

# Oak Ridge National Laboratory The Influence and Impact on Pressure Safety

Mark Lower  
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ORNL is managed by UT-Battelle LLC for the US Department of Energy

# ORNL's mission

Deliver scientific discoveries and technical breakthroughs that will accelerate the development and deployment of solutions in clean energy and global security, and in doing so create economic opportunity for the nation

## Signature strengths

Computational science and engineering

Materials science and engineering

Neutron science and technology

Nuclear science and technology

# ORNL's Secret Mission

1939

Albert Einstein writes to President Franklin Roosevelt warning of the possible development of "extremely powerful bombs of a new type"



1942

Army Corps of Engineers forms the Manhattan Engineer District. This leads to the decision to buy 59,000 acres in East Tennessee to separate uranium, and demonstrate plutonium production and separation



1943

The world's first operational nuclear reactor, the Graphite Reactor serves as a plutonium production pilot plant during World War II. It operates until November 1963, pioneering the production of radioisotopes, studies of radiation damage in materials, and development of neutron diffraction as a research tool.

## WWII Ends

The X-10 facilities served as a pilot plant for the massive plutonium production complex built at Hanford, Washington, which supplied the plutonium used in the "Fat Man" bomb.

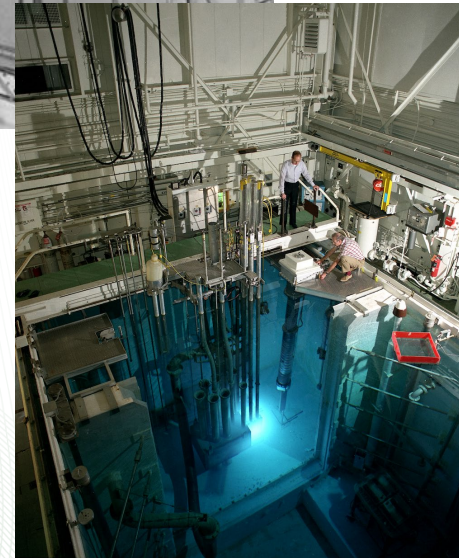
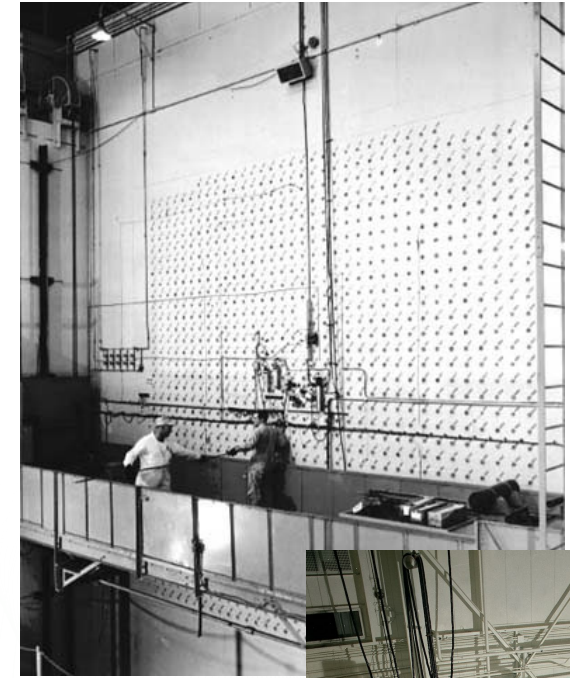
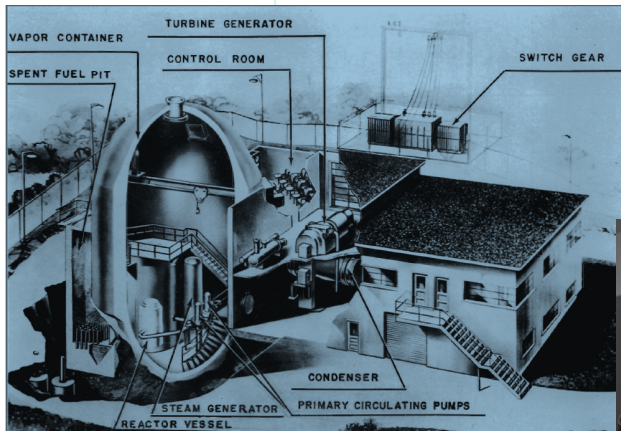
# Transition to Peacetime Laboratory

## Purpose

- use nuclear energy to pioneer medical therapies,
- study the nature of matter, and power homes

## Activities

- Construction of new research reactors to enable exploration of the potential of nuclear power for generating electricity
- Discoveries in materials, chemical, and nuclear sciences.

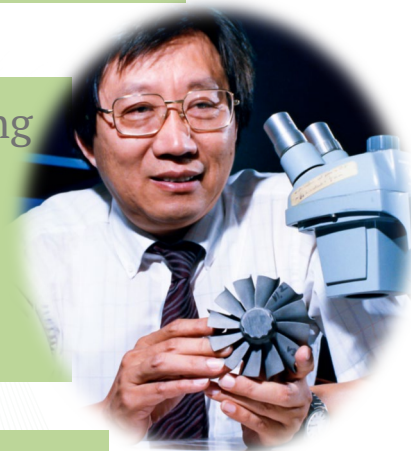


# Materials Research



Researchers investigate the properties of 120 laboratory melts and determine the recommended composition and heat treatment of a chrome-moly steel that has better tolerance of design stresses with no loss of ductility, higher resistance to thermal stress, immunity to stress corrosion cracking in chloride-bearing water, and resistance to radiation-induced swelling. Chrome-moly steel is used in electric utility boilers and oil refinery furnaces worldwide.

From the mid-1970s to early 1980s, ORNL works with Combustion Engineering (now Alston Power Inc.) to develop the first creep-strength enhanced ferritic (CSEF) steel, Grade 91. The steel debuts in 1982. Grade 91 and subsequent CSEF steels become a worldwide standard for achieving high efficiency and safe and reliable performance.



CF8C-Plus steel, developed through a cooperative research and development agreement between ORNL and Caterpillar, is commercialized by Caterpillar in 2007 for regeneration systems for diesel particulate filters, and 550 tons is used in more than 35,000 heavy-duty highway diesel engines.

# Supercomputing



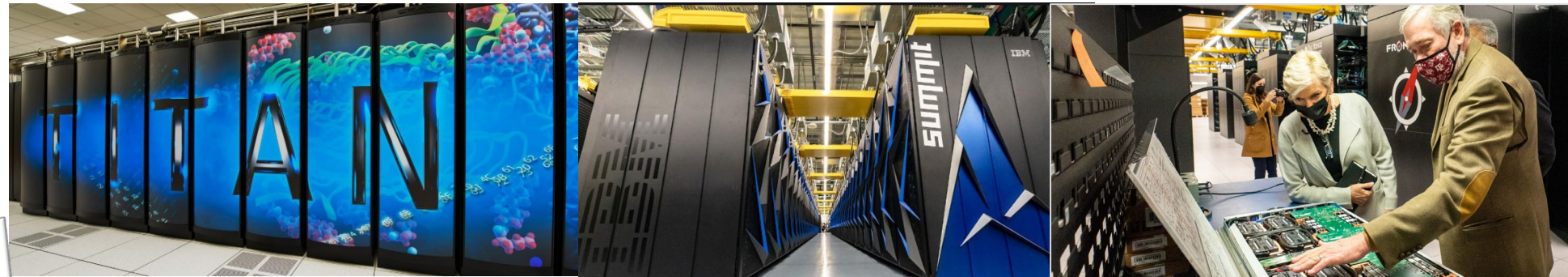
Oracle

14 kiloflops (1,000 floating-point operations per second). It has an original storage capacity of 1,024 words of 40 bits each and contains a magnetic-tape auxiliary memory.

Paragon

Jaguar  
#1 in 2009, 2010

Kraken

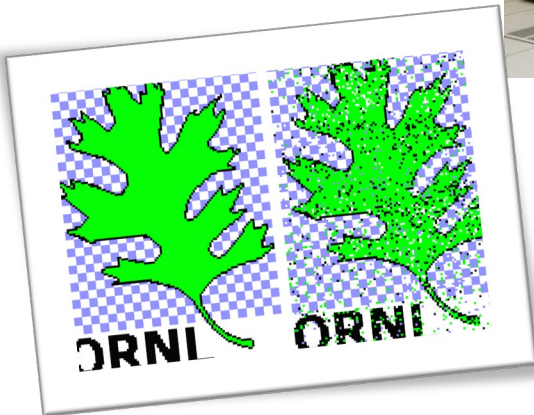


Titan  
#1 in 2012

Summit  
#1 in 2018

Frontier  
Debut in 2022

Performance >1.5 exaflops exceeding a quintillion, or  $10^{18}$ , calculations per second



~1M attacks per day

# One gram in 50 years

It is **really hard** to make neutrons.

Little known fact... Fermi was about a year or two away from discovering the Higgs Boson before CERN came online



**The Nobel Prize in Physics 1994**

*Clifford G. Shull, MIT, Cambridge, Massachusetts, U.S.A. receives one half of the 1994 Nobel Prize in Physics for development of the neutron diffraction technique.*

*Bertalan N. Brockhouse, McMaster University, Hamilton, Ontario, Canada, receives one half of the 1994 Nobel Prize in Physics for the development of neutron spectroscopy.*

**Neutrons reveal structure and dynamics**

Neutrons behave as particles and as waves

**S** Shull made use of elastic scattering i.e. of neutrons which change direction without losing energy when they collide with atoms.

Because of the wave nature of neutrons, a diffraction pattern can be recorded which indicates where in the sample the atoms are situated. Even the placing of light elements such as hydrogen in metals, hydroxides, or hydrogen, carbon and oxygen in organic substances can be determined.

The pattern also shows how atomic dipoles are oriented in magnetic materials, since neutrons are affected by magnetic forces. Shull also made use of this phenomenon in his neutron diffraction technique.

**B** Brockhouse made use of inelastic scattering i.e. of neutrons which change both direction and energy when they collide with atoms. They then start or cancel atomic oscillations in crystals and record movements in liquids and solids. Neutrons can also interact with spin waves in magnets.

With his 3-axis spectrometer Brockhouse measured energies of phonons (atomic vibrations) and magnons (magnetic waves). He also studied how atomic structures in liquid change with time.

**Neutrons show where atoms are**

When the neutrons collide with atoms in the sample material they change direction and scatter - elastic scattering

Atoms in a crystalline sample

Research reactor

Neutrons bounce against atomic nuclei. They also react to the magnetism of the atoms.

**Neutrons show what atoms do**

3-axis spectrometer with rotatable crystal and rotatable sample

Atoms in a crystalline sample

Changes in the energy of the neutrons are first analysed in an analyser crystal...

**Neutrons see more than X-rays**

X-rays are scattered by electron clouds in atoms and molecules. Neutrons are scattered by nuclei and also by the magnetic moments of atoms. Neutrons are scattered in a way that is very different from X-rays. Neutrons are scattered by the nuclei of atoms and molecules.

**Neutrons reveal inner stresses**

A hole has been punched in an iron pipe and all parts of the hole are under stress. Double and triple holes have been punched in the pipe. The stress lines show how the stress is distributed in the pipe. The stress lines are shown in red.

**Neutrons show what atoms remember**

Of their earlier position when they were scattered in relation to the hole in the pipe and each hole. How they have to find their way out of the hole in the pipe.

**How it started**

Brockhouse and Shull made their pioneering contributions at the first reactor in the USA and Canada back in the 1940s and 1950s. It was then that the resources of the neutron became available for neutron research.

**... how it continues**

Thousands of researchers are now working at the many neutron research centres throughout the world. New and very advanced neutron scattering installations have been built and more are planned in Europe, the USA and Asia. At these super-installations the researchers are studying the structure of new organic superconductors, molecular movements on the surfaces of interest for catalytic exhaust cleaning, virus structures and the connection between the structure and the elastic properties of polymers.

**Further reading:**

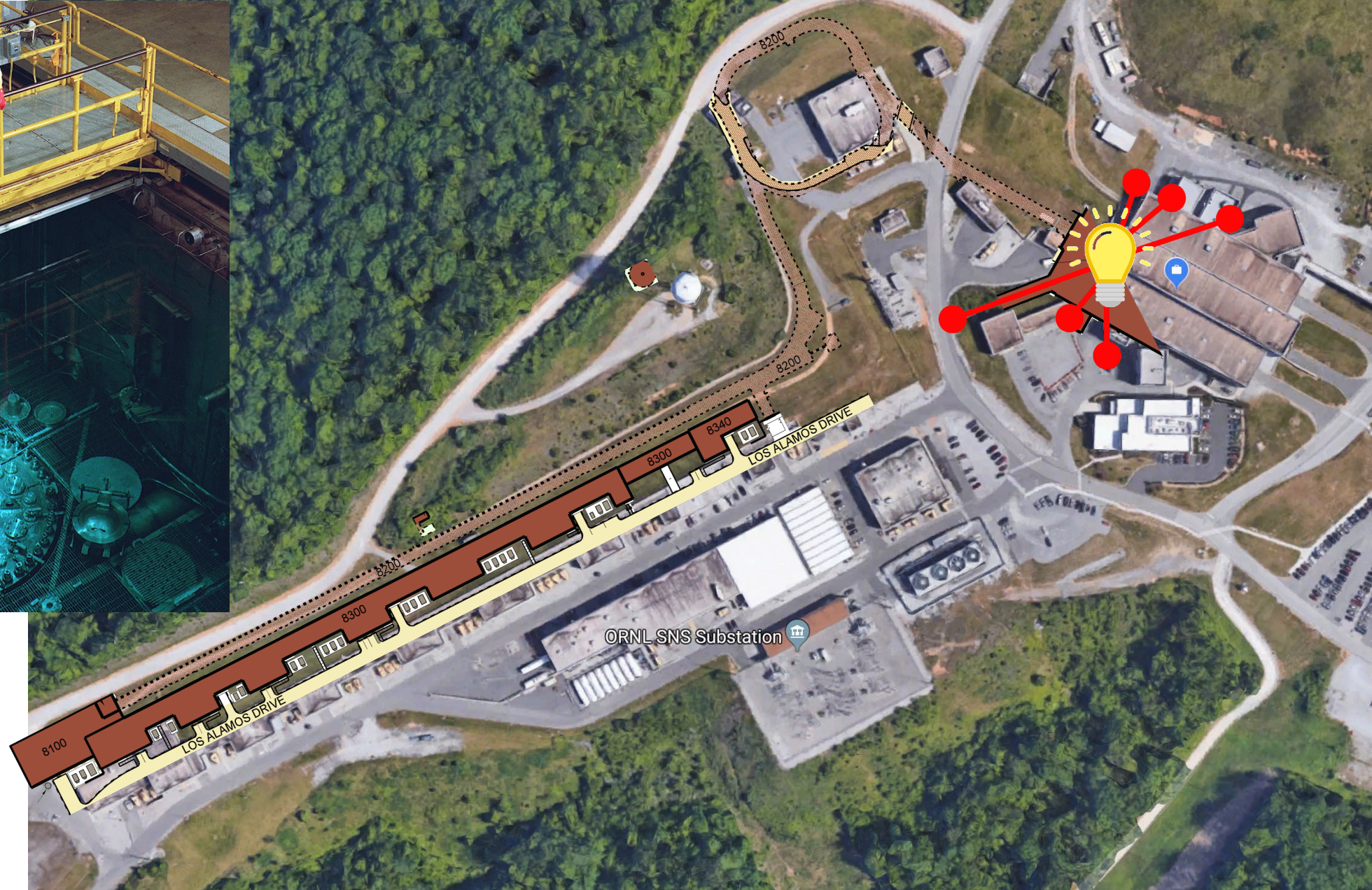
1994 Nobel Prize in Physics awarded to Clifford G. Shull and Bertalan N. Brockhouse

Clifford G. Shull and Bertalan N. Brockhouse receive the 1994 Nobel Prize in Physics

KUNGLIGA VETENSKAPSAKADEMIEN  
THE ROYAL SWEDISH ACADEMY OF SCIENCES



# How do we make neutrons





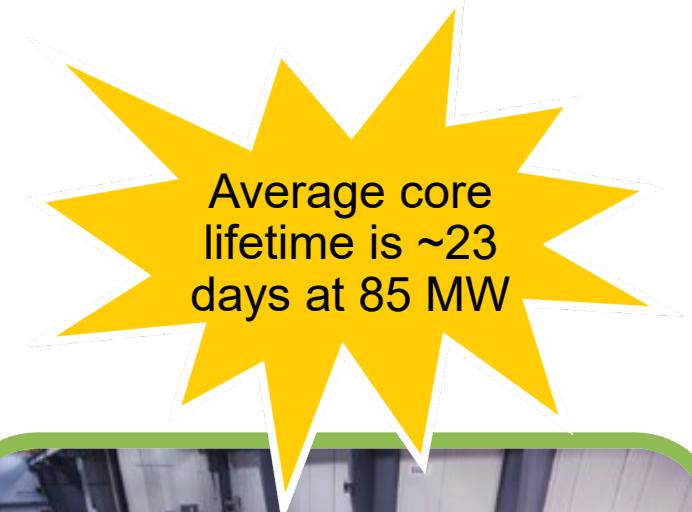
# High Flux Isotope Reactor



Constructed in the mid-1960s to fulfill a need for the production of transuranic isotopes—heavy elements such as plutonium and curium

World's highest producer of steady-state neutrons

Cold Source is designed to cool neutron beams to 20 K (-425°F)

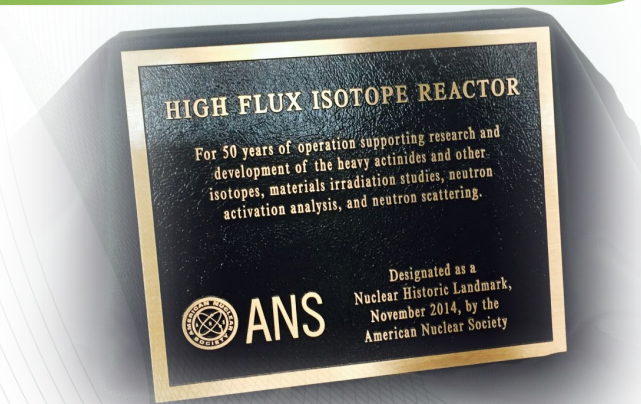


One of its original primary purposes was to produce californium-252 and other transuranic isotopes for research, industrial, and medical applications. HFIR is the western world's sole supplier of californium-252, an isotope used for cancer therapy and detection of pollutants in the environment and explosives in luggage.

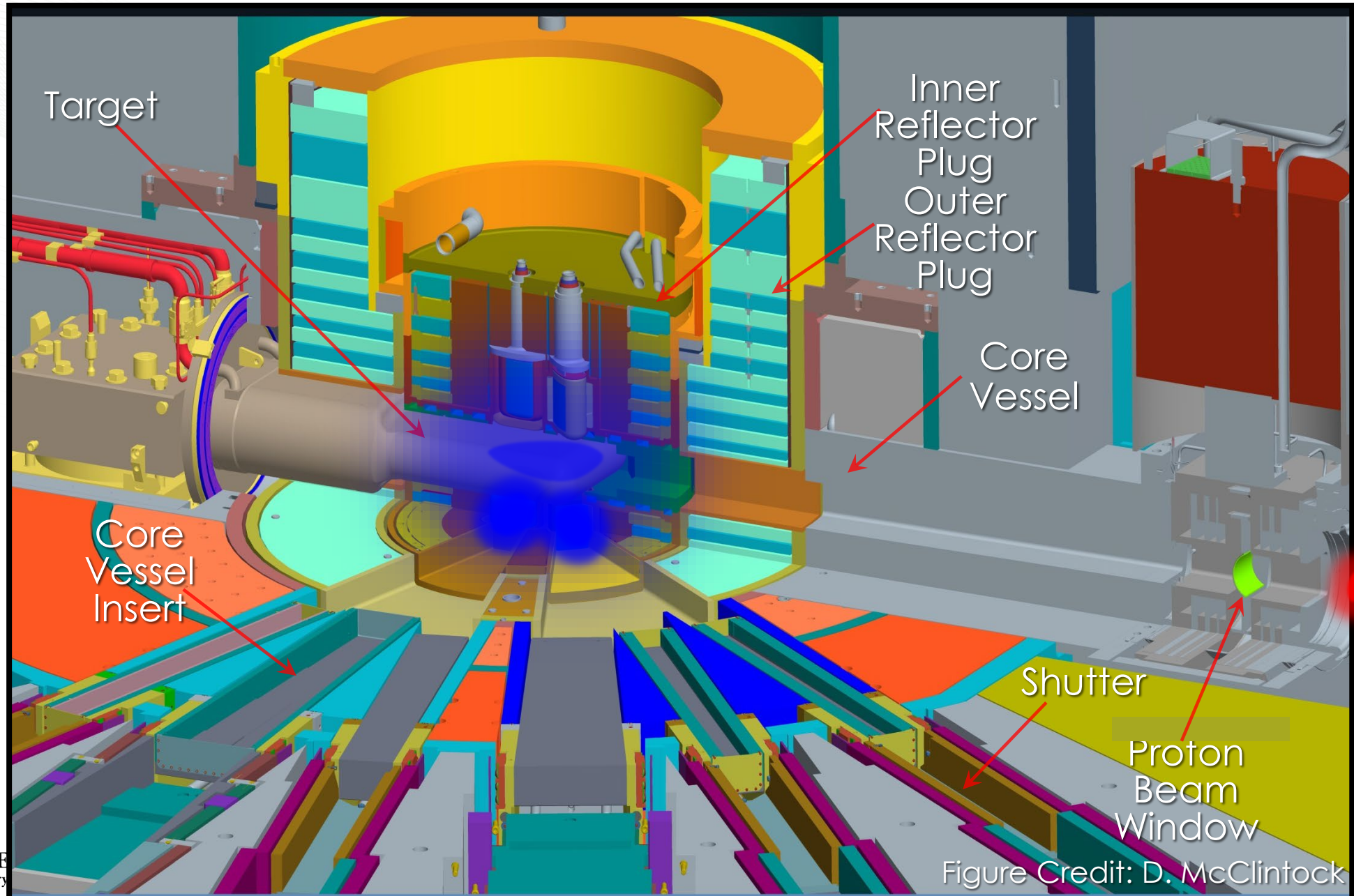


Mission now includes materials irradiation, neutron activation, and, most recently, neutron scattering.

capabilities enable the exploration of the molecular and magnetic structures and behaviors of materials including high temperature superconductors, polymers, metals, and biological samples.

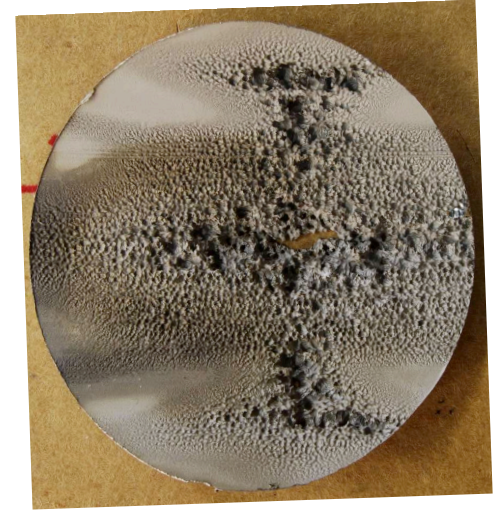


# The target provides neutrons to 24 beam lines



# A Stick of Dynamite 5 Million Times/Day!

- 1 gigaelectronvolt (GeV) 60 Hz proton beam aimed at nose of SNS target assembly
- Neutrons produced via spallation reaction with mercury
- Mercury flow approx. 23 L/s
- Local pressure from proton beam pulse can reach almost 6,000 psi
- Temperature rise from a 1.4 MW beam causes  $10^7$  K/s temperature rise
- Cryogenic Test Facility produces useable liquid helium bath at 2.1 K (-456°F)
- Niobium has a superconducting transition critical temperature of 9.2 K



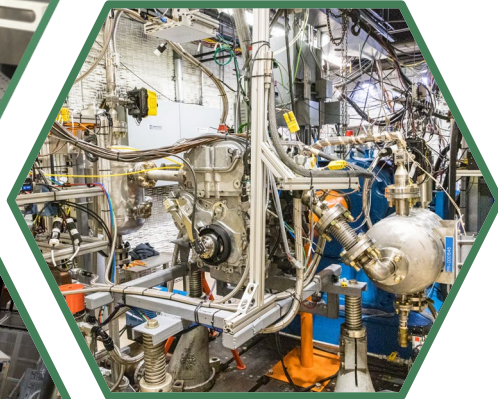
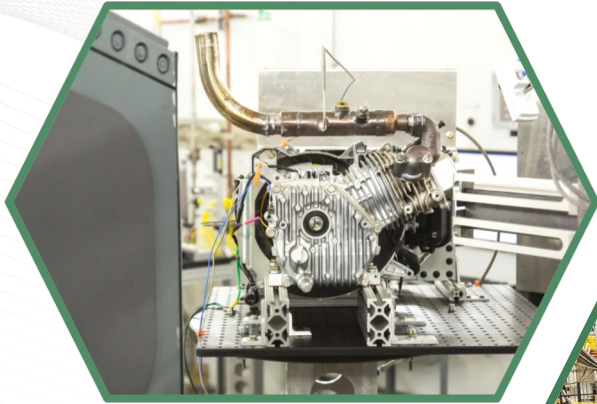
**Bare Niobium  
Cavity**



SNS makes the Guinness Book of World Records as the world's most powerful pulsed neutron source, producing  $4.8 \times 10^{16}$  neutrons per second.

Every time the SNS ramps up, it will set a new neutron production standard.

# Transportation & Grid Research



Wireless  
charging

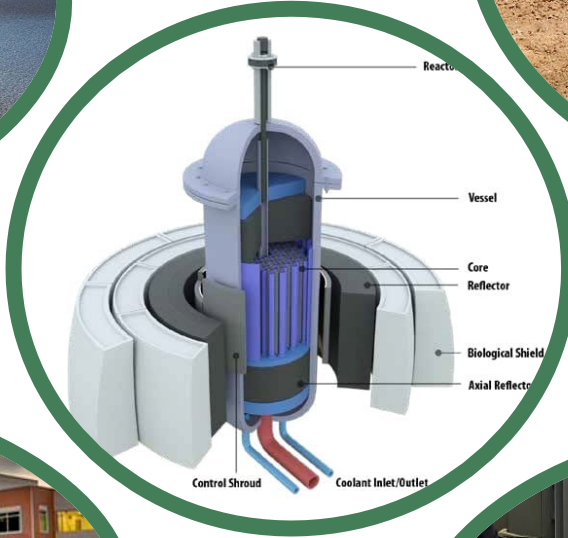
Vehicle  
Systems  
Integration

Neutrons

# Additive Manufacturing



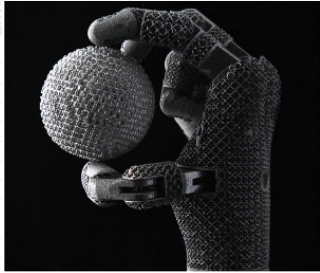
# Additive Manufacturing



# There are a lot of different technologies

Research in a Wide Range of AM Technologies

## Electron Beam Melting



- Developing in-situ characterization, feedback, and control
- Heated powder bed
- Expanding range of materials (Ti64, CoCr, 625, 718)
- Precision melting of powder materials



## Hybrid Manufacturing

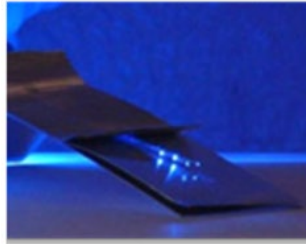


- Net shape manufacturing
- 5-Axis and more
- Laser wire, laser powder
- Direct manufacturing and repair.

Mazak



## Ultrasonic Additive Manufacturing



- Simultaneous additive and subtractive process for manufacturing complex geometries
- Solid-state process allows embedding of optical fibers and sensors



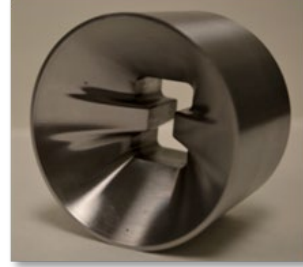
## Hot Isostatic Press



- First rapid-quench HIP in America
- 180mm diameter
- Can reach pressures of 25,000psi
- Cooling rates of 3000C/min when cooled from 3000C
- Can HIP and heat treatment in same cycle



## Laser Metal Deposition



- Site-specific material addition
- Application of advanced coating materials for corrosion and wear-resistance
- Repair of dies, turbines, etc.



## Large-Scale Polymer Deposition



- Deposits up to 1000lbs. of pellet feedstock material per hour
- Build volume up to 20' long x 6' wide x 8' tall
- Printed >37 different polymers and composites
- Dual material capabilities

CINCINNATI



## Selective Laser Melting



- Unheated powder bed
- Wide range of material choices (316L, 17-4PH, H13, Al, Ti, 718, 625)
- Precision melting of metal powders
- Up to 630 x 400 x 500mm build volume



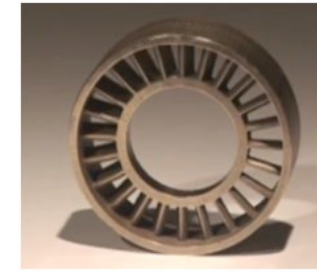
## Ingersoll Large-Scale Polymer Deposition



- Under development
- Will have 46' x 23' x 10' build volume
- Target deposition rate of 1000 lbs./hr.
- Will be 10x larger and faster than previous commercial systems



## Metal Binder Jetting



- Metal matrix composites and sintered materials including:
- Stainless steel + bronze
- Tungsten + titanium
- Ceramics + sand
- Large build volumes (10 x 10 x 16in)
- Fast build times (30 sec/layer)



## Thermostat Dual Material Extrusion



- Capable of depositing 300mL/minute
- Can control material properties and speed on the fly
- Cross-linking between layers
- 2-part resin



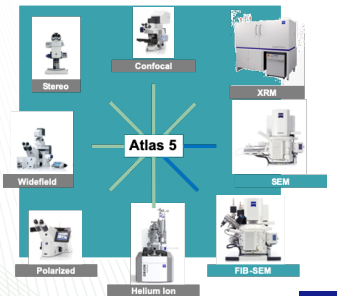
## Large-Scale Welding



- Open-air environment
- MIG welding arm with 6 DOF and 2 rotational degrees
- Print size not restricted
- Uses low-cost welding torches and wire
- CAD-to-path functionality



## Characterization



- X-Ray, CT, FIB
- Full suite of characterization from powder to part



MANUFACTURING DEMONSTRATION FACILITY

# 3-D Printed Shelby Cobra





# Hydraulic hand

- Additive processes enable integrated pump, fluid passages and pistons into a structure with mesh for weight reduction
- Titanium hand made using E-beam fusion (operating pressure 3000 psi)

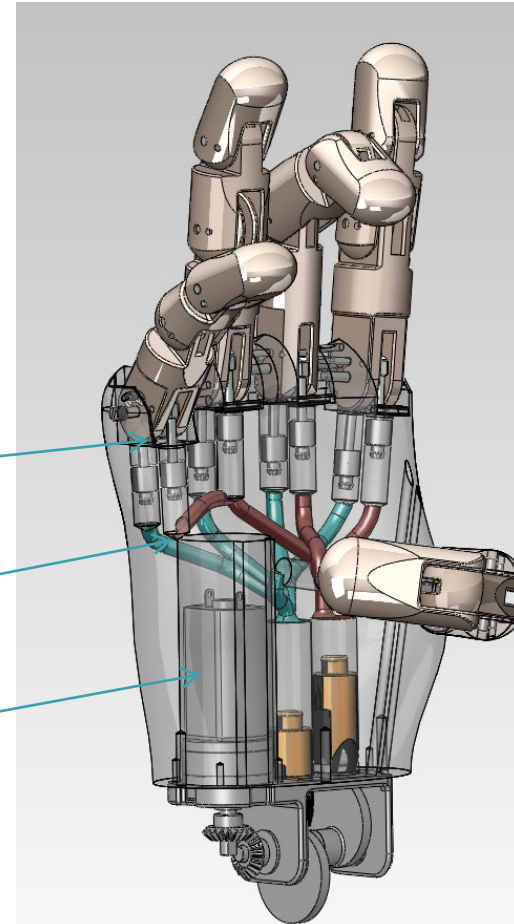


*Solid palm weighing 857 grams.  
Meshed palm weighing 178 grams*

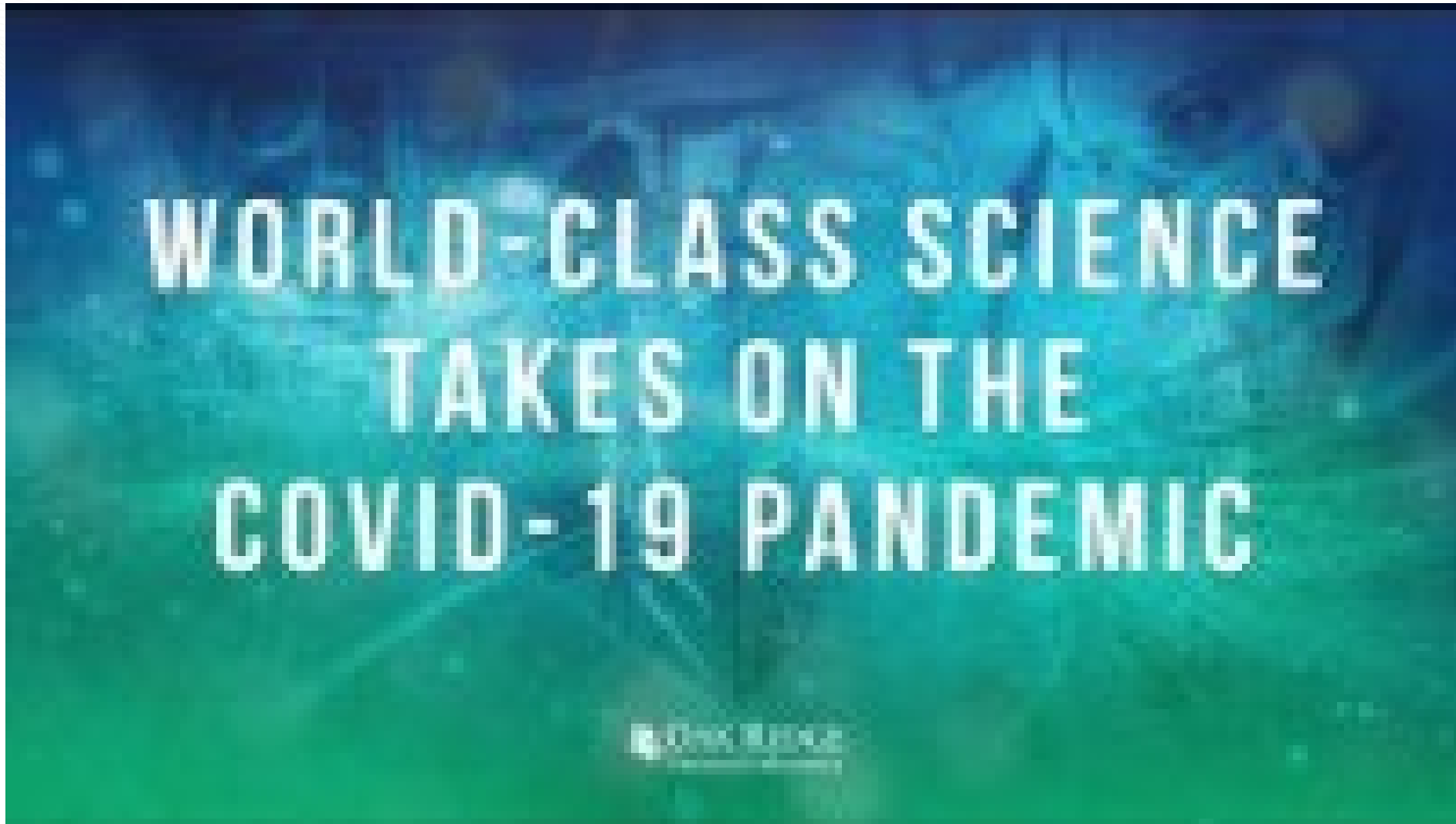
Pistons integrated into structure

Curved fluid passages

Integrated motor and pump

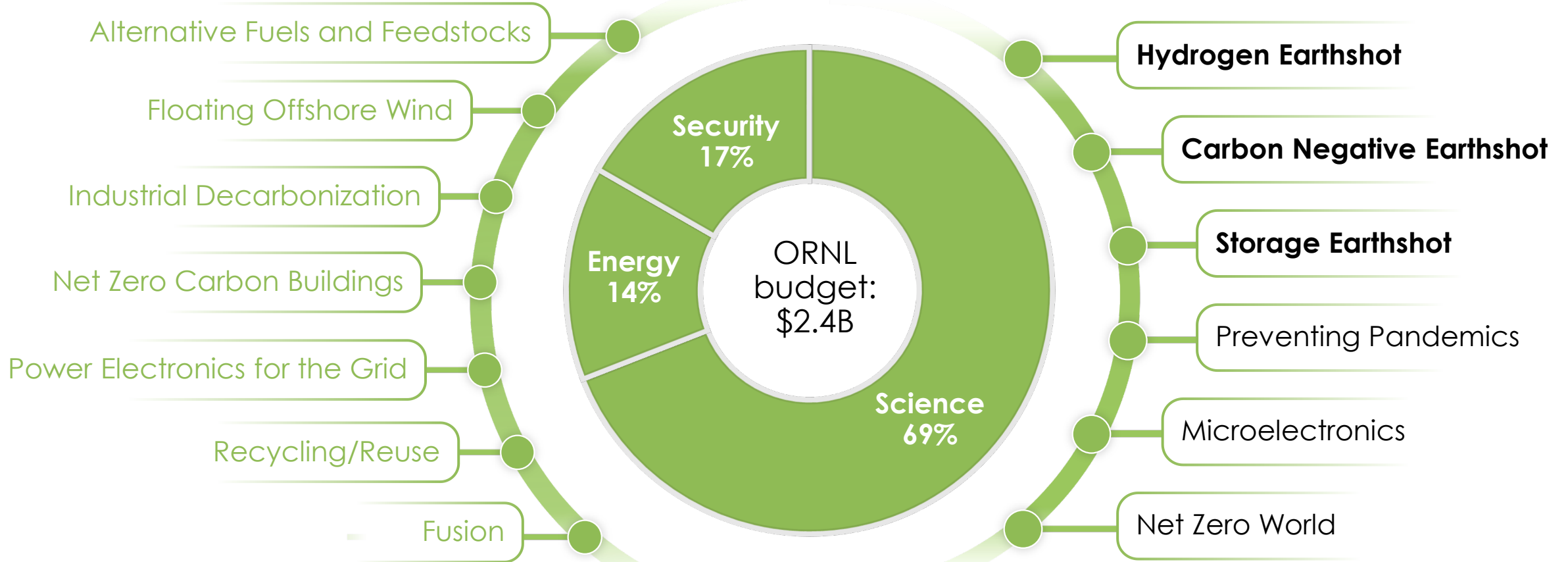


# World-Class Science



# DOE investments at ORNL enable solutions to the most compelling challenges of our time

## DOE Ideation sessions (April/May)



# Questions??



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