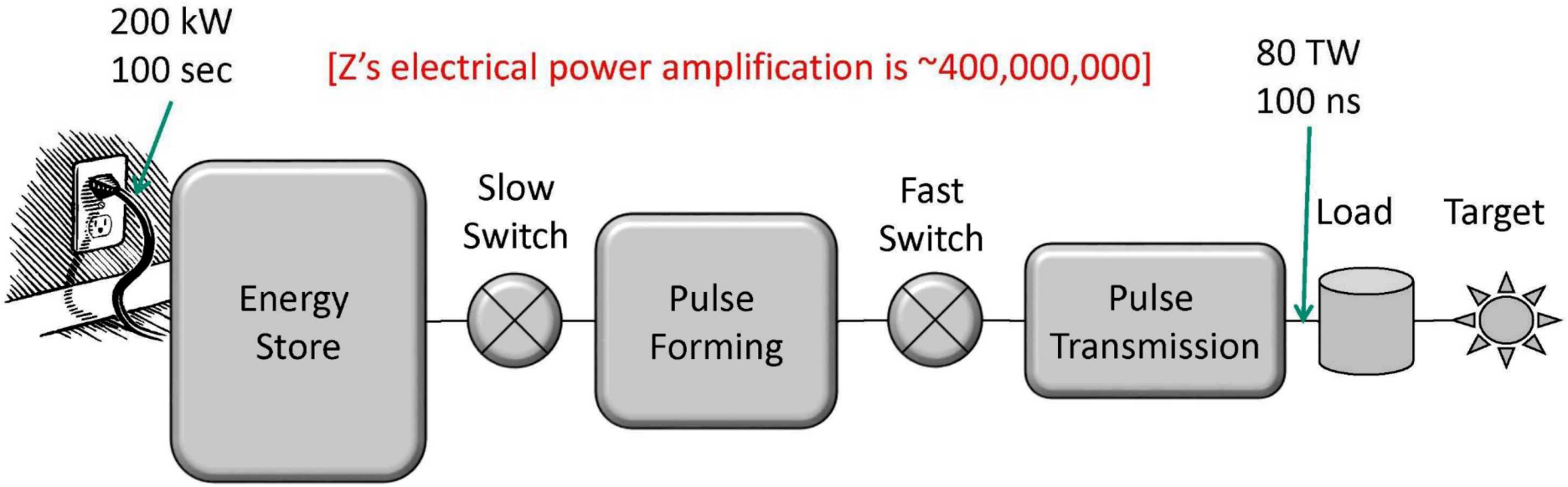
PTS (2012)





The Z facility is the world's most powerful pulsed power facility

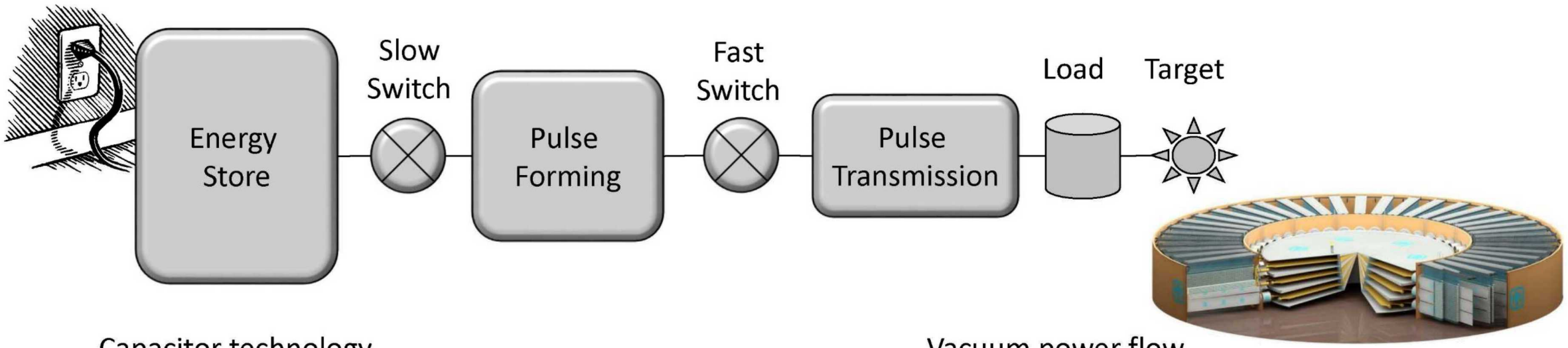




Path Forward

- Key technology roadmap components:
  - UQ and QMU of intended temperature change and unintended consequences,
  - Sensing techniques and supporting models.
  - Lead this discussion within the national security community: DOE, IC, DOD, State, whatever future US agency is tasked with a runaway climate

Confidence in scaling components to Z-Next levels of performance requires investments in several key S&T capabilities



Capacitor technology

Vacuum power flow

Precision timing

Impact of plasmas

Insulator performance

Advanced materials

Improved system architectures

Improved diagnostics

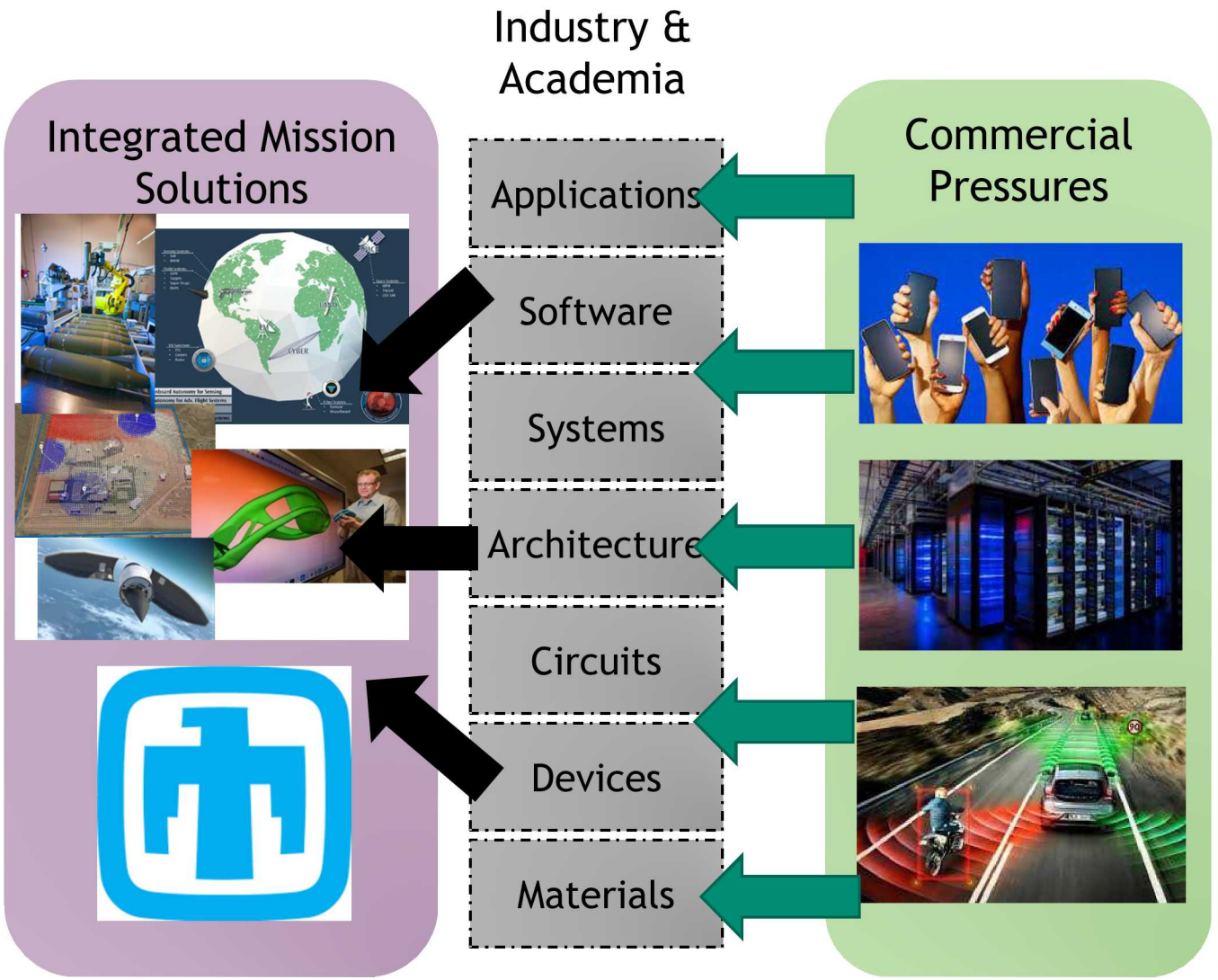
From Bits to Brilliance

Industry and commercial markets will continue to drive computing technology

- All levels of technology are facing disruptive changes
- We should continue to partner with industry in traditional (e.g., HPC) and new (e.g., AI) areas

Sandia must lead in tailoring tech to our mission

- Computing requirements for national security will continue to be different than consumer demands
- Sandia has world-class expertise at all computing scales



From Bits to Brilliance

Computing is a cross-cutting Sandia challenge

- Materials & Devices (1800, 8300)
- Circuits & Architectures (1400, 5200)
- Algorithms & Applications (1400, 8700, everyone…)

Sandia must avoid temptation to simply be reactive

- Advancing specific technologies is not enough
- Need radical ideas for cross-scale integration

From Bits to Brilliance

- Despite slowing of Moore's Law, computing is becoming ubiquitous, compact, more diverse, and smarter every day

Sandia ASCI Red 1.3 TFLOP/s

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Back Up Slides

Path Forward

FY20:
- Additional due diligence, such as detailed threat-informed analysis
- Analyze ethical and legal frameworks, both US and international
- Mission campaign (MC) LDRD
- Develop partners in OFAs, industry, universities for coordinated R&D
- Work with DOE and DoD on coordinated roadmap to counter threats

	2025	2030	2035	2040	2050
Simulation and Modeling (Sandia leads)	"In silico" emulation of a cockroach brain (or similar complexity); methods can accommodate neuromorphic hardware	Foundational science for computing, "beyond supercomputing" to simulate cognition—"how the brain thinks"; handles for interfaces		Theoretical model of a higher order model (such as a dog); including multisystem augmentations and interactions	Predictive model of human cognition and effect of augmentation.
Methodology for Augmentations (Sandia leads)		Human centric interface, data integration and presentation. Non-invasive targeted augmentation of vigilance and attention. Sensors to remotely detect augmented humans.		Creation of environments which are hostile to augmented humans/augmented functions. Dynamic and individually tailored brain stimulation for augmentation of human performance.	Suite of tools to determine threats; detect/deny/defeat augmented humans. Full functionality of "neural copilot."
Human/Machine Interfaces (Sandia partners)	Human-embedded wireless communications.	Integrated interface for human communications.		Non-invasive wireless communications to the nervous system.	Seamless mental communications with external devices such as remote computers, sensors, and actuators.
Augmentation Tools (Partners lead)		Biocompatible materials enable multiplexed implantable sensors and actuators. Reprogrammers for gene expression.	Optogenetics for interface and activation of augmentations.	Implantation of adjunct functionality to humans, such as pseudo-organs (e.g. data storage, artificial digestive system)	Programmable developmental biomaterials; chemical alphabet for two-way communications (e.g. artificial pheromone communications)
Power for Augmentation and Fusion (Sandia leads)		Watt-level conversion from human body to provide power for external electronics or gadgets.		Reduce power needs for augmentation technologies, feasible for both external and internal power coupling and conversion	Modify human (or animal) metabolism.
Integration and Delivery of Tools (Partners lead)		Targeted pharmaceuticals with fewer side effects and known inter-compatibility; rotation of augmentation technologies to avoid habituation.		Real-time monitoring of full bio state; delivery methods for augmentations.	Integration of external situational monitoring; context-based smart delivery of augmentations and suite of augmentations; turning augmentations on and off.

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- Phase 4-5 refocused by Steve Younger, tasking the team to deliver 2-5 candidate visionary research themes with potential to dramatically enhance Sandia's national security impact over the next 20-30 years.
- The ES&T priority team went through a process to develop candidate themes and established vetting criteria. The process resulted in seven candidate themes.
- Seven workshops were held, and seven concept whitepapers developed. After meeting with Steve Younger and Susan Seestrom, six were presented to SLT.
- SLT adopted five to mature in FY20 (and beyond as appropriate).
- In parallel, a whitepaper on AI and Autonomy recommended areas for action: ensure R&D quality, coordinate investments, and balance emphasis on foundational and applied R&D.
- Concurrent with Labs strategy activities,