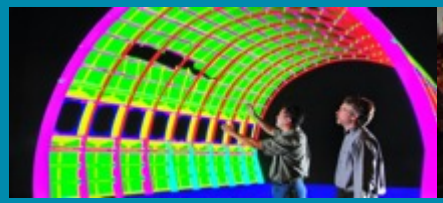
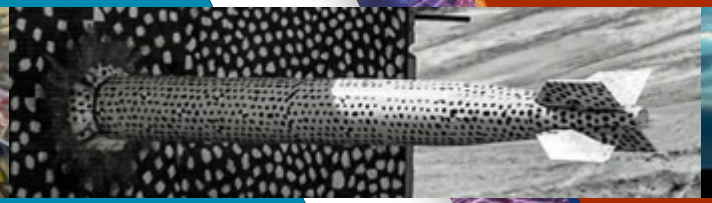
SAND2021-14207PE

Sandia National Laboratories

Exceptional service in the national interest








Nuclear Waste Disposal: Career in Environmental Science

Cal Poly ESCI 550 – Advanced Environmental Science

Nov 17, 2021 (via Zoom)

Kristopher L. Kuhlman, PhD

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology and Engineering Solutions of Sandia LLC, a wholly owned subsidiary of Honeywell International Inc. for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

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About Me

1994-1998: BS Geological Engineering, Colorado School of Mines

1998-2002: Groundwater modeling consultant (Los Angeles, CA)

2002-2008: PhD Hydrology, University of Arizona

2008-now: Sandia National Laboratories

SCHOOL OF MINES 1874 COLORADO

ARIZONA

Sandia National Laboratories

Careers in Geoscience

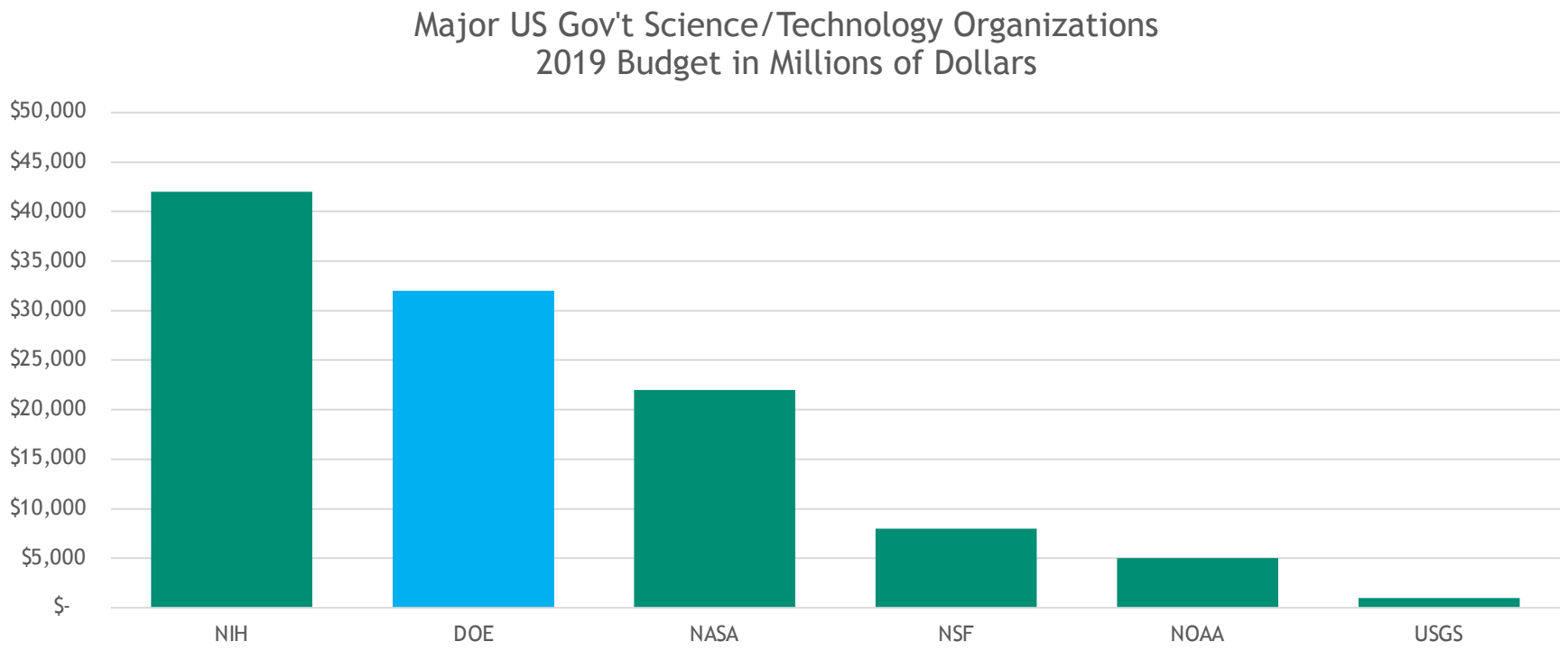
1. What are DOE National Labs?
2. What is Sandia?
3. Nuclear Waste Disposal
4. Brine Availability Test in Salt
5. Working at Labs

What are DOE National Labs?

Department of Energy (DOE): National Labs

DOE is major funder of technology & research

½ of DOE budget funds National Lab system



NIH: National Institutes of Health

NASA: National Aeronautics & Space Administration

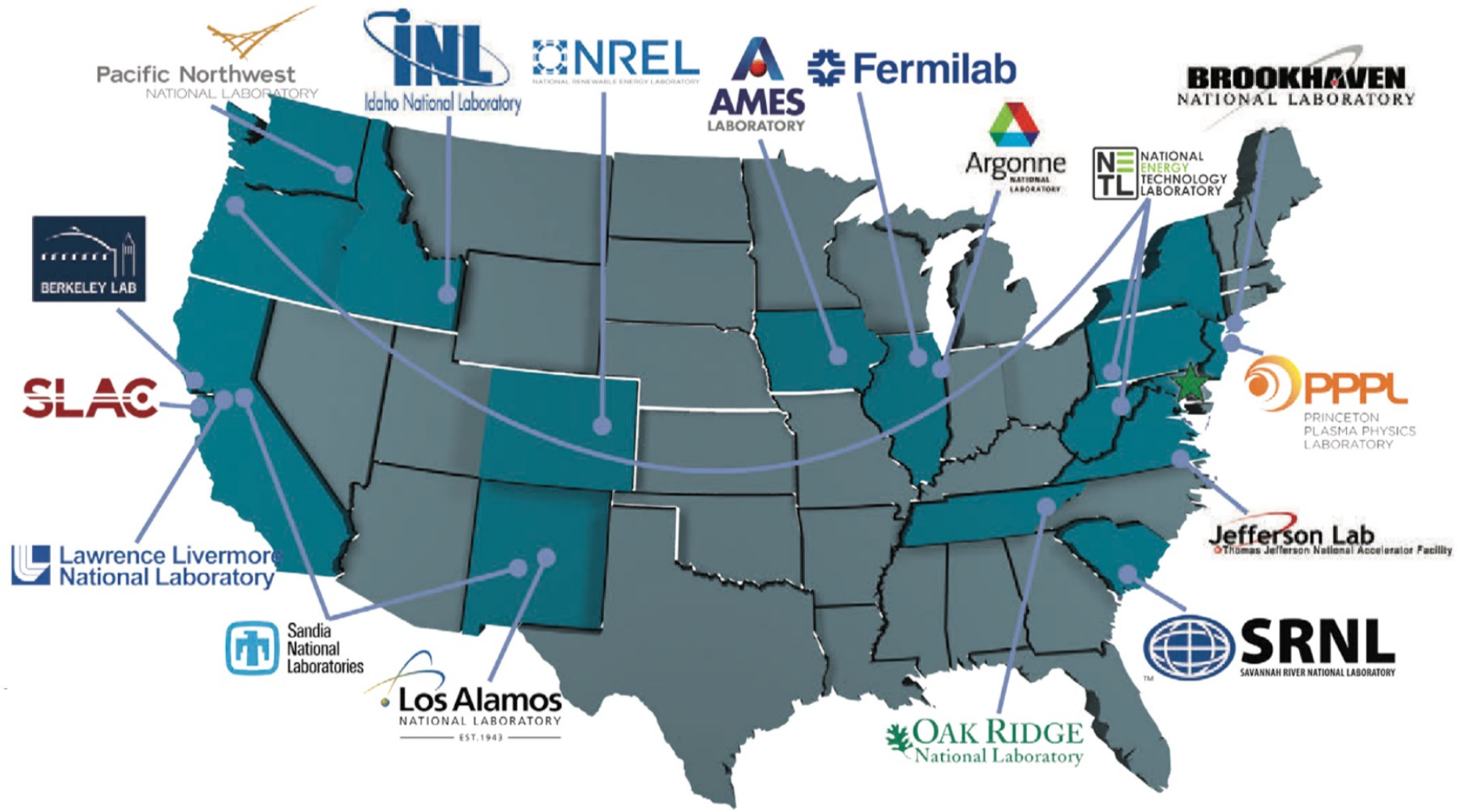
NSF: National Science Foundation

NOAA: National Oceanic and Atmospheric Administration

USGS: US Geological Survey

Source: Congressional Budget Office www.cbo.gov

DOE National Lab System: 17 labs

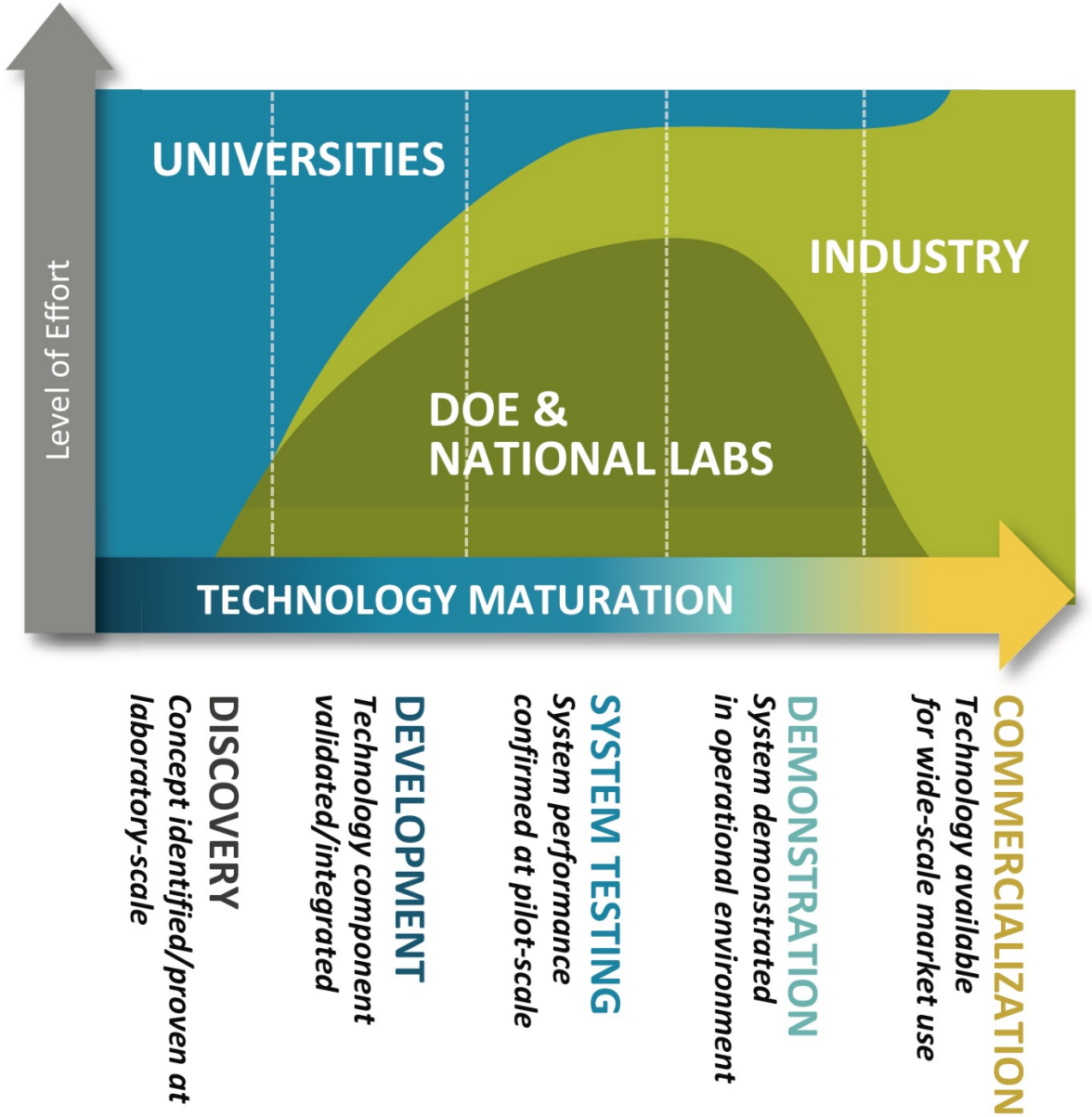


Source: “DOE State of the National Labs Report” (2017)

DOE National Labs

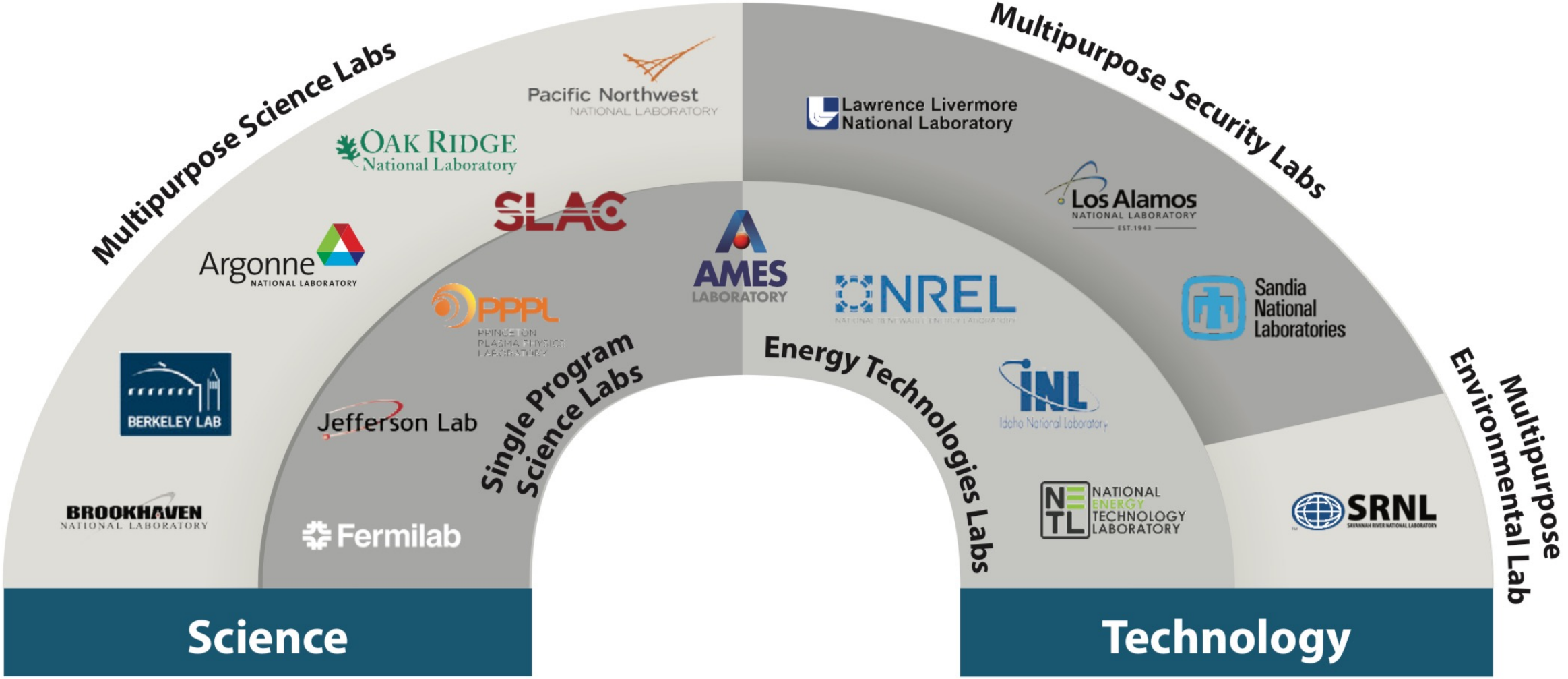
1. More staff, fewer students than university
2. Started from Manhattan Project (WWII project to develop nuclear bombs)
3. Wide range of missions
4. Cannot compete with industry

Ex: Particle accelerators, clean rooms, supercomputers, hydrofracking, DNA decoding, space probe power …



Source: "DOE State of the National Labs Report" (2017) and "75 Breakthroughs by America's National Laboratories" (2018)

DOE National Labs



Source: "DOE State of the National Labs Report" (2017)

DOE National Labs

Up to 75 year history

115 Nobel Prizes total

Discovered 22 elements

~11,000 peer-reviewed papers/year

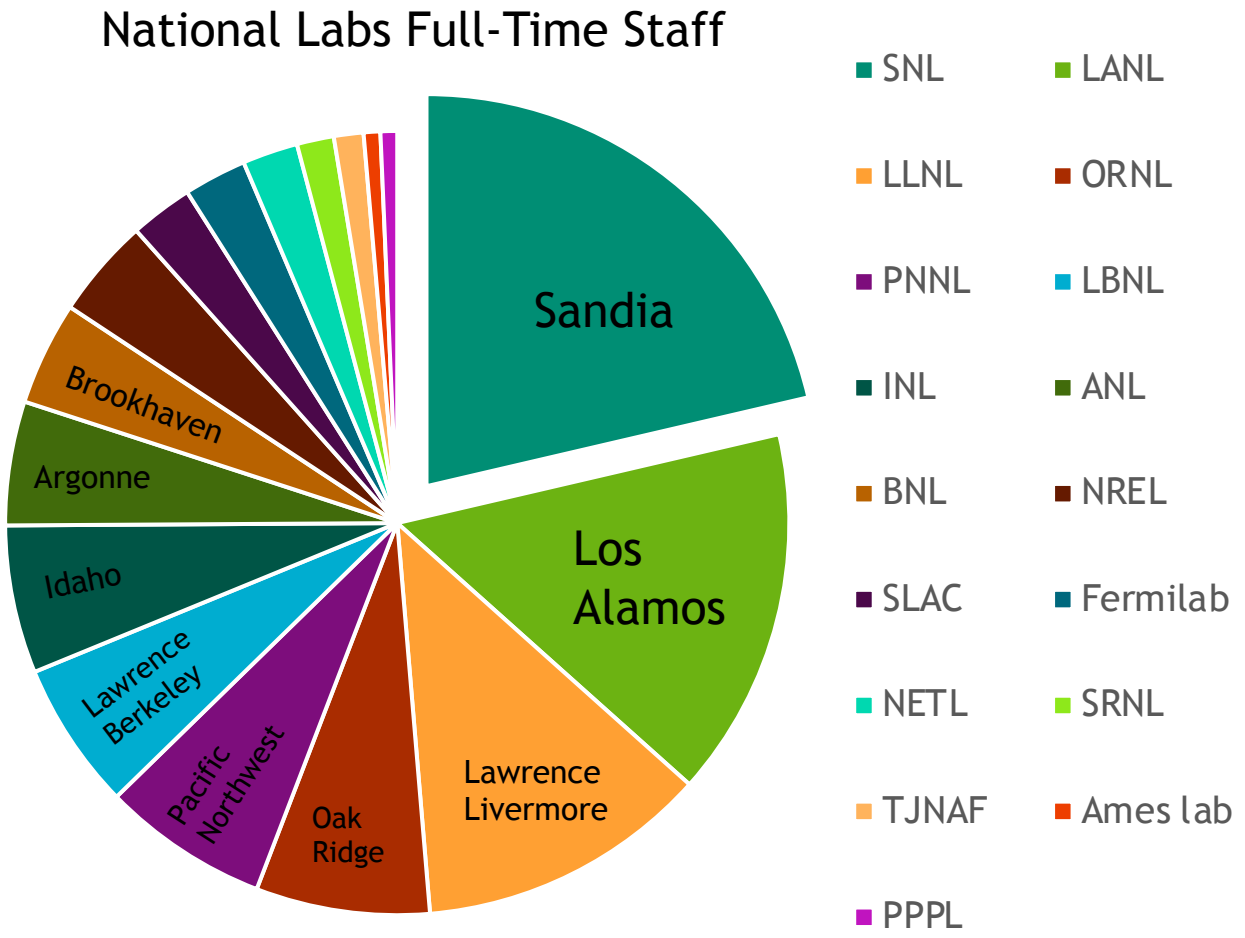
57,000 full-time employees

>20,000 scientists/engineers

2,300 post-docs

2,000 grad students

3,000 undergrads



Ames Laboratory (Ames)
Argonne National Laboratory (ANL)
Brookhaven National Laboratory (BNL)
Fermi National Accelerator Laboratory (FNAL)
Idaho National Laboratory (INL)
Lawrence Berkeley National Laboratory (LBNL)
Lawrence Livermore National Laboratory (LLNL)
Los Alamos National Laboratory (LANL)
National Energy Technology Laboratory (NETL)
National Renewable Energy Laboratory (NREL)
Oak Ridge National Laboratory (ORNL)
Pacific Northwest National Laboratory (PNNL)
Princeton Plasma Physics Laboratory (PPPL)
Sandia National Laboratories (SNL)
Savannah River National Laboratory (SRNL)
SLAC National Accelerator Laboratory (SLAC)
Thomas Jefferson National Accelerator Facility (TJNAF)

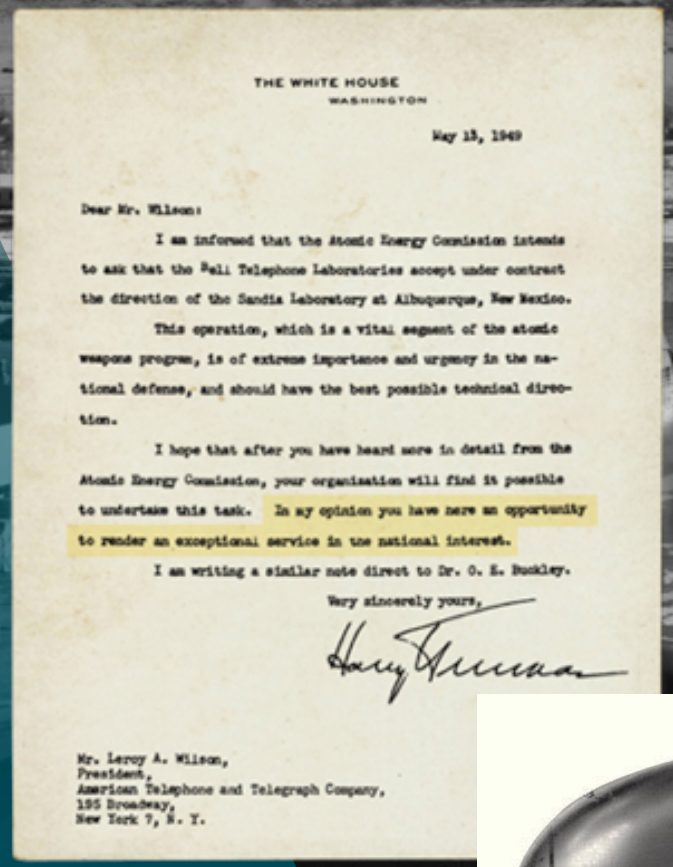
Source: “DOE State of the National Labs Report” (2017)

What is Sandia?

SANDIA'S HISTORY IS TRACED TO THE MANHATTAN PROJECT

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

- July 1945
  Los Alamos creates Z Division
- Nonnuclear component engineering
- November 1, 1949
  Sandia Laboratory established
- AT&T: 1949–1993
- Martin Marietta: 1993–1995
- Lockheed Martin: 1995–2017
- Honeywell: 2017–present



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.

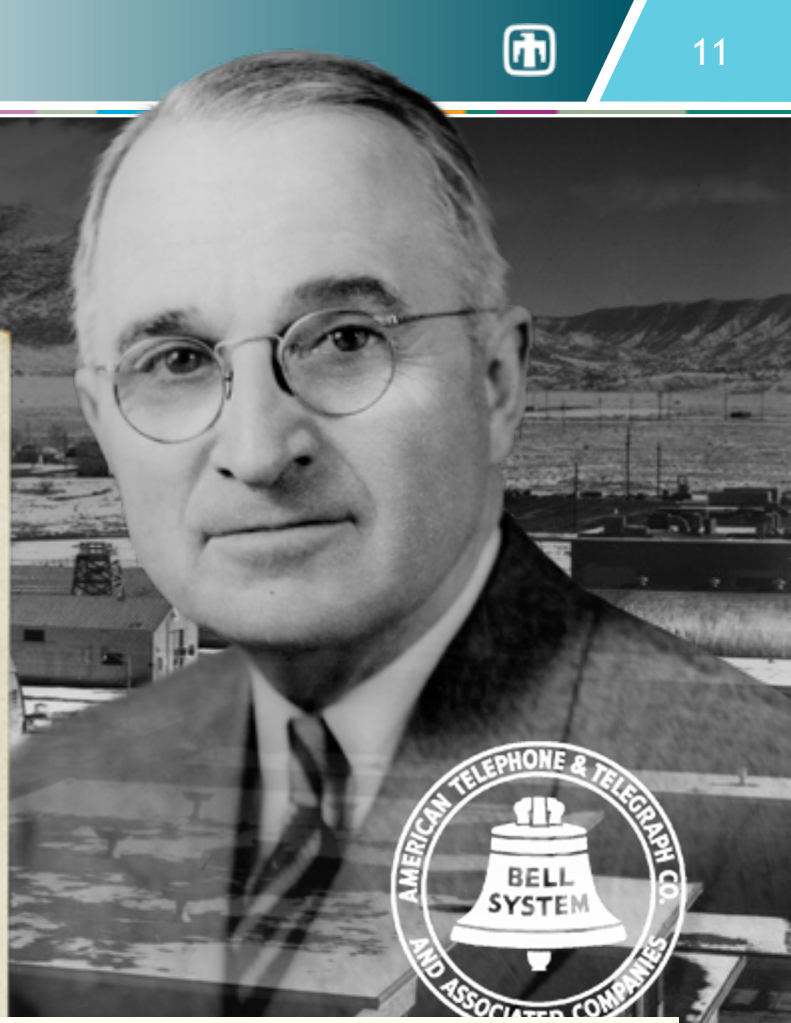
I hope that after you have heard more in detail from the Atomic Energy Commission, your organization will find it possible to undertake this task. In my opinion you have here an opportunity to render an exceptional service in the national interest.

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.

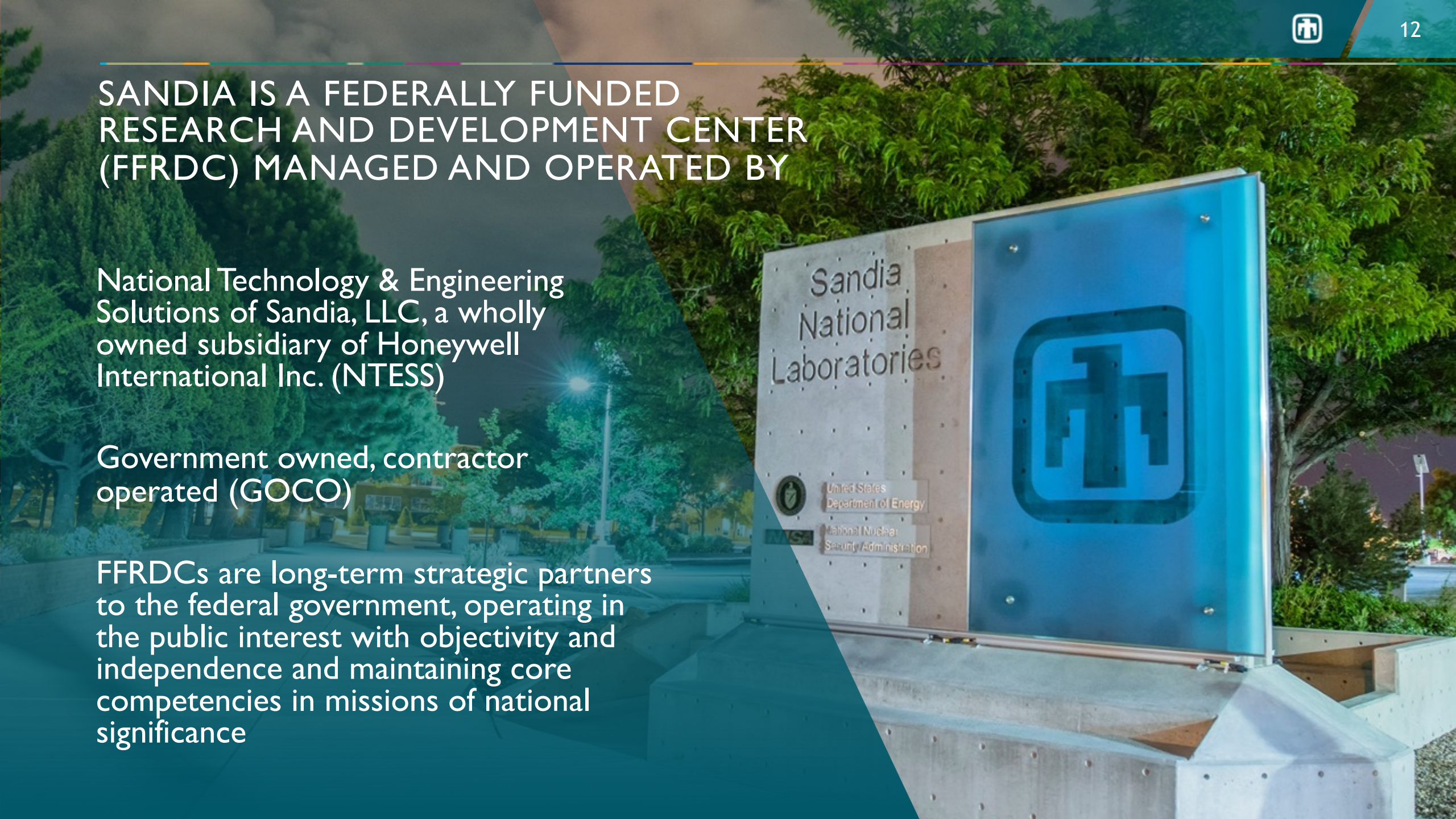


SANDIA IS A FEDERALLY FUNDED RESEARCH AND DEVELOPMENT CENTER (FFRDC) MANAGED AND OPERATED BY

National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc. (NTESS)

Government owned, contractor operated (GOCO)

FFRDCs are long-term strategic partners to the federal government, operating in the public interest with objectivity and independence and maintaining core competencies in missions of national significance



SANDIA HAS FACILITIES ACROSS THE NATION

Activity locations

- Kauai, Hawaii
- Waste Isolation Pilot Plant, Carlsbad, New Mexico
- Pantex Plant, Amarillo, Texas
- Tonopah, Nevada

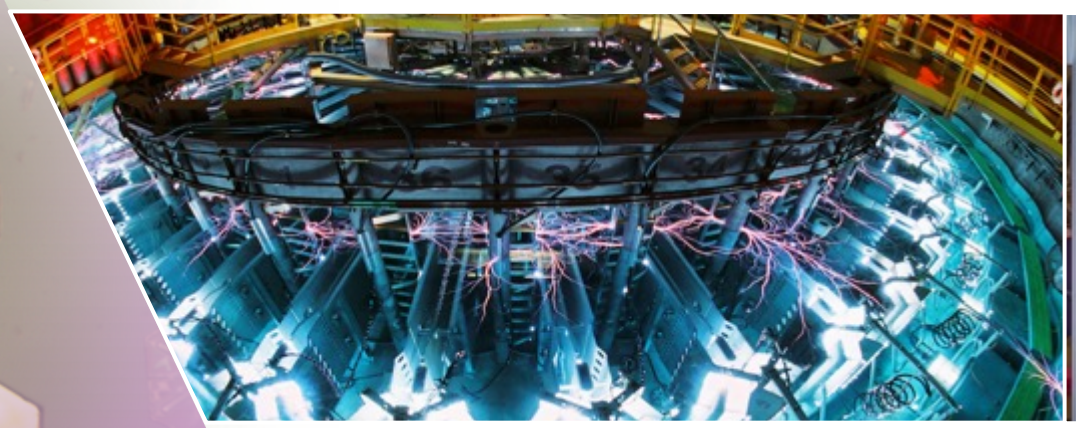
Main sites

- Albuquerque, New Mexico
- Livermore, California

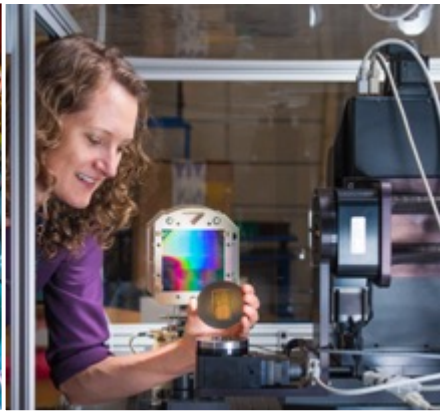
ADVANCED SCIENCE & TECHNOLOGY

Research Foundations play an integral role in mission delivery

Nanodevices & Microsystems

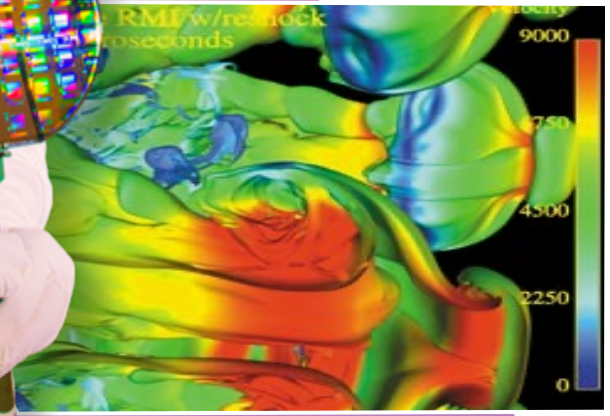


Radiation Effects & High Energy Density Science



Materials Science

Computing & Information Science



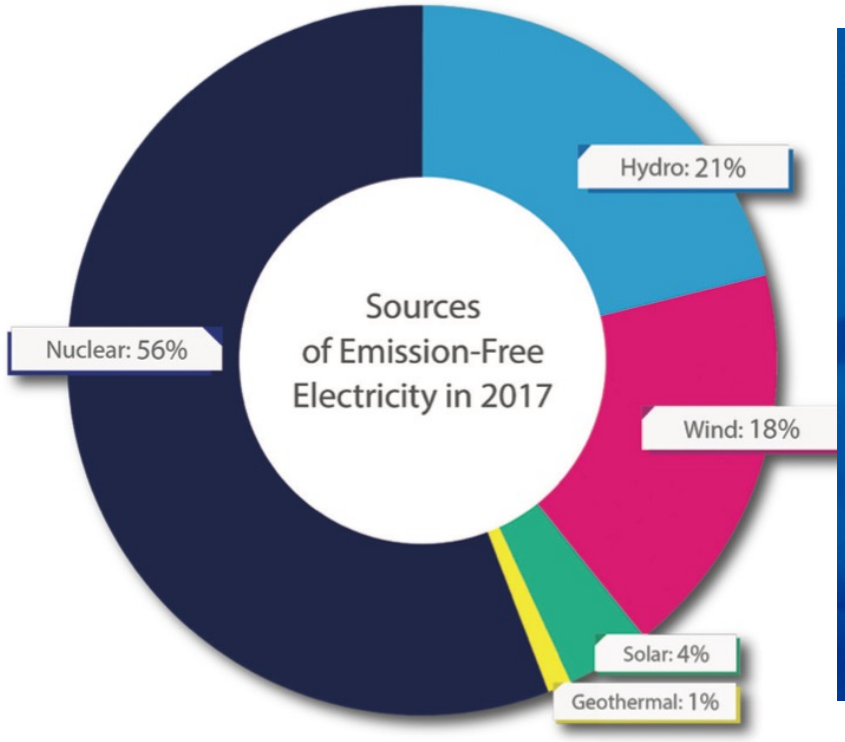
Engineering Science

Geoscience
(~150 staff)

Bioscience

Nuclear Waste Disposal

Nuclear Energy is >50% of clean energy in US



Spent nuclear fuel is kept in pools or dry-cask storage

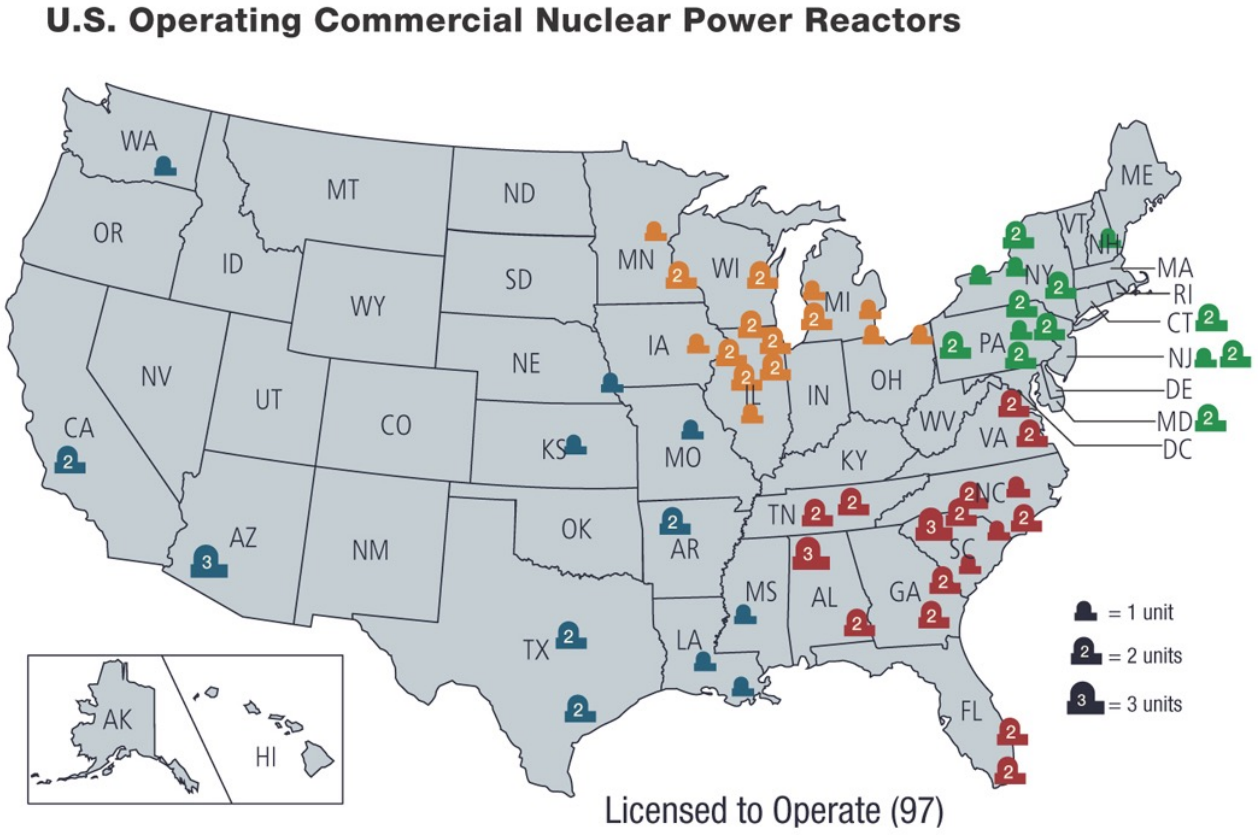
Need a permanent disposal option for heat-generating waste

Source: “Ultimate Fast Facts guide to Nuclear Energy” (2019)

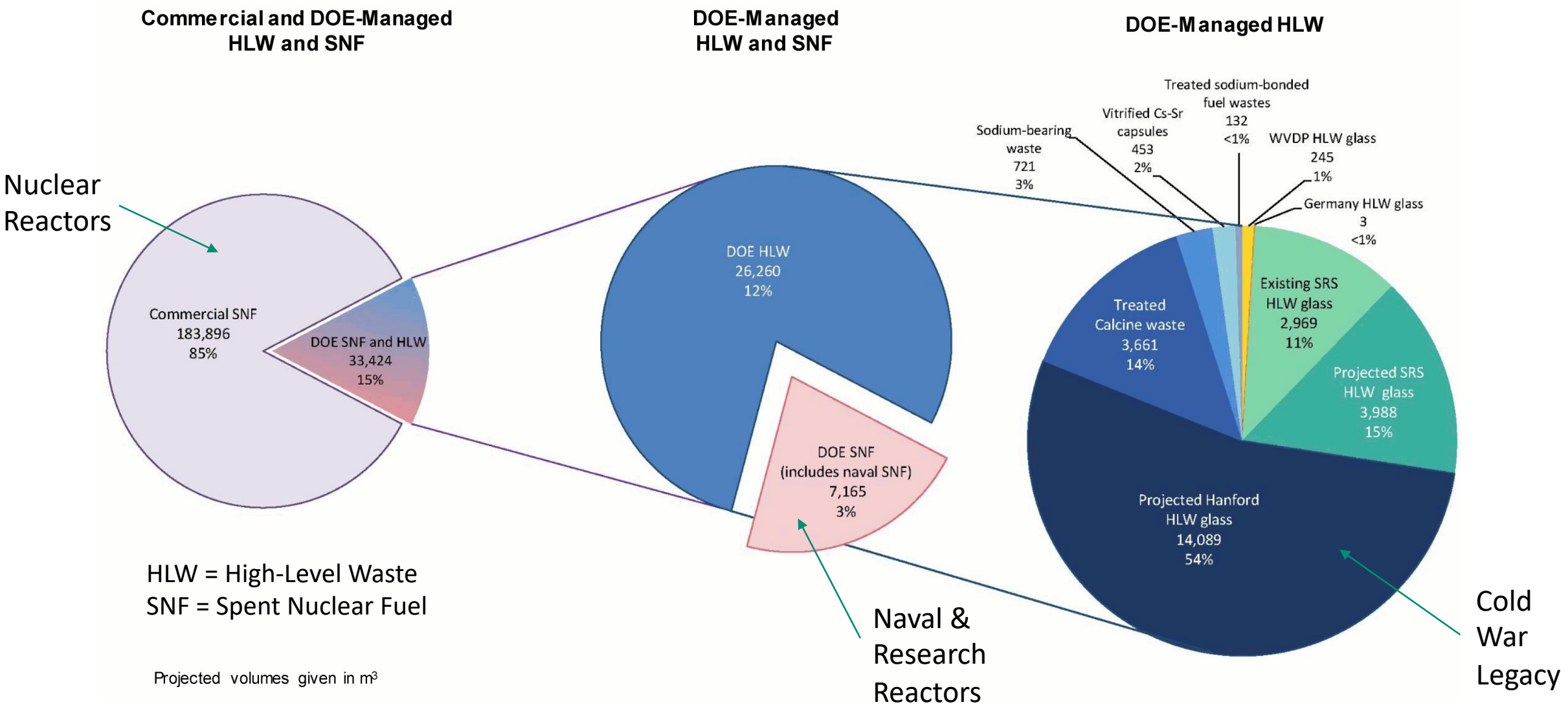
Nuclear Waste Types

US Nuclear waste

1. Power generation
2. Cold War legacy
3. Nuclear Navy
4. Research reactors
5. Medical isotope production



Nuclear Waste Types: By Volume



Source: "Assessment of Disposal Options for DOE-Managed High-Level Radioactive Waste and Spent Fuel" (2014)

DOE Office of Nuclear Energy (DOE-NE)

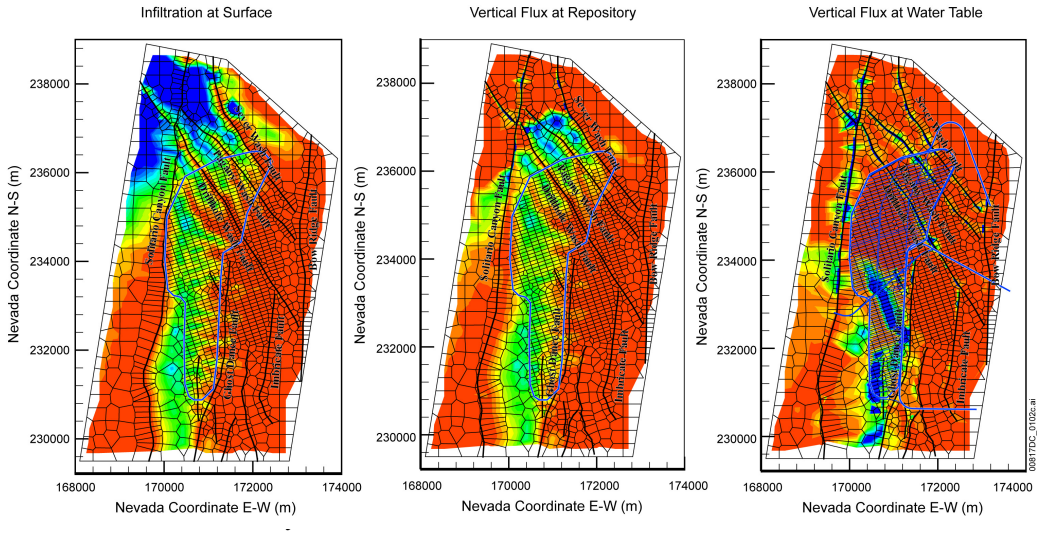
Generic disposal options

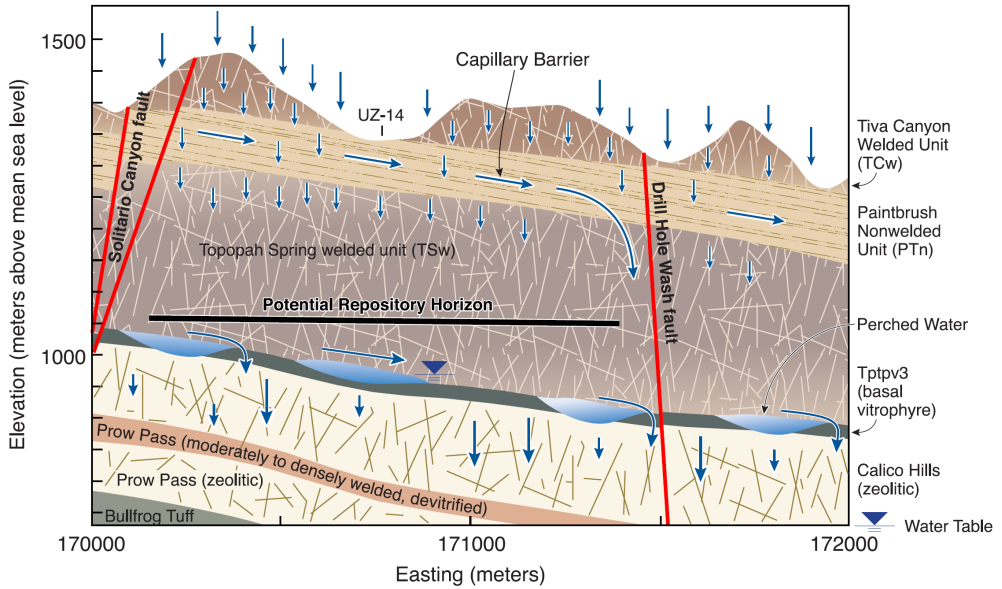
1. Crystalline rock (e.g., granite)
2. Argillaceous rock (e.g., claystone)
3. Evaporite rocks (e.g., salt)

Field experiments for data

Simulate safety of repository

Performance Assessment





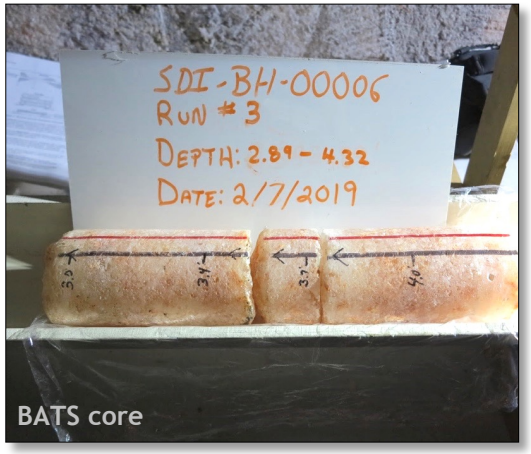
Source: "Repository Science at Sandia: WIPP, Yucca Mountain, and the Path Forward", P. Swift (2012) SAND2012-6969P.

Brine Availability Test in Salt (BATS)

Research into Disposal of High-Level Waste in Salt

Brine Availability Test in Salt at WIPP (BATS)

Monitoring brine from heated salt using geophysics and sampling.



BATS core


Drilling BATS boreholes

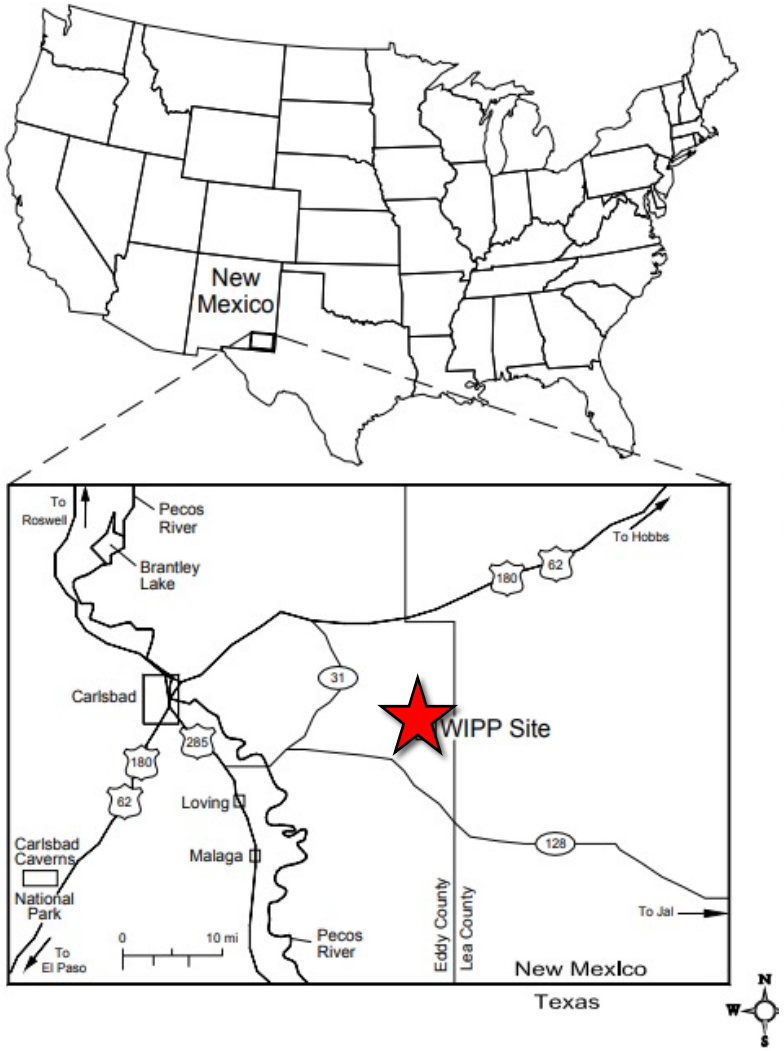

BATS test drift

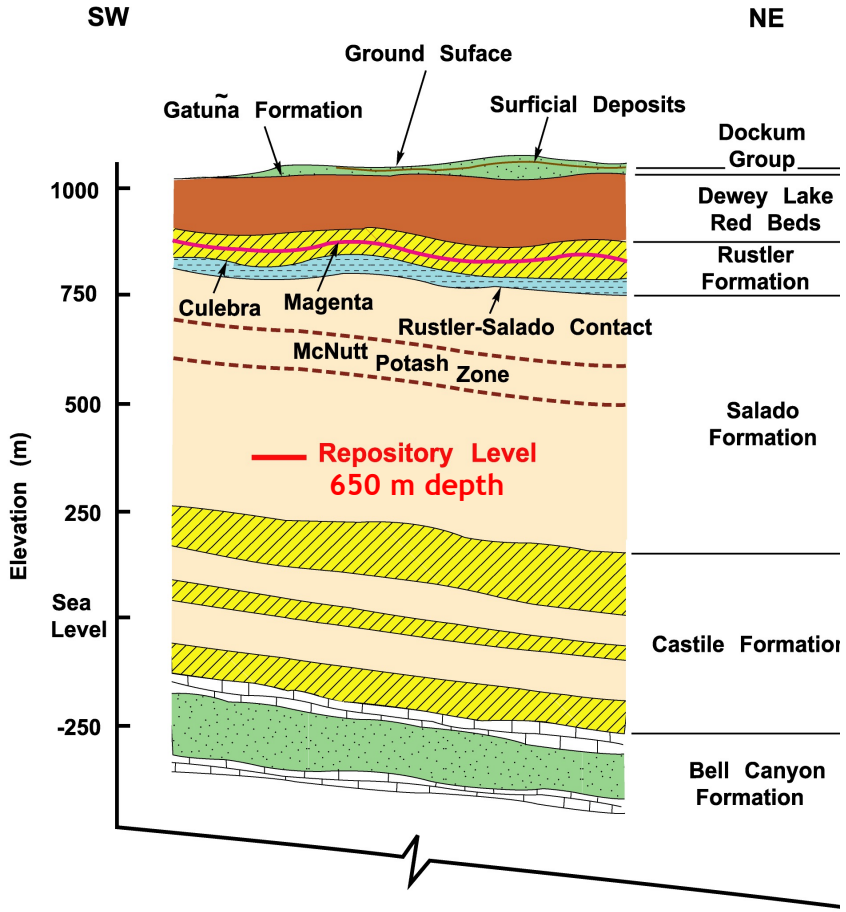
Sandia National Laboratories

Los Alamos NATIONAL LABORATORY EST. 1943

BERKELEY LAB

Waste Isolation Pilot Plant (WIPP): Existing Disposal Facility





WIPP repository for TRU (transuranic) waste

1. *WIPP operating since 1999*
2. *Cleaning up Cold War legacy*
3. *WIPP allows us to use their facility*

Why Geologic Salt?

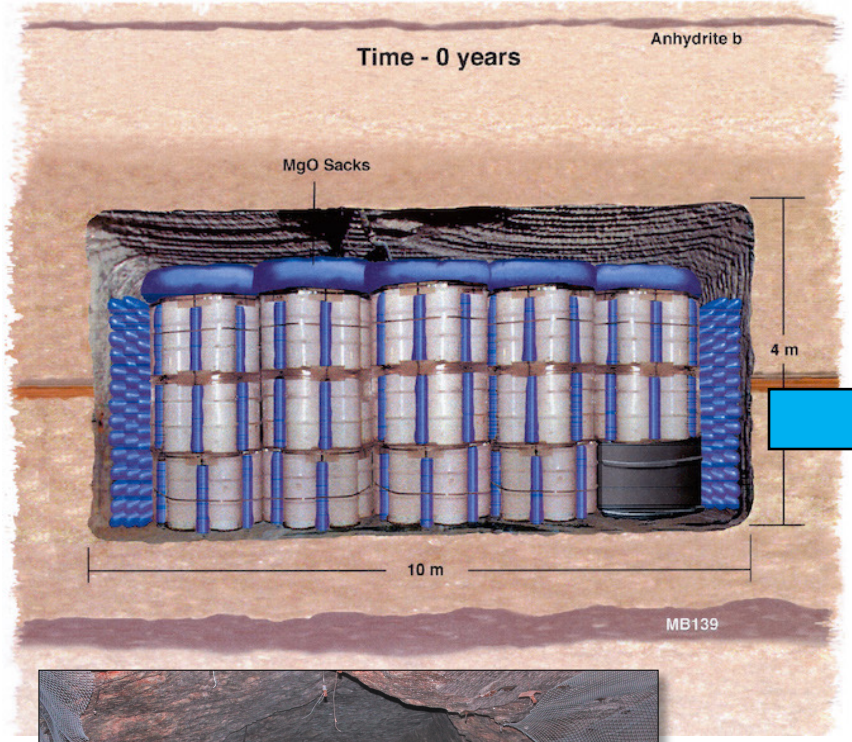
Long-term benefits

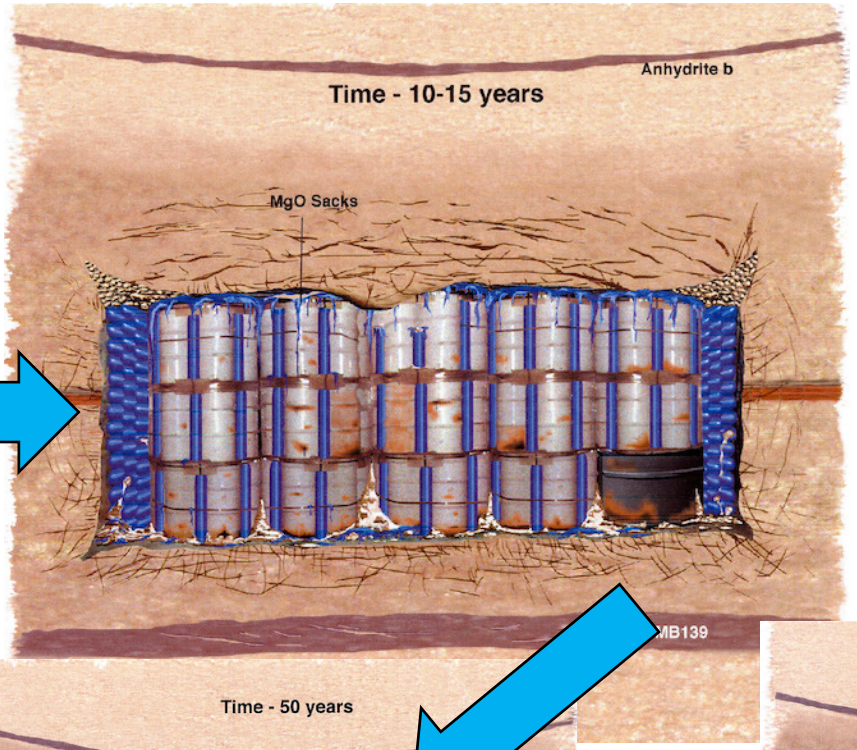
- Low connected porosity (0.1 vol-%) and permeability ($\leq 10^{-22}$ m^2)
- High thermal conductivity (~ 5 W/(m · K))
- No flowing groundwater (≤ 5 wt-% water)
- Hypersaline brine is biologically simple, has less-stable colloids
- Permian salt has been stable for ~250 M yrs
- Excavations, damage, and fractures will creep closed
- Mined salt reconsolidates and heals to intact salt properties

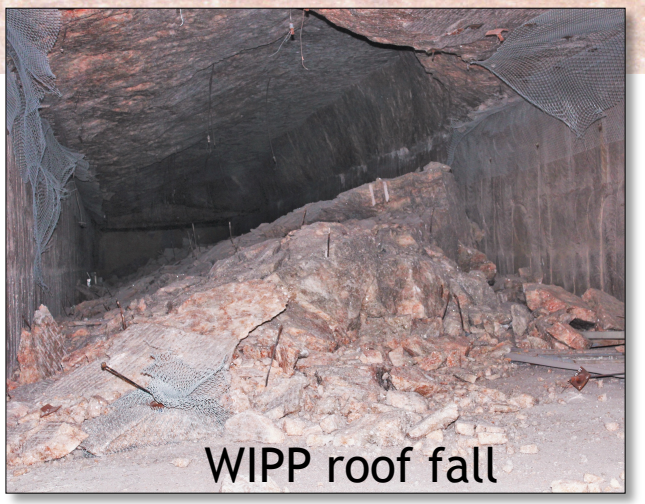
Near-field short-term complexities

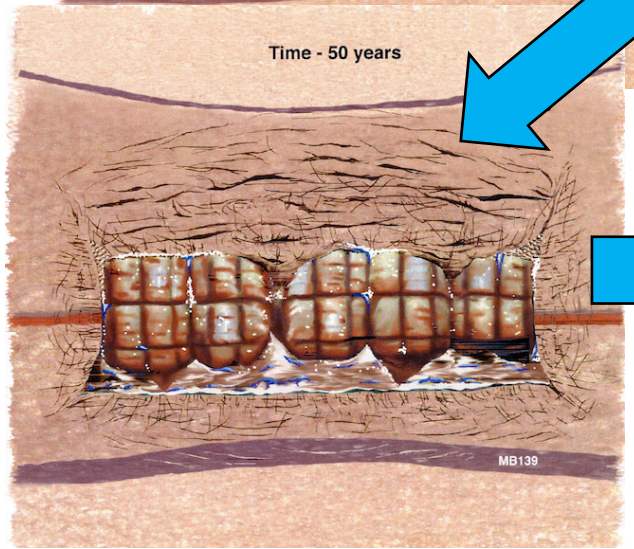
- Hypersaline brine is corrosive
- Salt is very soluble in fresh water
- Salt creep requires excavation maintenance

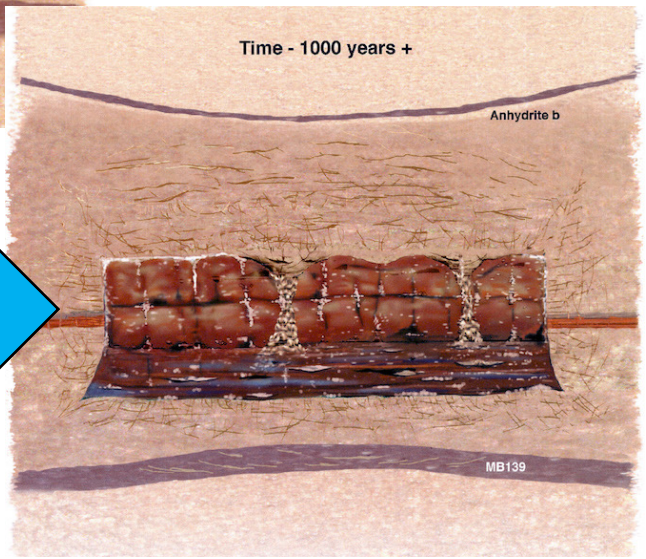
Creep Closure of Rooms at WIPP











Why is Brine Important in a Repository?

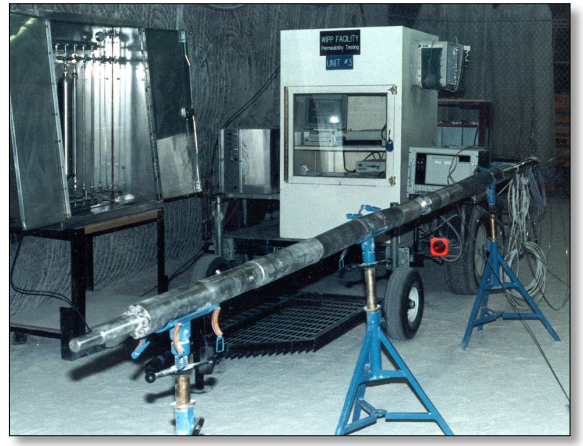
Brine Availability: *Brine distribution in salt & how it flows to excavations*

- Predicting where brine and permeability are around excavations
- Brine causes corrosion of waste package / waste form
- Brine is primary radionuclide transport vector
- Liquid back-pressure can resist drift creep closure

WIPP Room B heated brine migration

WIPP Room J canister tests

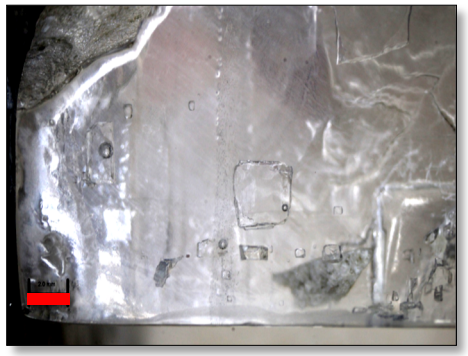
WIPP Room Q brine inflow



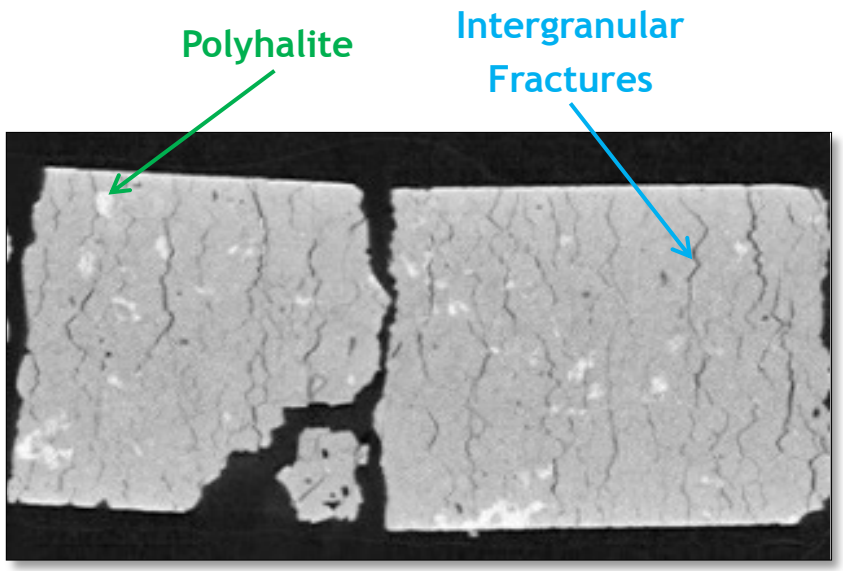
WIPP brine permeability testing

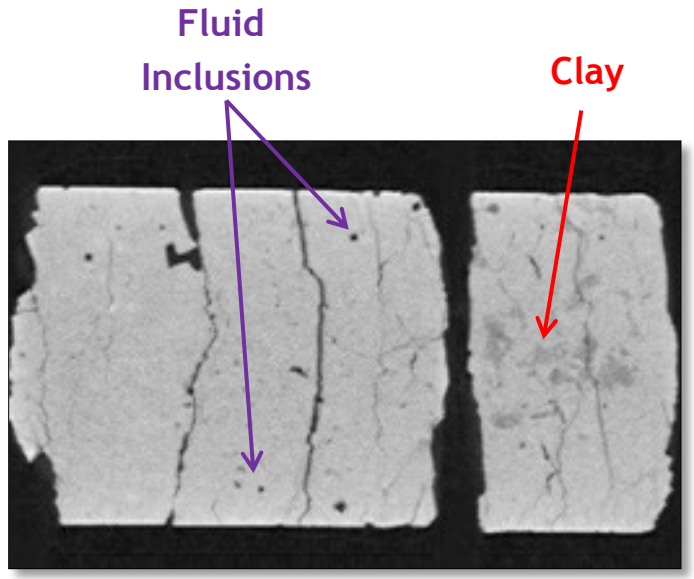
Brine in Bedded Salt

- Water in salt from Permian* deposition
  1. Disseminated clay (< 5 vol-% total; ~25 vol-% brine)
  2. Intragranular brine (fluid inclusions; 1 – 2 vol-%)
  3. Hydrous minerals (e.g., polyhalite, bischofite, epsomite)
  4. Intergranular brine (between salt crystals; << 1 vol-%)
- These water types:
  - respond differently to heat & pressure
  - have varying chemical composition
  - differ in stable water isotope makeup



WIPP fluid inclusions, 2 mm scale bar
(Caporuscio et al., 2013)





10.1 cm diameter core CT data (Betters et al., 2020)

- Damaged zone increases porosity → primary flow path

How do water types contribute to *Brine Availability*?

* Permian geologic period was 252 – 299 million years ago

BATS Borehole Arrays

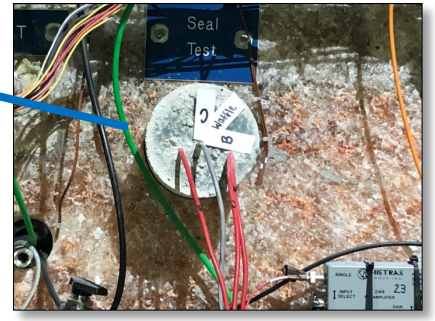
AE sensors on de-centralizers

T = Temp Only Holes
AE = Acoustic Emissions
SL = Seal
D = D2O + Tracer Source
E = ERT Electrodes
F = Fiber Optic (T and/or Strain)
SM = Sampling
HP = Heater and Packer

ERT (E1)

Seal (SL)

Lab-made seal installed in borehole subsequently sealed behind packer



AE1

Source (D)

Heater/N_2 (HP)

Thermocouples (T1-2)

Fiber (F2)

AE3

Field (BATS)

Lab (GRS)

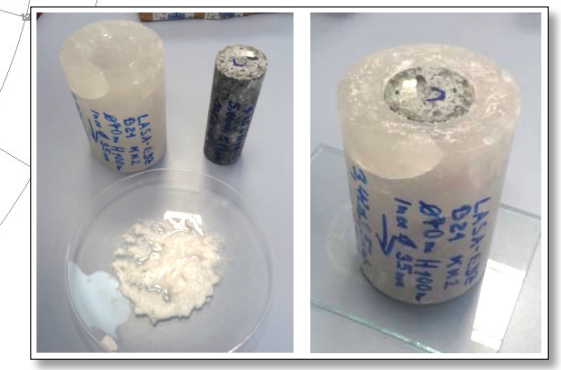
Sampling (SM)

Diamonds = grouted

Circles = not grouted/packer

ERT (E2)

Fiber (F1)



Czaikowski et al. (2016)

Fiber optic DSS/DST

ERT controller

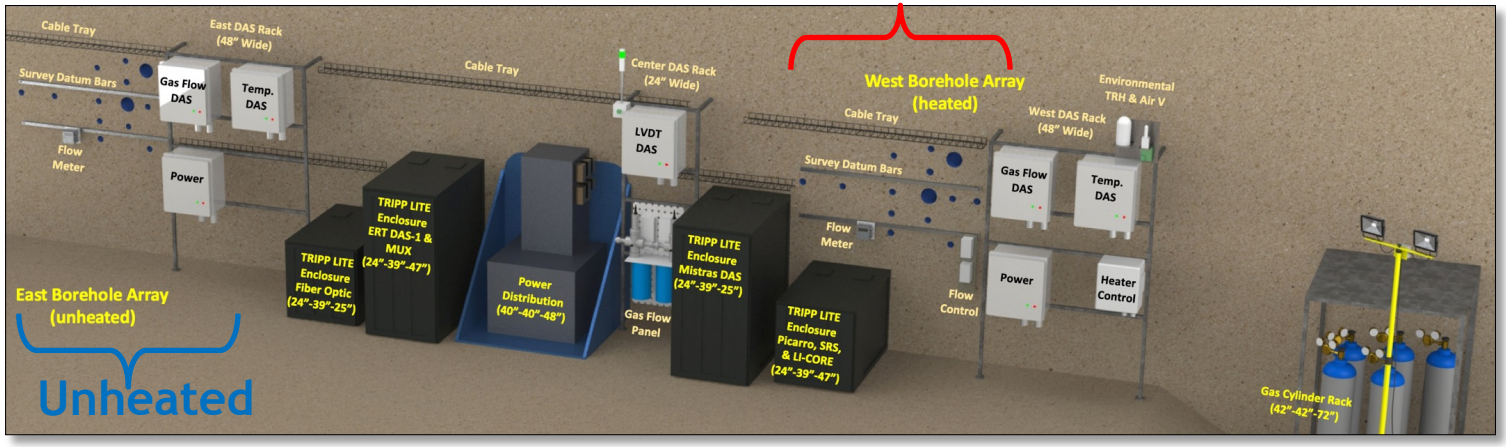
Acoustic Emission (AE2)

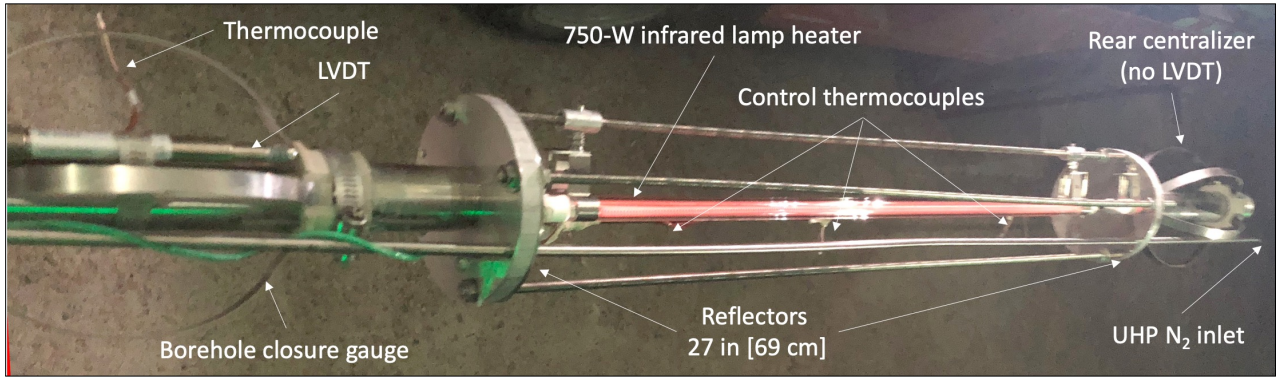
ERT (E3)

(Borehole layout drawing by WIPP TCO)

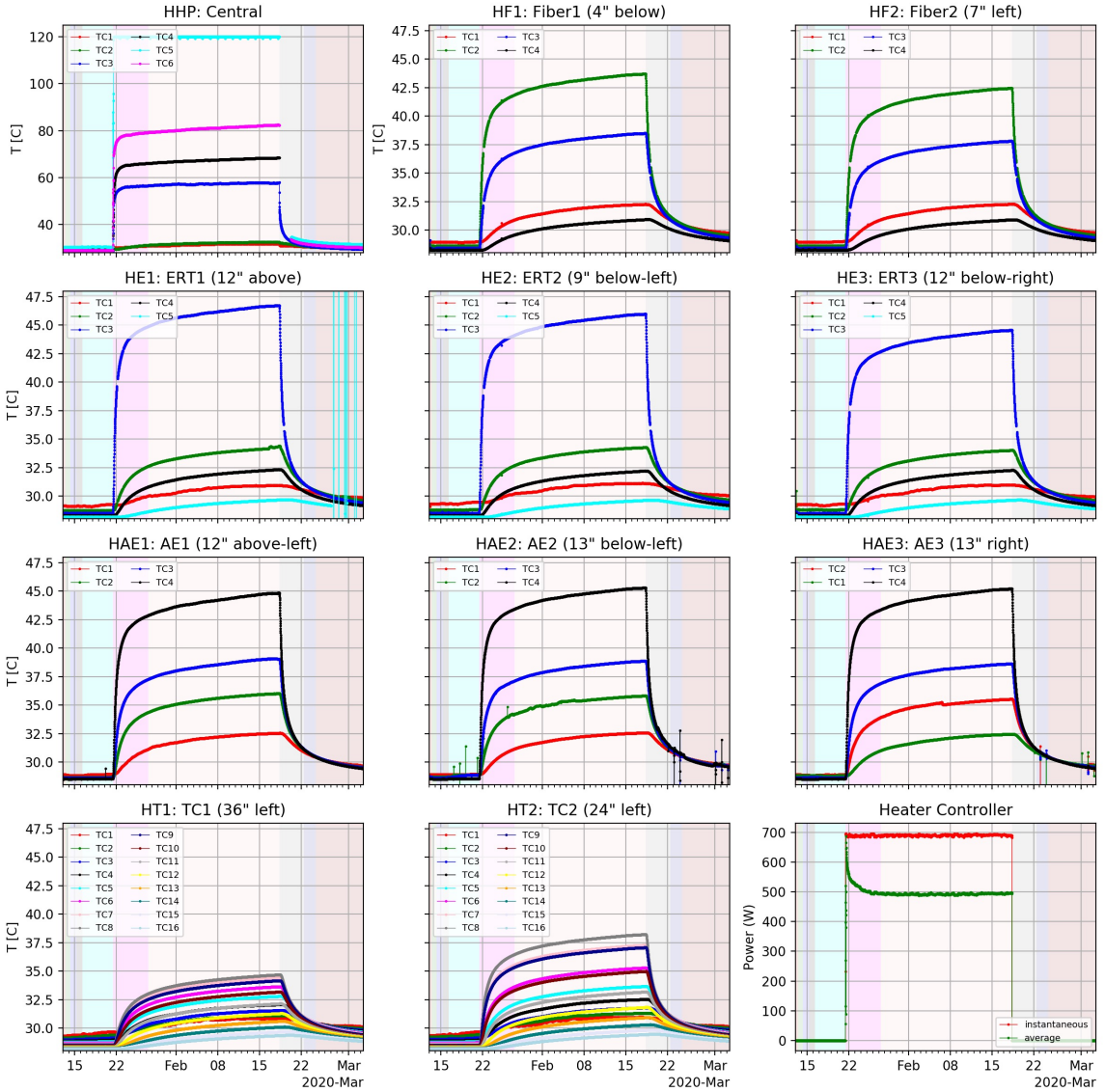
What Data are We Collecting?

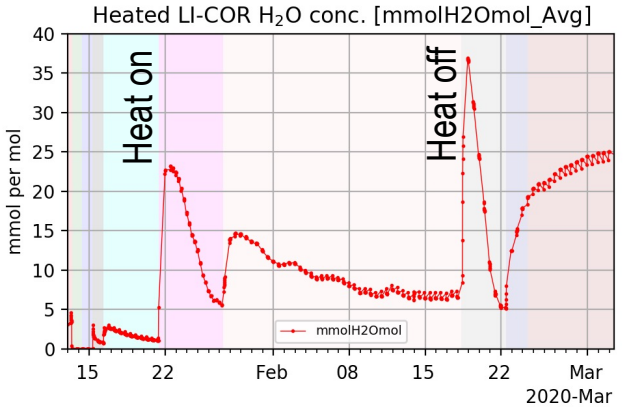
- Two Arrays: Heated / Unheated
- Behind packer
  - Circulate dry N_2
  - Quartz lamp heater (750 W)
  - Borehole closure gage
- Samples / Analyses
  - Gas stream (natural / applied tracers and isotopic makeup)
  - Liquid brine (natural chemistry and natural / applied tracers)
  - Cores (X-ray CT and fluorescence at NETL)
- Cement Seals
  - Sorel cement + Salt concrete: 3-axis strain & temperature
- Geophysics
  - 3× Electrical resistivity tomography (ERT)
  - 3× Acoustic emissions (AE)
  - 2× Fiber optic distributed strain / temperature sensing

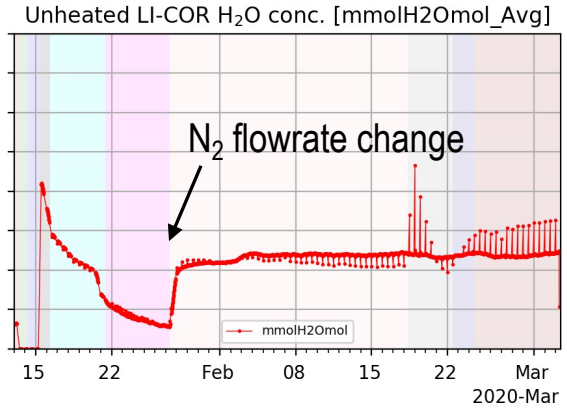


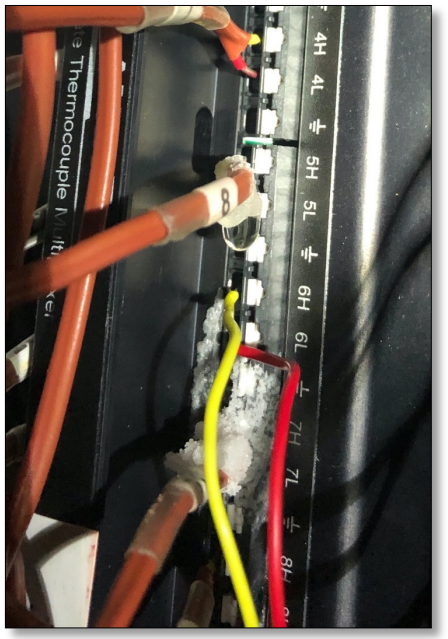


Temperature and Brine Inflow





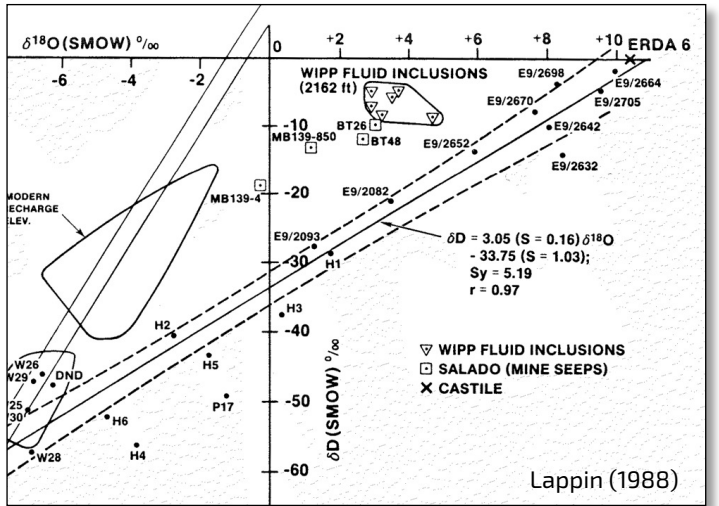




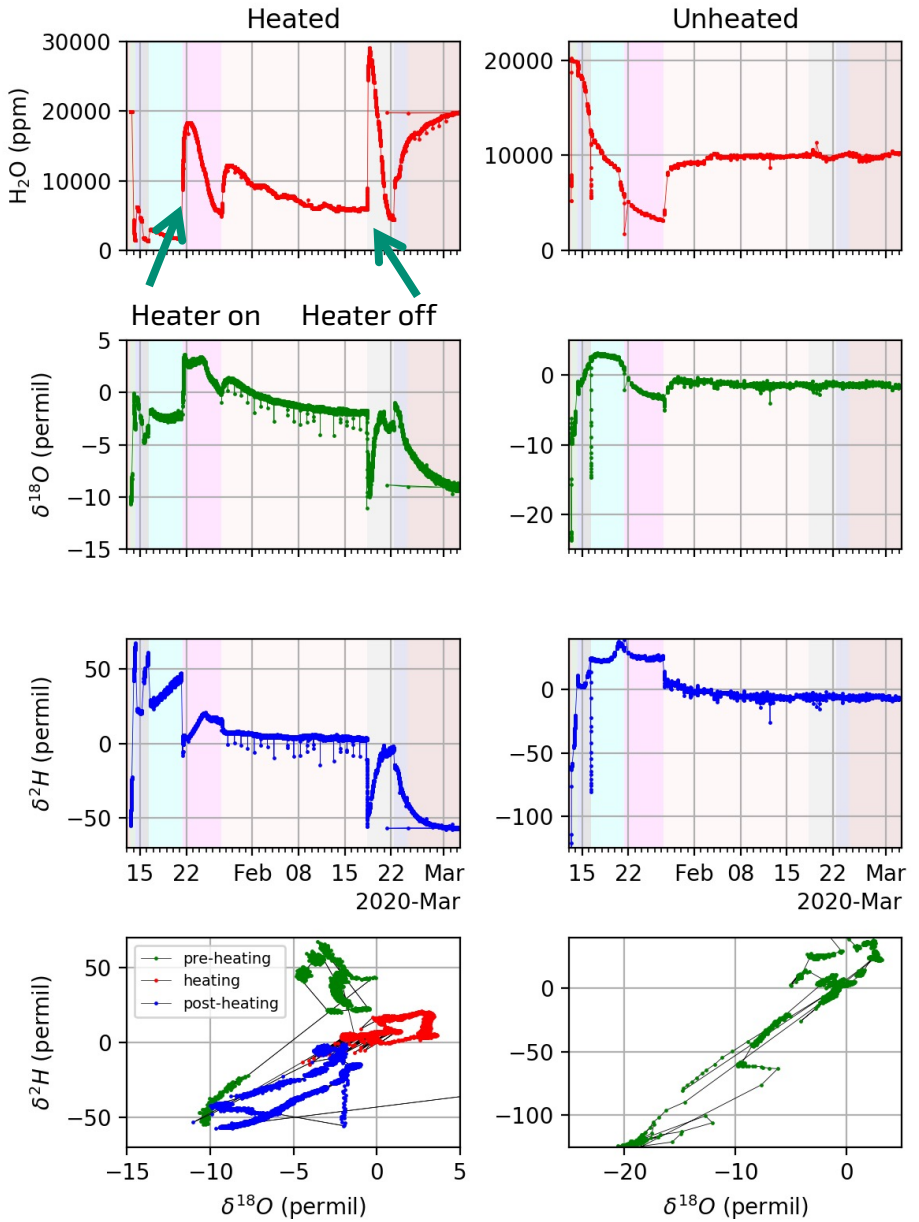
Lesson: Brine can seep through thermocouple wires!

Water Isotopic Composition

- Continuously analyze gas stream
- Isotopic makeup of humidity stream
  - Info on brine source (fluid inclusions vs. clays)
  - When is there a puddle in back of borehole?
- Data informs:
  - Isotopic identification of brine types
  - Advection / diffusion / reaction (water as a tracer)

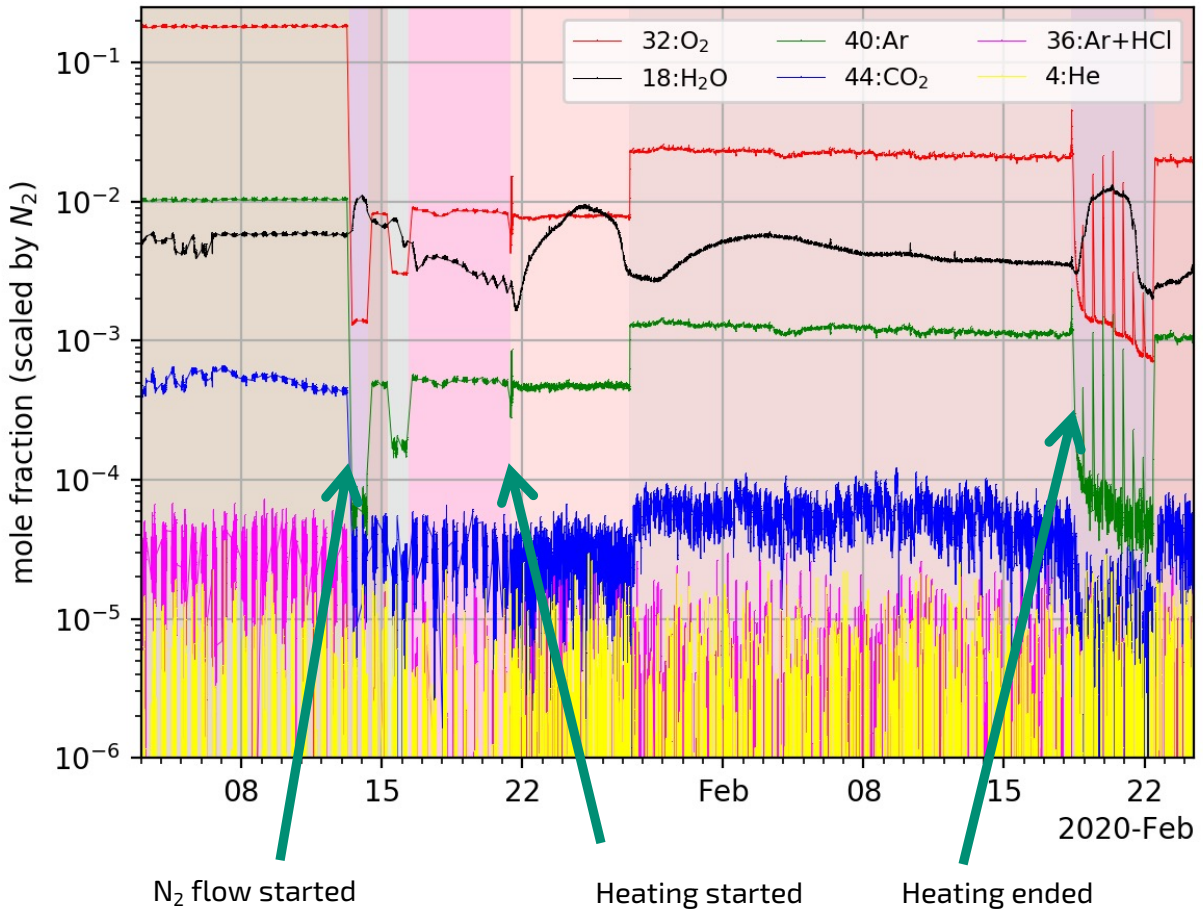


Picarro cavity ringdown Spectrometer (CRDS)



Gas Stream Composition

- Continuously analyze gas stream
- Gases may come from
  - Dissolved in brine
    - Less soluble in lower pressure, hotter brine
  - Sorbed to salt (CO_2)
  - Geogenic gases within salt (e.g., He & Ar)
  - Added gas tracers (Ne, Kr & SF_6)
- Data informs:
  - Gases produced from heating salt
  - Leakiness of packer system
  - Advection / diffusion /reaction (tracer)
- Lesson: QMS is sensitive instrument (dust bad)



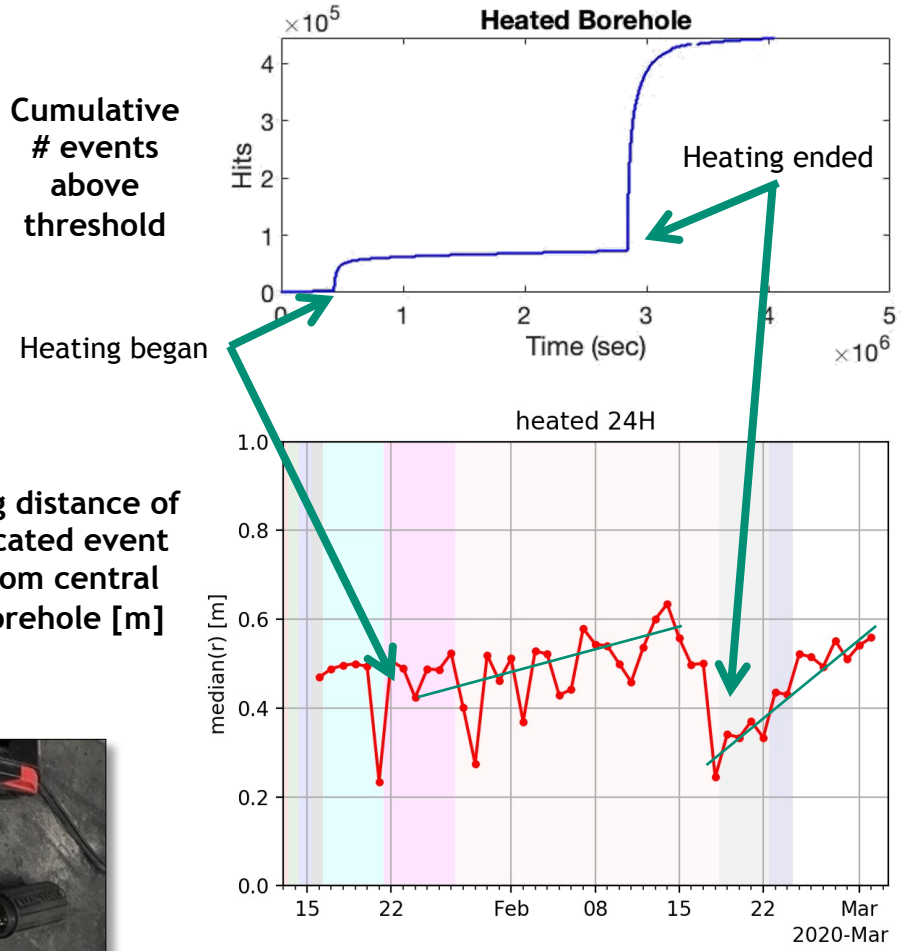
SRS quadrupole mass spectrometer (QMS) gas analyzer

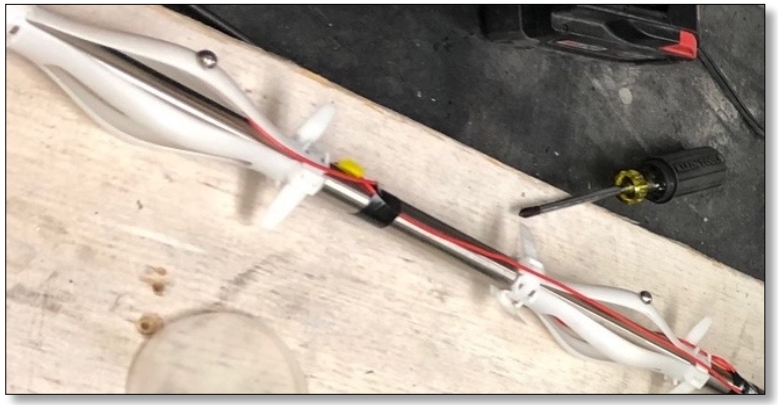
Acoustic Emissions (AE)

Listen to salt with piezoelectric transducers

- Salt cracking during heat up & cool-down
- Triangulate AE sources around heated borehole
- AE correlated with permeability increases
- >75% of events from cool-down

- Data inform:
  - Where & when damage occurs
  - Estimate damage extent
  - Monitor damage evolution

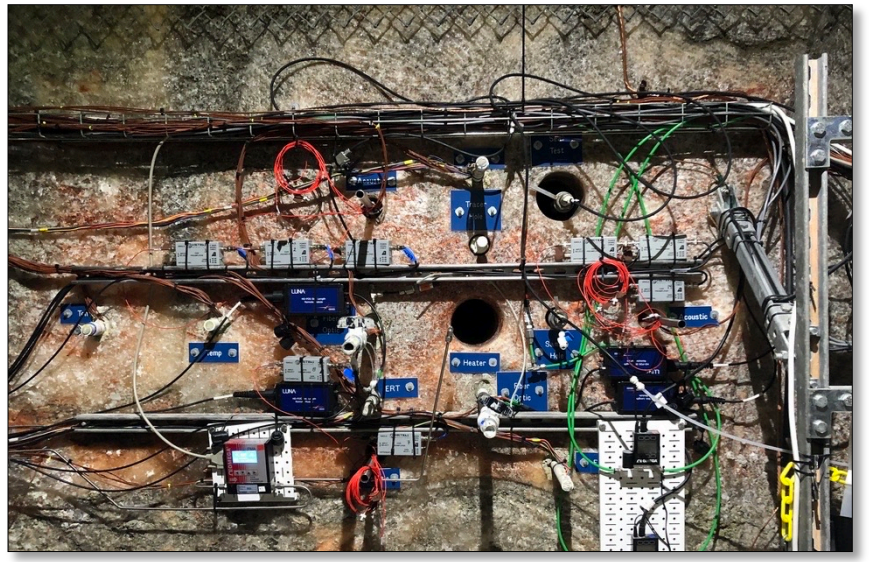


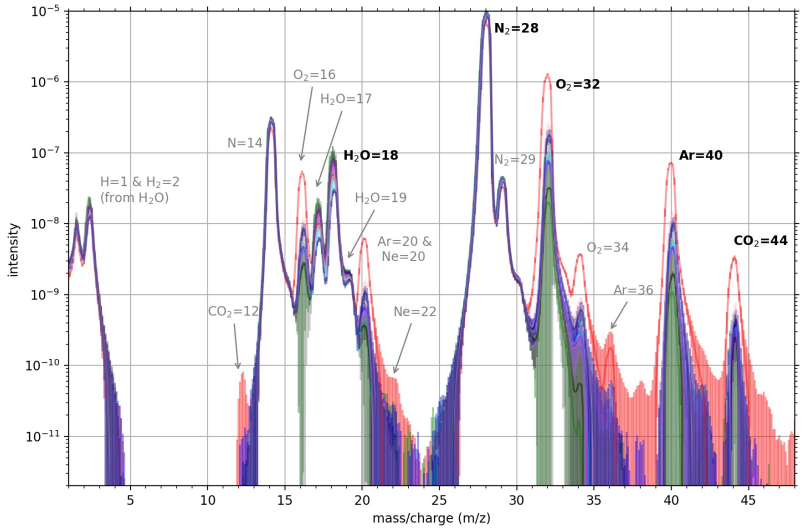


Decentralizers and piezoelectric transducers

Why are These Data Useful?

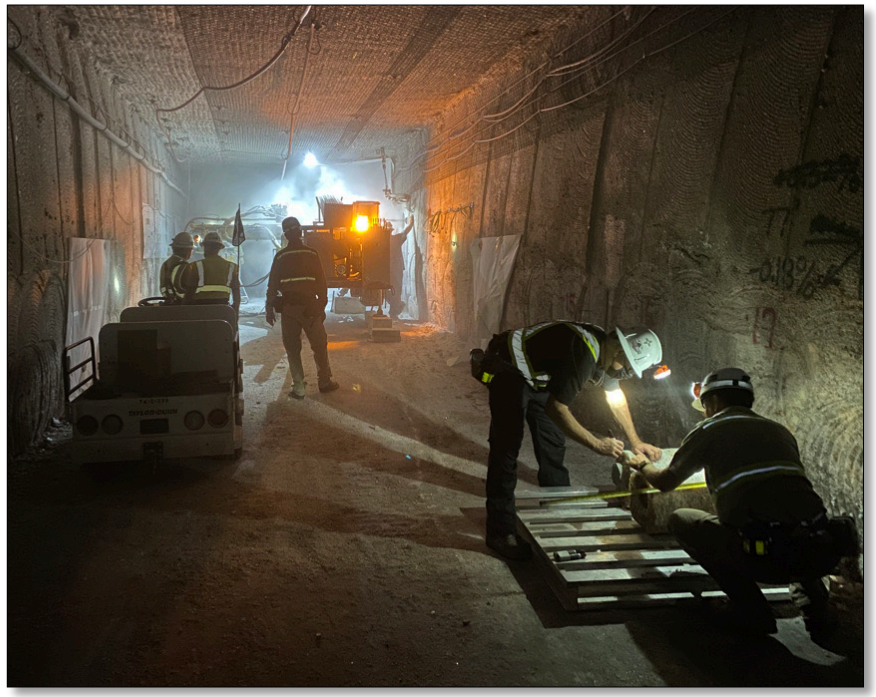
- Brine composition samples / H_2O isotope data
  - Observe change in brine sources with temperature
- Geophysics
  - Evolution of **saturation** / **porosity** / **permeability**
- Temperature distribution
  - More brine at high T (inclusions + hydrous minerals)
  - Salt dry-out near borehole (above boiling)
- Tracer migration through salt
  - Monitor brine movement through salt damage zone
- Coupled processes in salt
  - Permeability(damage(stress(temperature)))
  - $k[\epsilon(\sigma(T))]$

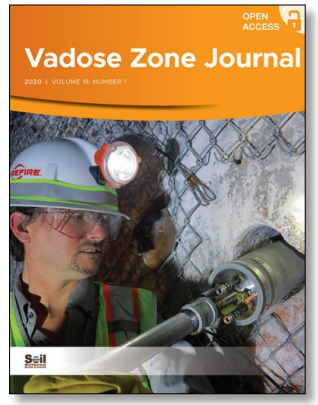




BATS Test Status

- Boreholes drilled/installed (2019)
- BATS 1a heated phase (Jan-Mar 2020)
- COVID-19
- Gas tracer tests (Jan-July 2021)
- BATS 2.0 construction (now)
- BATS publications
  - Vadose Zone Journal
  - Minerals

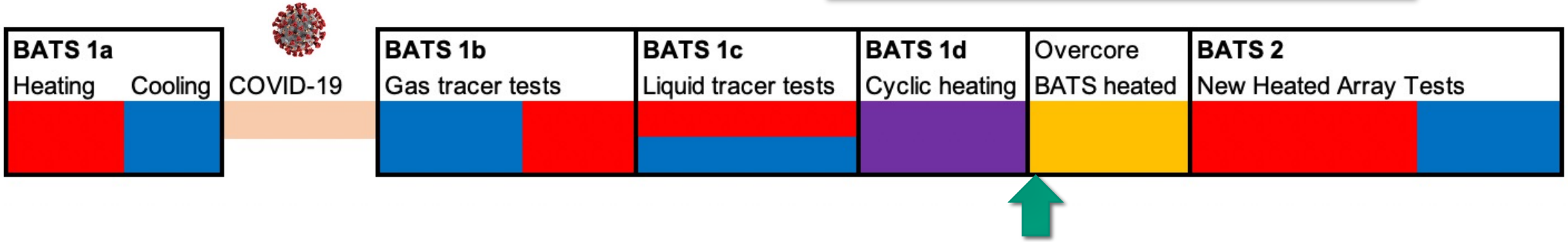





minerals

Article

Utilizing Temperature and Brine Inflow Measurements to Constrain Reservoir Parameters During a Salt Heater Test



Benefits of BATS Tests

- Field data for validating numerical models
  - Complex processes in a salt repository
  - Impacts of heat on amount of brine to expect
  - New geophysical methods on hard problems
- New generation of repository scientists
  - Significant testing in 1980s , but previous staff retired
- International collaborations
  - DEvelopment of COupled models and their VALidation against EXperiments
  - International modeling collaboration (Task E)

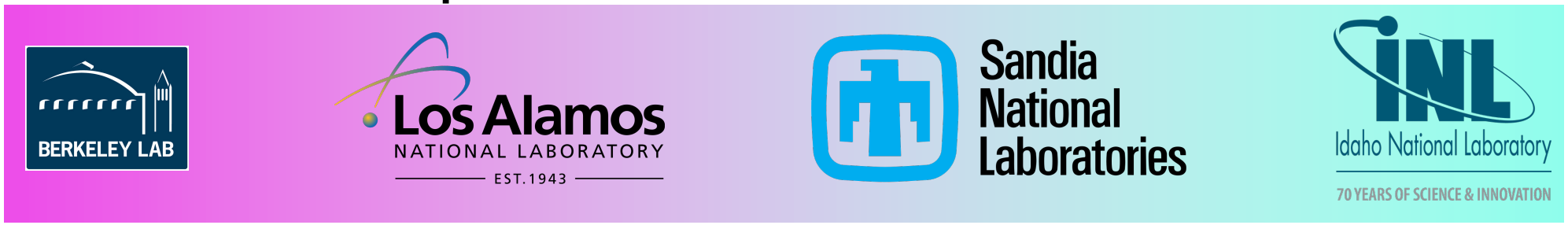
DECOVALEX 2023

www.decovalex.org

Working at Labs

Spectrum of National Labs

Research Universities



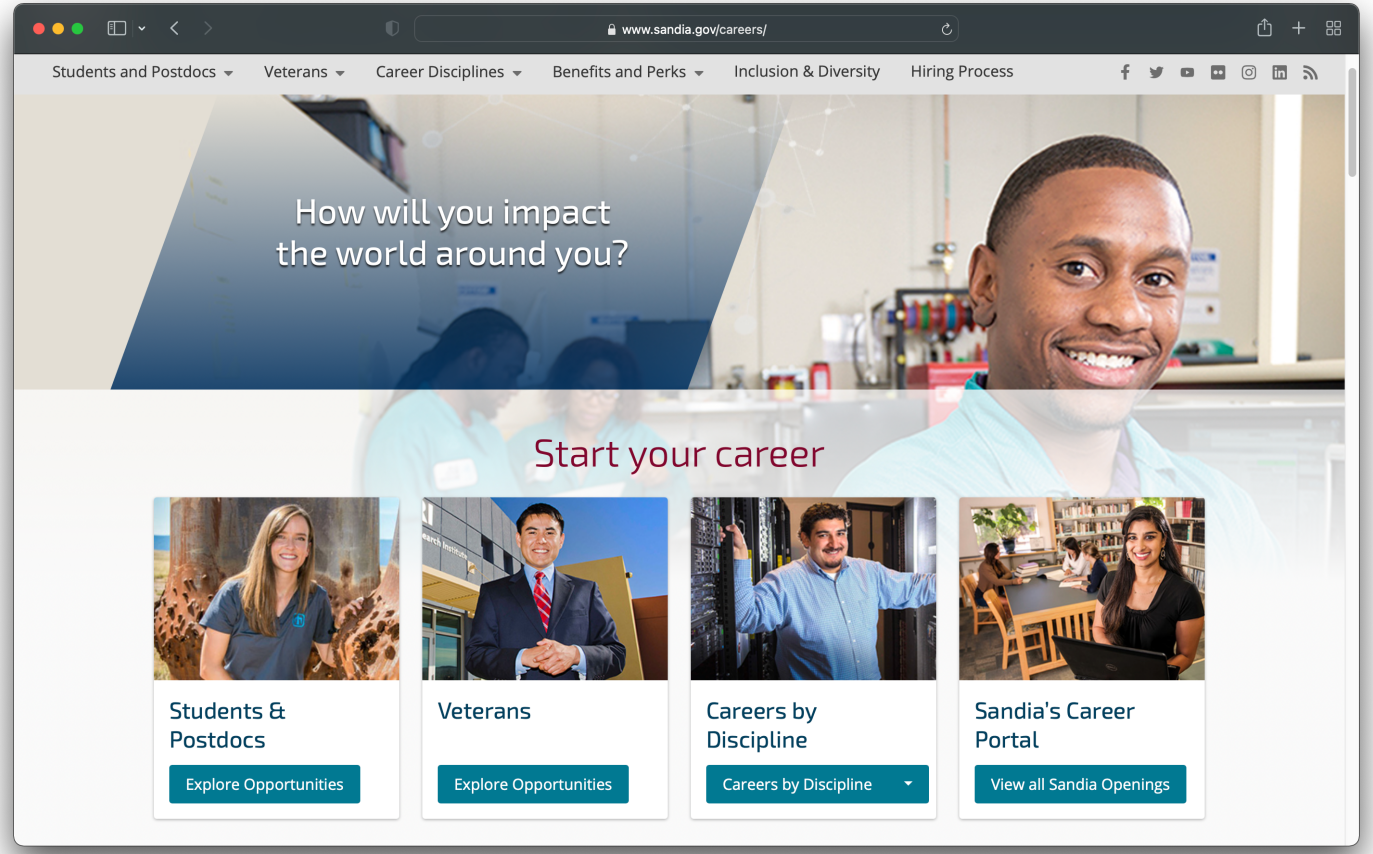
Engineering/ Consulting

- At National Labs:
  - Work on projects of national importance
  - Collaborate with universities (i.e., summer students)
  - Changing careers is possible!
- Labs or consulting:
  - Real-world experience before/during grad school

Sandia Opportunities

sandia.gov/careers

- Summer internships
  - Deadline in Jan/Feb
- Staff Jobs
  - Keep good grades!
  - US Citizenship (security clearance)
- MS or PhD for technical jobs
- BS for lab technician jobs



Search *"One-Shot Physics," "Rocket Sled,"* or *"Z-Machine"* on Sandia YouTube channel for cool videos!

Thank You!