TRAILBLAZING TECHNOLOGIES

Year: yyyy

Laboratories Involved: xxxx

<Trailblazing technology description here>

Link: Link here

REVOLUTIONIZED MEDICAL DIAGNOSTICS

Year: 1946[1]

Laboratories Involved: Brookhaven, Lawrence Berkeley, Los Alamos, Oak Ridge[2]

Modern medical imaging began with discoveries during the nuclear medicine program of the 1940s to 1990s and was funded by DOE. Nuclear Magnetic Resonance (NMR) spectroscopy is one of the advancements developed in this program. [3] The modern era of nuclear medicine is an outgrowth of the original charge of the Atomic Energy Commission (AEC) "to exploit nuclear energy to promote human health."[4]

Nuclear medicine images are produced by the energy emitted from radiopharmaceuticals inside a patient's body with imaging systems ("scanners") that detect and process the energy signals. Today, nuclear medicine helps millions of patients annually in the United States. Nearly every nuclear medicine scan or test used today was made possible by past DOE-funded research on radiotracers, radiation detection devices, gamma cameras, PET and SPECT scanners, and computer science.[5]

Link: https://medicalsciences.energy.gov/timeline.shtml

---

[1] From *US Department of Energy Molecular Nuclear Medicine Legacy,* Department of Energy, https://medicalsciences.energy.gov/historypetmri.shtml

[2] From *Nuclear Medicine: Converting Energy to Medical Progress*, Department of Energy, 2001, https://medicalsciences.energy.gov/DOESC0033pr.pdf

[3]From *US Department of Energy Molecular Nuclear Medicine Legacy,* Department of Energy, https://medicalsciences.energy.gov/historypetmri.shtml

[4] From *Nuclear Medicine: Converting Energy to Medical Progress*, Department of Energy, 2001, https://medicalsciences.energy.gov/DOESC0033pr.pdf

[5] From *Nuclear Medicine: Converting Energy to Medical Progress*, Department of Energy, 2001, https://medicalsciences.energy.gov/DOESC0033pr.pdf

BUILT FIRST NUCLEAR POWER PLANT

Year: 1951[6]

Laboratories Involved: Argonne, (present-day) Idaho[7]

After the war, the United States government encouraged the development of nuclear energy for peaceful civilian purposes. Congress created the Atomic Energy Commission (AEC) in 1946. The AEC authorized the construction of Experimental Breeder Reactor I at a site in Idaho. The reactor generated the first electricity from nuclear energy on December 20, 1951.

A major goal of nuclear research in the mid-1950s was to show that nuclear energy could produce electricity for commercial use. The first commercial electricity-generating plant powered by nuclear energy was located in Shippingport, Pennsylvania. It reached its full design power in 1957. The nuclear power industry in the U.S. grew rapidly in the 1960s. Utility companies saw this new form of electricity production as economical, environmentally clean, and safe.[8]

Link: https://factsheets.inl.gov/FactSheets/ExperimentalBreederReactorI.pdf

[6] From *The History of Nuclear Energy,* Department of Energy, https://www.energy.gov/ne/articles/history-nuclear-energy
[7] From *Experimental Breeder Reactor-I Factsheet,* Idaho National Laboratory, https://factsheets.inl.gov/FactSheets/ExperimentalBreederReactorI.pdf
[8] From *The History of Nuclear Energy,* Department of Energy, DOE/NE-0088, https://www.energy.gov/ne/articles/history-nuclear-energy

POWERED SUBMARINES

Year: 1954[9]

Laboratories Involved: Argonne, (present-day) Idaho [10]

In 1954, the culmination of one of Argonne National Laboratory's most important early research projects slid down a ramp into the icy waters off Groton, Conn. -- the U.S.S. Nautilus, the world's first atomic-powered submarine. Nuclear power was still in its infancy when the decision was made to use an atomic reactor to power a submarine. Argonne's Naval Reactor Division was formed in 1948 (six years after Chicago Pile 1), and over the next six years the division helped turn the atomic ship engine from a concept into a reality.

Argonne scientists and engineers performed much of the early materials research and design and feasibility studies for the Nautilus reactor. The first prototype, Submarine Thermal Reactor Mark I, was completed in 1953 at what is now Idaho National Laboratory. STR Mark II was installed in the Nautilus, launched the following year. Some of that reactor's basic concepts are used in today's commercial nuclear power plants.[11]

Link: https://www.ne.anl.gov/About/hn/news960121.shtml

[9] From *Argonne's Nuclear Science and Technology Legacy*, Argonne National Laboratory, 1996, https://www.ne.anl.gov/About/hn/news960121.shtml
[10] From *Argonne's Nuclear Science and Technology Legacy*, Argonne National Laboratory, 1996, https://www.ne.anl.gov/About/hn/news960121.shtml
[11] From *Argonne's Nuclear Science and Technology Legacy*, Argonne National Laboratory, 1996, https://www.ne.anl.gov/About/hn/news960121.shtml

CREATED FIRST ANIMATED CLIMATE MODEL

Year: 1959[12]

Laboratories Involved: Lawrence Livermore [13]

Even in the early days of Lawrence Livermore National Laboratory, researchers understood that the same computational approaches for simulating nuclear weapons could be applied to better simulate evolution of the weather and for applications such as tracking releases of radioactive materials. In the late 1950s, Livermore scientist Cecil "Chuck" Leith developed one of Livermore's first-ever numerical models capable of simulating the hydrodynamic and radiative processes in a thermonuclear explosion. Recognizing fundamental similarities in the underlying equations, Leith turned his attention to creating more comprehensive weather system models.

Leith's Livermore Atmospheric Model (LAM) was the world's first global atmospheric circulation model that calculated temperature, winds, humidity, clouds, precipitation, the day-and-night cycle, and weather systems around the globe, all starting from first-principles equations for the conservation of mass, momentum, energy, and water vapor. Leith also created the first animation of atmospheric modeling results by colorizing photographs of a black-and-white video screen and stitching them together into a film.[14]

Link: https://str.llnl.gov/past-issues/december-2017/atmosphere-around-climate-models

[12] From *A History of LLNL Computers*, Lawrence Livermore National Laboratory, https://computing.llnl.gov/about/machine-history

[13] From *A History of LLNL Computers*, Lawrence Livermore National Laboratory, https://computing.llnl.gov/about/machine-history

[14] From *The Atmosphere Around Climate Models*, Science and Technology Review, Lawrence Livermore National Laboratory, 2017, https://str.llnl.gov/past-issues/december-2017/atmosphere-around-climate-models

SAFEGUARDED NUCLEAR WEAPONS

Year: 1960[15]

Laboratories Involved: Sandia[16]

In 1960, Sandia developed the permissive action link, a coded electromechanical security lock that prevents unauthorized use of a U.S. nuclear weapon. The technology helped reassure the public that a scenario involving a stolen nuclear weapon was impossible.[17]

In 1962, President Kennedy issued National Security Action Memorandum No. 160 requiring Permissive Action Links (PAL) on all nuclear weapons. It further instructed the Chairman of the Atomic Energy Commission and the Secretary of Defense to pursue with urgency research on advanced permissive link devices. After the memorandum was issued, Sandia pursued advanced PAL options. Kennedy visited Sandia's New Mexico site in the same year and received a briefing on the Lab's technical programs.[18]

Link: https://www.sandia.gov/70-ways/

[15] From *75 Ways Sandia has Changed the Nation*, Sandia National Laboratories, 2024, https://www.sandia.gov/70-ways/
[16] From *75 Ways Sandia has Changed the Nation*, Sandia National Laboratories, 2024, https://www.sandia.gov/70-ways/
[17] From *75 Ways Sandia has Changed the Nation*, Sandia National Laboratories, 2024, https://www.sandia.gov/70-ways/
[18] From *Sandia History: 1960s – Spinning Off New Capabilities, New Directions*, Sandia National Laboratories, https://www.sandia.gov/about/history/1960s/

MONITORED NUCLEAR TESTS FROM SPACE

Year: 1963[19]

Laboratories Involved: Los Alamos, Sandia[20]

Los Alamos and Sandia helped develop the Vela satellites to detect gamma rays, neutrons and X-rays that are the signature of nuclear tests. Vela satellites were developed to verify compliance with the Limited Test Ban Treaty of 1963[21], and were capable of real-time data transmission to Earth[22]. The program presented new technical challenges: how to create a hands-off sensor system for space, shrinking rooms full of equipment to a few hundred pounds and have it all survive harsh environments.[23]

Between 1963 and 1970, Project Vela yielded six launches, each with twin satellites. In addition to the data they provided for nuclear detonation detection, the satellites enabled a host of other scientific research projects, including the historic discovery of gamma-ray bursts.[24] Vela satellites continued to transmit telemetry data until 1984. Their development led to myriad contributions to subsequent payloads on Defense Support Program satellites and Global Positioning System (GPS) satellites.[25]

Link: https://www.sandia.gov/labnews/2023/10/19/happy-60th-birthday-to-vela-watchman-for-nuclear-detonations/

---

[19] From *Looking Back*, Sandia News, Sandia National Laboratories, 2017, https://www.sandia.gov/news/publications/research-magazine/article/looking-back-2/
[20] From *Looking Back*, Sandia News, Sandia National Laboratories, 2017, https://www.sandia.gov/news/publications/research-magazine/article/looking-back-2/
[21] From *Looking Back*, Sandia News, Sandia National Laboratories, 2017, https://www.sandia.gov/news/publications/research-magazine/article/looking-back-2/
[22] From *Cold War Watchmen*, National Security Science, Los Alamos National Laboratory, 2020, https://discover.lanl.gov/publications/national-security-science/2020-summer/cold-war-watchmen/
[23] From *Looking Back*, Sandia News, Sandia National Laboratories, 2017, https://www.sandia.gov/news/publications/research-magazine/article/looking-back-2/
[24] From *Cold War Watchmen*, National Security Science, Los Alamos National Laboratory, 2020, https://discover.lanl.gov/publications/national-security-science/2020-summer/cold-war-watchmen/
[25] From *Looking Back*, Sandia News, Sandia National Laboratories, 2017, https://www.sandia.gov/news/publications/research-magazine/article/looking-back-2/

MADE CELLULAR BIOLOGY QUANTITATIVE

Year: 1965[26]

Laboratories Involved: Los Alamos[27]

In 1965, Los Alamos scientist Mack Fulwyler was evaluating blood cells in solution and needed a way to quickly identify and isolate specific types of cells for further study. After reading about the invention of the ink-jet printer, which uses vibration to create a stream of individual tiny ink droplets, he was inspired to create something new. Fulwyler's prototype flow cytometer suspended blood cells in droplets of solution, making them easier to separate and sort than if they were in a steady stream.[28]

In the years since Fulwyler built the first cell separator, the descendants of that original instrument have become ubiquitous in research and clinical laboratories all over the world. The development of flow cytometry (cell measurement) with cell sorting transformed cellular biology from a descriptive, qualitative science to a quantitative science.[29]

Link: https://cdn.lanl.gov/files/1663-nov-2013_18fb6.pdf

[26] From *Los Alamos Firsts: Cell Sorter*, 1663 Magazine, Los Alamos National Laboratory, 2013, https://cdn.lanl.gov/files/1663-nov-2013_18fb6.pdf
[27] From *Los Alamos Firsts: Cell Sorter*, 1663 Magazine, Los Alamos National Laboratory, 2013, https://cdn.lanl.gov/files/1663-nov-2013_18fb6.pdf
[28] From *In Their Own Words: Science and Serendipity*, 1663 Magazine, Los Alamos National Laboratory, 2023, https://discover.lanl.gov/publications/1663/spring-2023/science-and-serendipity/
[29] From *Los Alamos Firsts: Cell Sorter*, 1663 Magazine, Los Alamos National Laboratory, 2013, https://cdn.lanl.gov/files/1663-nov-2013_18fb6.pdf

PIONEERED REACTOR SAFETY MODELING

Year: 1966[30]

Laboratories Involved: Idaho[31]

Idaho National Laboratory originally developed the Reactor Excursion and Leak Analysis Program (RELAP) because the Nuclear Regulatory Commission needed a way to model nuclear reactor coolant and core behavior in a pressurized water reactor, especially during abnormal conditions. Today, RELAP is used throughout the world to support reactor safety analysis, reactor design, university education and operator training. It has more than 100 license agreements and is one of the most widely licensed software products within the U.S. Department of Energy.

After generations of updates, the current code, RELAP5-3D, can model all types of advanced reactors, regardless of the fuel or coolant technology used, as well as some other unlikely phenomena. Surprising uses include: modeling reactors under acceleration; modeling blood flow through arteries and veins; and modeling reactors on a lengthy interplanetary trip (such as to Mars).[32]

Link: https://inl.gov/nuclear-energy/how-inls-reactor-safety-code-extends-beyond-nuclear/

[30] From *How INL's Reactor Safety Code Extends Beyond Nuclear*, Idaho National Laboratory, 2020, https://inl.gov/nuclear-energy/how-inls-reactor-safety-code-extends-beyond-nuclear/
[31] From *How INL's Reactor Safety Code Extends Beyond Nuclear*, Idaho National Laboratory, 2020, https://inl.gov/nuclear-energy/how-inls-reactor-safety-code-extends-beyond-nuclear/
[32] From *How INL's Reactor Safety Code Extends Beyond Nuclear*, Idaho National Laboratory, 2020, https://inl.gov/nuclear-energy/how-inls-reactor-safety-code-extends-beyond-nuclear/

LEVITATED TRAINS WITH MAGNETS

Year: 1968 (patented)[33]

Laboratories Involved: Brookhaven[34]

Maglev -- short for magnetic levitation -- trains can trace their roots to technology pioneered at Brookhaven National Laboratory. James Powell and Gordon Danby of Brookhaven received the first patent for a magnetically levitated train design in the late 1960s. The idea came to Powell as he sat in a traffic jam, thinking that there must be a better way to travel on land than cars or traditional trains. He dreamed up the idea of using superconducting magnets to levitate a train car. Superconducting magnets are electromagnets that are cooled to extreme temperatures during use, which dramatically increases the power of the magnetic field.[35]

The first commercially operated high-speed superconducting Maglev train opened in Shanghai in 2004, while others are in operation in Japan and South Korea.[36] Like the first steam locomotives, automobiles, and passenger airplanes, maglev vehicles have the potential to radically change how we get where we want to go.[37]

Link: https://www.bnl.gov/newsroom/news.php?a=111820

[33] From *The Top 10 Things You Didn't Know about Brookhaven National Lab!*, Brookhaven National Laboratory, 2014, https://www.bnl.gov/newsroom/news.php?a=24923
[34] From *The Top 10 Things You Didn't Know about Brookhaven National Lab!*, Brookhaven National Laboratory, 2014, https://www.bnl.gov/newsroom/news.php?a=24923
[35] From *How Maglev Works*, Department of Energy, 2016, https://www.energy.gov/articles/how-maglev-works
[36] From *How Maglev Works*, Department of Energy, 2016, https://www.energy.gov/articles/how-maglev-works
[37] From *Powell and Danby's Grand Idea: 50 Years of Maglev History,* Brookhaven National Laboratory, 2016, https://www.bnl.gov/newsroom/news.php?a=111820

INVENTED CD/DVD RECORDING PROCESS

Year: 1974[38]

Laboratories Involved: Pacific Northwest[39]

In 1974, Pacific Northwest researcher James Russell patented a way to record tiny "bits" of light and dark, each one a micron in diameter, and a laser to read the tiny "pits" (binary patterns), as well as a computer to convert the data into an electrical signal. This process was called Optical Digital Recording (ODR). Battelle asked Russell to apply it to digitizing and reproducing music. Eventually, Sony and Phillips licensed it, establishing a proprietary ODR format for audio called "Compact Disk" (CD), and delivered a commercial product in 1982, followed in 1985 with a related ODR for data called CD-ROM.[40]

Link: https://solvers.battelle.org/90

[38] From *Batelle: 90 Years Solving*, Battelle, https://solvers.battelle.org/90
[39] From *Batelle: 90 Years Solving*, Battelle, https://solvers.battelle.org/90
[40] From *Batelle: 90 Years Solving*, Battelle, https://solvers.battelle.org/90

JUMP-STARTED THE SHALE GAS REVOLUTION

Year: 1975[41]

Laboratories Involved: National Energy Technology Laboratory[42]

In 1975, a DOE-industry joint venture drilled the first Appalachian Basin directional wells to tap shale gas, and shortly thereafter completed the first horizontal shale well to employ seven individual hydraulically fractured intervals. The basic core and geologic data from this well were integrated to prepare the first publicly available estimates of technically recoverable gas for shales in West Virginia, Ohio and Kentucky.[43]

From the 1970s to the 1990s, multiple National Energy Technology Laboratory (NETL)-funded research and development (R&D) technologies would optimize production of shale gas across the United States: directional drilling, microseismic monitoring of multi-stage hydraulic fracturing treatments, and modeling. These investments—combined with industry collaboration—made the American shale gas revolution possible.[44]

Link: https://www.energy.gov/sites/prod/files/2016/07/f33/Overview.pdf

---

[41] From *Natural Gas from Shale: Questions and Answers*, Department of Energy, https://www.energy.gov/fecm/articles/shale-gas-what-happened

[42] From *Office of Oil and Natural Gas: Unconventional Oil and Gas Resources*, Department of Energy, https://www.energy.gov/sites/prod/files/2016/07/f33/Overview.pdf

[43] From *Natural Gas from Shale: Questions and Answers*, Department of Energy, https://www.energy.gov/fecm/articles/shale-gas-what-happened

[44] From *Office of Oil and Natural Gas: Unconventional Oil and Gas Resources*, Department of Energy, https://www.energy.gov/sites/prod/files/2016/07/f33/Overview.pdf

POWERED NASA SPACECRAFT

Year: 1977[45]

Laboratories Involved: Idaho, Los Alamos, Oak Ridge[46]

DOE and its predecessors have provided radioisotope power systems that have safely enabled deep space exploration and national security missions for five decades. Radioisotope power systems (RPSs) convert the heat from the decay of the radioactive isotope plutonium-238 (Pu-238) into electricity. RPSs are capable of producing heat and electricity under the harsh conditions encountered in deep space for decades. They have proven safe, reliable, and maintenance-free in missions to study the moon and all of the planets in the solar system except Mercury.

DOE maintains the infrastructure to develop, manufacture, test, analyze, and deliver RPSs for space exploration and national security missions. DOE provides two general types of systems – power systems that provide electricity, such as radioisotope thermoelectric generators (RTGs), and small heat sources called radioisotope heater units (RHUs) that keep spacecraft components warm in harsh environments. DOE also maintains responsibility for nuclear safety throughout all aspects of the missions.[47]

Link: https://www.energy.gov/ne/space-and-defense-power-systems

[45] From *What is a Radioisotope Power System*, Department of Energy, 2021, https://www.energy.gov/ne/articles/what-radioisotope-power-system

[46] From *What is a Radioisotope Power System*, Department of Energy, 2021, https://www.energy.gov/ne/articles/what-radioisotope-power-system

[47] From *Space and Defense Power Systems,* Department of Energy, https://www.energy.gov/ne/space-and-defense-power-systems

CONCENTRATED THE POWER OF THE SUN

Year: 1981 (First Operating Solar Tower)[48]

Laboratories Involved: Sandia [49]

In the late 1970s, Sandia National Laboratories began concentrating solar power research at the newly constructed National Solar Thermal Test Facility, funded by the Department of Energy during the height of the oil crisis. This facility housed the world's first multimegawatt solar tower, which used a large steam receiver to absorb the heat from concentrated sunlight.

In 1981 the research at Sandia lead to an effort with Rocketdyne, a rocket manufacturer, to develop Solar One, which became the world's first operating solar tower. An operating tower can deliver power to the electrical grid, but not on a commercial basis. Solar One was based in Barstow, California, used a steam receiver and had about 10 times more mirror-like heliostats than Sandia's research tower, giving it a 10 megawatt electric output. In 1995 Sandia and Rocketdyne converted it to Solar Two, which used a molten salt receiver.

Link: https://newsreleases.sandia.gov/solar_anniversary/

[48] From *From Concept to Commercialization: 40 Years of Concentrating Solar Power Research*, Sandia National Laboratories, 2018, https://newsreleases.sandia.gov/solar_anniversary/

[49] From *From Concept to Commercialization: 40 Years of Concentrating Solar Power Research*, Sandia National Laboratories, 2018, https://newsreleases.sandia.gov/solar_anniversary/

SHARPLY CURTAILED POWER PLANT EMISSIONS

Year: 1985[50]

Laboratories Involved: National Energy Technology Laboratory[51]

The Clean Coal Technology (CCT) Demonstration Program was administered by the National Energy Technology Laboratory (NETL) from 1985-1993 with a goal of developing innovative, environmentally friendly coal utilization processes for the world energy marketplace. This program was co-funded by industry and government and involved a series of commercial-scale demonstration projects providing data for design, construction, operation, and technical/economic evaluation of full-scale applications.[52]

Ultimately some 20 innovative technologies – such as low nitrogen oxide burners, flue gas desulfurization (scrubbers) and fluidized bed combustion – were produced through this program, many of which are now in the marketplace and benefitting energy production and air quality improvements.[53] The program also opened a channel to policy-making bodies by providing data from cutting-edge technologies to aid in formulating regulatory decisions.[54]

Link: https://www.energy.gov/fecm/articles/fossil-energy-rd-returns-significant-national-benefit-more-three-decades-achievement

[50] From *Clean Coal Technology: The Wabash River Goal Gasification Repowering Project*, National Energy Technology Laboratory, 2000, https://www.netl.doe.gov/sites/default/files/netl-file/topical20.pdf
[51] From *Clean Coal Technology: The Wabash River Goal Gasification Repowering Project*, National Energy Technology Laboratory, 2000, https://www.netl.doe.gov/sites/default/files/netl-file/topical20.pdf
[52] From *Clean Coal Technology: The Wabash River Goal Gasification Repowering Project*, National Energy Technology Laboratory, 2000, https://www.netl.doe.gov/sites/default/files/netl-file/topical20.pdf
[53] From *Fossil Energy R&D Returns Significant National Benefit in More than Three Decades of Achievement*, Department of Energy, 2011, https://www.energy.gov/fecm/articles/fossil-energy-rd-returns-significant-national-benefit-more-three-decades-achievement
[54] From *Clean Coal Technology: The Wabash River Goal Gasification Repowering Project*, National Energy Technology Laboratory, 2000, https://www.netl.doe.gov/sites/default/files/netl-file/topical20.pdf

SIMULATED PLANES, TRAINS, AND CARS

Year: 1987 (Company Founded)[55]

Laboratories Involved: Lawrence Livermore[56]

This three-dimensional computer DYNA3d code was developed by Lawrence Livermore mechanical engineers to meet the needs of the nuclear weapons program, and it grew to become a remarkable "swords to plowshares" story. Interest in DYNA3d rapidly expanded due to the code's applicability to a wide range of structural analysis problems. The computer code has been used by industry for making everything from safer planes, trains, and automobiles to better beer cans.[57]

DYNA3d was released as open source, in the public domain, which allowed many companies to use DYNA3D for a variety of applications. One was to analyze the impact of vehicle crashes for automakers in their quest to meet regulations from the National Highway Traffic Safety Administration. The aerospace industry used the software to simulate bird strikes, blade containment and structural failure, and NASA used it to simulate flight re-entry. [58] The company founded to produce the software sold to ANSYS Inc. in 2019 for $775 million.[59]

Link: https://www.llnl.gov/article/40036/computer-code-led-entrepreneurial-success

[55] From *Technology Transfer with DYNA3D,* Lawrence Livermore National Laboratory: 70 Years of Making the Impossible Possible, Lawrence Livermore National Laboratory, 2017, https://www.llnl.gov/news/publications
[56] From *Technology Transfer with DYNA3D,* Lawrence Livermore National Laboratory: 70 Years of Making the Impossible Possible, Lawrence Livermore National Laboratory, 2017, https://www.llnl.gov/news/publications
[57] From *Technology Transfer with DYNA3D,* Lawrence Livermore National Laboratory: 70 Years of Making the Impossible Possible, Lawrence Livermore National Laboratory, 2017, https://www.llnl.gov/news/publications
[58] From *A Computer Code Led to Entrepreneurial Success*, Lawrence Livermore National Laboratory, 2014, https://www.llnl.gov/article/40036/computer-code-led-entrepreneurial-success
[59] From *Fueling California's Economy*, Lawrence Livermore National Laboratory, 2020, https://www.llnl.gov/sites/www/files/2021-01/FY20%20CA%20Economic%20Impact%20Fact%20Sheet.pdf

UPGRADED WIND TURBINE DESIGNS

Year: 1991[60]

Laboratories Involved: National Renewable Energy Laboratory[61]

Airfoils have come a long way since the early days of the wind energy industry, when designers selected shapes for their wind turbine blades from a library designed for aircraft wings. It became clear to researchers at the National Renewable Energy Laboratory that achieving better, more robust performance would require new airfoils tailored specifically for wind turbine applications. The result of this research was the first "airfoil family" for wind turbines. These families prioritized the design aspects of airfoils to address aerodynamic and structural requirements.

The DOE-funded effort created a total of seven airfoil families that were validated and published in a series of reports and patents through the mid-1990s. Combined, they set the standard for efficiency in wind turbine blade design, and annual energy production increased to 10%–35% over the once-standard airfoils from the 1970s.[62]

Link: https://www.energy.gov/eere/wind/articles/airfoils-where-turbine-meets-wind

[60] From *Airfoils, Where the Turbine Meets the Wind,* Department of Energy, 2023, https://www.energy.gov/eere/wind/articles/airfoils-where-turbine-meets-wind
[61] From *Airfoils, Where the Turbine Meets the Wind,* Department of Energy, 2023, https://www.energy.gov/eere/wind/articles/airfoils-where-turbine-meets-wind
[62] From *Airfoils, Where the Turbine Meets the Wind,* Department of Energy, 2023, https://www.energy.gov/eere/wind/articles/airfoils-where-turbine-meets-wind

IDENTIFIED CHEMICALS IN WEAPONS

Year: 1992[63]

Laboratories Involved: Idaho[64]

Weapons of mass destruction threaten national security and public safety. The Portable Isotopic Neutron Spectroscopy System, or PINS, was developed to detect and assess chemical warfare agents. As munitions are recovered these weapons cause a severe safety hazard due to their age, lack of records or documentation, and the degradation of materials inside.

PINS uses neutrons to interact with the unknown item that induces gamma-ray emission. The spectra of induced gamma rays are analyzed by the PINS detector and software. PINS provides accurate, isotopic composition information about dangerous substances without requiring operators to open or interact with a suspect container or munition shell. Unlike traditional laboratory-based neutron activation devices, which are large, stationary and exist only in laboratory facilities, PINS can be easily transported to different locations and set up in the field, making it a valuable tool for a wide range of applications.[65]

Link: https://inl.gov/document/portable-isotopic-neutron-spectroscopy-system/

[63] From *Portable Isotopic Neutron Spectroscopy System*, Idaho National Laboratory, https://factsheets.inl.gov/FactSheets/Portable%20Isotopic%20Neutron%20Spectroscopy%20System.pdf
[64] From *Portable Isotopic Neutron Spectroscopy System,* Idaho National Laboratory, https://inl.gov/document/portable-isotopic-neutron-spectroscopy-system/
[65] From *Portable Isotopic Neutron Spectroscopy System,* Idaho National Laboratory, https://inl.gov/document/portable-isotopic-neutron-spectroscopy-system/

MAPPED THE DARK SIDE OF THE MOON

Year: 1994[66]

Laboratories Involved: Lawrence Livermore[67]

In 1994 the space probe Clementine was launched to orbit the Moon carrying cameras and other equipment developed by Lawrence Livermore National Laboratory (LLNL). Imaging in 13 different spectral bands, Clementine's cameras mapped 99.9% of the lunar surface. Many of the 1.7 million lunar images are available on the Internet. LLNL designed and built the advanced sensor suite, which included six onboard cameras and weighed less than 16 pounds. The collected data enabled global mapping of lunar-crust rock types and the first detailed investigation of the geology of the lunar polar regions and far side.[68]

The satellite orbited the Moon for more than two months, taking and transmitting high-resolution pictures and range data until it built up a detailed map of the entire lunar surface. The satellite was named Clementine because it carried only enough fuel to complete its mission before it was "lost and gone forever," as in the old ballad "My Darling Clementine."[69]

Link: https://www.llnl.gov/sites/www/files/2020-05/clementine-etr-jun-94.pdf

[66] From *The Clementine Satellite*, Energy and Technology Review, Lawrence Livermore National Laboratory, 1994, https://www.llnl.gov/sites/www/files/2020-05/clementine-etr-jun-94.pdf
[67] From *The Clementine Satellite*, Energy and Technology Review, Lawrence Livermore National Laboratory, 1994, https://www.llnl.gov/sites/www/files/2020-05/clementine-etr-jun-94.pdf
[68] From *Our History: Making History and a Difference: 1990s*, Lawrence Livermore National Laboratory, https://www.llnl.gov/purpose/history/1990s#event-clementine-maps-the-moon
[69] From *The Clementine Satellite*, Energy and Technology Review, Lawrence Livermore National Laboratory, 1994, https://www.llnl.gov/sites/www/files/2020-05/clementine-etr-jun-94.pdf

GOT THE LEAD OUT OF ELECTRONICS

Year: 1996[70]

Laboratories Involved: Ames, Sandia[71]

Lead has long been recognized as a highly toxic material that can cause brain damage. But a burgeoning source—electronic waste—posed a substantial new threat to the environment beginning in the 1990s as lead and other chemicals were leached from computers, computer monitors, televisions (with cathode ray screens), cell phones, and other electronic devices being buried in landfills. The persistent source of lead in electronics was solder, the shiny metallic "glue" that holds components on circuit boards and bonds other electrical connections.[72]

Ames Laboratory researchers developed a silver-copper-tin solder with ideal properties that eliminated lead from the equation.[73] Sandia tested the properties of the new solder. When it appeared on the market — hardy, environmentally safe, and low-temperature — it was bought all over the world.[74] Licensed by more than 65 companies worldwide and used in cell phones and all types of electronic devices, the lead-free solder generated nearly $60 million in royalties.[75]

Link: https://science.osti.gov/Science-Features/News-Archive/Featured-Articles/2011/127012

[70] From *Sandia's Highest-Grossing Patent, Granted in 1996, Ends its Run*, Sandia National Laboratories, 2014, https://www.sandia.gov/labnews/2014/01/10/14-10-01-3/
[71] From *Sandia's Highest-Grossing Patent, Granted in 1996, Ends its Run*, Sandia National Laboratories, 2014, https://www.sandia.gov/labnews/2014/01/10/14-10-01-3/
[72] From *Getting the Lead Out*, Department of Energy, 2011, https://science.osti.gov/Science-Features/News-Archive/Featured-Articles/2011/127012
[73] From *Success Stories*, Ames National Laboratory, https://www.ameslab.gov/work-us/success-stories
[74] From *Sandia's Highest-Grossing Patent, Granted in 1996, Ends its Run*, Sandia National Laboratories, 2014, https://www.sandia.gov/labnews/2014/01/10/14-10-01-3/
[75] From *Success Stories*, Ames National Laboratory, https://www.ameslab.gov/work-us/success-stories

LAUNCHED THE LED LIGHTING REVOLUTION

Year: 1999[76]

Laboratories Involved: Sandia[77]

In the late 1990s, when the efficiency of phosphor-converted white light LEDs was only a few percent, few researchers thought these glowing white rocks might someday be used for general illumination. However, scientists at Sandia National Labs and Hewlett Packard co-authored a paper that predicted efficiencies as high as 50 percent, and the enormous energy-savings potential that would be realized if achieved.[78] This paper was the first to discuss the vast technological and energy-savings potential of this technology[79], and is widely credited with inspiring solid-state lighting activity all over the world.[80]

Sandians later served on DOE committees that roadmapped possible paths for improved LED lighting, and came up with new ways of improving LED efficiencies and usefulness.[81]

Link: https://www.sandia.gov/media/NewsRel/NR2002/LEDS2.htm

[76] From *Hope Michelesen, Jeff Tsao Elected Fellows of the Optical Society*, Sandia National Laboratories, 2017, https://www.sandia.gov/labnews/2017/10/27/optical-society-fellows/
[77] From *Hope Michelesen, Jeff Tsao Elected Fellows of the Optical Society*, Sandia National Laboratories, 2017, https://www.sandia.gov/labnews/2017/10/27/optical-society-fellows/
[78] From *Hope Michelesen, Jeff Tsao Elected Fellows of the Optical Society*, Sandia National Laboratories, 2017, https://www.sandia.gov/labnews/2017/10/27/optical-society-fellows/
[79] From *Solid State Lighting*, Sandia National Laboratories, https://www.sandia.gov/-jytsao/solid-state-lighting/
[80] From *Hope Michelesen, Jeff Tsao Elected Fellows of the Optical Society*, Sandia National Laboratories, 2017, https://www.sandia.gov/labnews/2017/10/27/optical-society-fellows/
[81] From *Hope Michelesen, Jeff Tsao Elected Fellows of the Optical Society*, Sandia National Laboratories, 2017, https://www.sandia.gov/labnews/2017/10/27/optical-society-fellows/

CLEANED UP ANTHRAX

Year: 2001[82]

Laboratories Involved: Sandia[83]

Sandia chemical engineers began work on a decontamination foam in 1997 with funding from the Department of Energy. The resulting liquid foam decontaminant was developed for rapid response to terrorist threats. Its formulation includes a collection of mild nontoxic and noncorrosive chemical found in common household products, like hair conditioner and toothpaste. The foam was licensed to EnviroFoam Technologies of Huntsville, Alabama.

Within a few weeks of the 9/11 attacks there were a series of anthrax attacks resulting in contamination—on Capitol Hill, in mailrooms, and at various media headquarters. EnviroFoam put the decontamination foam into service. It was effective and was also used in cleaning up offices on Capitol Hill, New York, and in Florida.[84]

Link: https://www.sandia.gov/media/NewsRel/NR2001/dcnfoam.htm

[82] From *Sandia-Developed Formulation Among Products Selected to Help Rid US Facilities of Anthrax,* Sandia National Laboratories, https://www.sandia.gov/media/NewsRel/NR2001/dcnfoam.htm
[83] From *Sandia-Developed Formulation Among Products Selected to Help Rid US Facilities of Anthrax,* Sandia National Laboratories, https://www.sandia.gov/media/NewsRel/NR2001/dcnfoam.htm
[84] From *Sandia History: 2000s: National Security after 9/11*, Sandia National Laboratories, https://www.sandia.gov/about/history/2000s/

DEVELOPED AIRPORT BODY SCANNERS

Year: 2003[85]

Laboratories Involved: Pacific Northwest[86]

The events of 9/11 transformed airport security, bringing not only tighter regulations and increased security measures but also technological advances that make our airports and air travel safer. Imaging technology for security applications emerged as a need when the Federal Aviation Administration sought ways to detect concealed plastic threats that would not be picked up by traditional metal detectors in airports.

Researchers at PNNL engineered a high-resolution radar imaging technology as a way to rapidly scan for potential threats. Millimeter waves harmlessly penetrate clothing and reflect off of the body, sending signals back to a transceiver; the transceiver then sends the signals to a high-speed computer, which reconstructs them to create a final 3-D holographic image. Under the auspices of the TSA, the technology was successfully demonstrated in U.S. airports. L3 Communications has licensed the technology, and their ProVision™ whole body imaging system is currently being deployed for security screening at airports around the world.[87]

Link: https://www.pnnl.gov/available-technologies/3-d-body-holographic-millimeter-wave-scanner

[85] From *Millimeter Wave Technology at a Glance*, Pacific Northwest National Laboratory, https://www.pnnl.gov/nationalsecurity/millimeterwave/learn_more.stm
[86] From *Available Technologies: 3D Body Holographic (Millimeter Wave) Scanner*, Pacific Northwest National Laboratory, https://www.pnnl.gov/available-technologies/3-d-body-holographic-millimeter-wave-scanner
[87] From *Available Technologies: 3D Body Holographic (Millimeter Wave) Scanner*, Pacific Northwest National Laboratory, https://www.pnnl.gov/available-technologies/3-d-body-holographic-millimeter-wave-scanner

RECOVERED LOST WORK OF ARCHIMEDES

Year: 2005[88]

Laboratories Involved: SLAC[89]

In May 2005, the ancient collided with the ultra-modern at the Stanford Linear Accelerator Center (SLAC), bringing brilliant, long-hidden ideas to light with brilliant X-ray light. A synchrotron X-ray beam at the Department of Energy facility illuminated an obscured work—erased, written over and even painted over—of ancient mathematical genius Archimedes, born 287 B.C. in Sicily.

The Archimedes Palimpsest is a 1,000-year-old parchment made of goatskin containing Archimedes' work as laboriously copied down by a 10th century scribe. Two centuries later, with parchment harder to come by, the ink was erased with a weak acid (like lemon juice) and scraped off with a pumice stone, and the parchment was written on again to make a prayer book. The intense synchrotron X-ray beam induced X-ray fluorescence—X-ray light tuned to a specific energy causes the remaining traces of iron ink to fluoresce. A detector caught the fluorescence and rendered the 2,000-year-old thoughts of the mathematical genius readable.[90]

Link: https://www6.slac.stanford.edu/news/2005-06-16-archimedes-manuscript-yields-secrets-under-x-ray-gaze

[88] From *Archimedes Manuscript Yields Secrets under X-Ray Gaze*, SLAC National Accelerator Laboratory, 2005, https://www6.slac.stanford.edu/news/2005-06-16-archimedes-manuscript-yields-secrets-under-x-ray-gaze
[89] From *Archimedes Manuscript Yields Secrets under X-Ray Gaze*, SLAC National Accelerator Laboratory, 2005, https://www6.slac.stanford.edu/news/2005-06-16-archimedes-manuscript-yields-secrets-under-x-ray-gaze
[90] From *Archimedes Manuscript Yields Secrets under X-Ray Gaze*, SLAC National Accelerator Laboratory, 2005, https://www6.slac.stanford.edu/news/2005-06-16-archimedes-manuscript-yields-secrets-under-x-ray-gaze

HELPED CONSUMERS GO GRID FRIENDLY

Year: 2007[91]

Laboratories Involved: Pacific Northwest[92]

The Grid Friendly Appliance Controller (GFA) senses conditions on a power grid by monitoring the frequency of the system and then provides an automatic response in times of disruption by reducing the demand – with no apparent disruption visible to the consumer's everyday life. The simple computer chip can be installed in household appliances, such as washers, dryers, refrigerators, air conditioners, water heaters, etc., and can turn them off for a short period of time – just a few seconds up to a few minutes – to allow the grid to stabilize.

Pacific Northwest National Laboratory and appliance manufacturer Whirlpool teamed up with the Bonneville Power Administration and the U.S. Department of Energy to transfer the technology into hundreds of homes in the Northwest as part of a demonstration project conducted to assess the effectiveness of the technology and its potential impact on power grid stability.[93]

Link: https://www.pnnl.gov/available-technologies/grid-friendly-appliance-controller

[91] From *Federal Laboratory Consortium Awards for Technology Transfer*, Pacific Northwest National Laboratory, https://www.pnnl.gov/about/federal-laboratory-consortium-awards#2007
[92] From *Federal Laboratory Consortium Awards for Technology Transfer*, Pacific Northwest National Laboratory, https://www.pnnl.gov/about/federal-laboratory-consortium-awards#2007
[93] From *Federal Laboratory Consortium Awards for Technology Transfer*, Pacific Northwest National Laboratory, https://www.pnnl.gov/about/federal-laboratory-consortium-awards#2007

PUT THE JOLT IN CHEVY VOLT

Year: 2011[94]

Laboratories Involved: Argonne[95]

Intense X-rays from the U.S. Department of Energy Office of Science's Advanced Photon Source (APS) at Argonne National Laboratory were used to help Argonne design the technology used in the battery cell that powers General Motors Company's Chevrolet Volt. This plug-in hybrid electric vehicle has a range of 53 pure electric miles and up to 420 miles with a full charge and a full tank of gas.

The Argonne-developed technology offered the longest-lasting energy available to date in the smallest, lightest package: a 50-100% increase in energy storage capacity over conventional cathode materials. Its unique lithium- and manganese-rich mixed-metal oxide combination extended the operating time between charges, increases calendar life, and improves the inherent safety of lithium-ion cells. Because the cathodes design is more stable than those traditionally used in batteries, the new batteries are also safer and less likely to overheat.[96]

Link: https://www.anl.gov/article/argonne-battery-technology-helps-power-chevy-volt

[94] From *Argonne Battery Technology Helps Power Chevy Volt*, Argonne National Laboratory, 2011, https://www.anl.gov/article/argonne-battery-technology-helps-power-chevy-volt
[95] From *Argonne Battery Technology Helps Power Chevy Volt*, Argonne National Laboratory, 2011, https://www.anl.gov/article/argonne-battery-technology-helps-power-chevy-volt
[96] From *Argonne Battery Technology Helps Power Chevy Volt: Brochure*, Argonne National Laboratory, 2017, https://www.anl.gov/sites/www/files/2018-08/Argonne_APS_ChevyVolt.pdf

PERFECTED POWDER FOR MANUFACTURING

Year: 2012 (winner of Department of Energy's America's Next Top Energy Innovator Challenge)[97]

Laboratories Involved: Ames[98]

Gas atomization is a powder production method that uses high-pressure gas flow to disintegrate molten metal into particles. The smooth spherical particles produced by Ames Laboratory's gas atomization method are an improvement over traditionally manufactured powders.[99] According to the Powder Metallurgy Review, the titanium atomization process developed at Ames Laboratory may be 10 times more efficient than traditional powder-making methods and could lower manufacturing costs by 80%.[100]

Given the rapid progress in 3D printing and additive manufacturing technology, ready access to affordable custom metal powders is likely to expedite further advancements in these energy-efficient production processes.[101] The gas atomization process has garnered Ames Laboratory at least 16 patents, and helped create a spin-off company exclusively licensing the patents to introduce titanium powder to an eager marketplace.[102]

Link: https://alvideo.ameslab.gov/Inquiry/2016-1/files/assets/common/downloads/publication.pdf

---

[97] From *Report on Technology Transfer and Related Technology Partnering Activities at the National Laboratories and Other Facilities for the Fiscal Year 2014,* Department of Energy, 2016, https://www.energy.gov/sites/prod/files/2016/06/f33/Technology%20Transfer%20Report%20to%20Congress%20FY14.pdf

[98] From *Perfect Powder: Ames Laboratory's Processes Perfect Metal Powders for Manufacturing*, Inquiry, Ames Laboratory, 2016 (Issue 1), https://alvideo.ameslab.gov/Inquiry/2016-1/files/assets/common/downloads/publication.pdf

[99] From *Perfect Powder: Ames Laboratory's Processes Perfect Metal Powders for Manufacturing*, Inquiry, Ames Laboratory, 2016 (Issue 1), https://alvideo.ameslab.gov/Inquiry/2016-1/files/assets/common/downloads/publication.pdf

[100] From *Additive Manufacturing: Building the Future – Success Stories*, Department of Energy, 2019, https://www.energy.gov/sites/prod/files/2019/03/f60/2019-March%20-%20Additive%20Manufacturing%20Success%20Stories.pdf

[101] From *Additive Manufacturing: Building the Future – Success Stories*, Department of Energy, 2019, https://www.energy.gov/sites/prod/files/2019/03/f60/2019-March%20-%20Additive%20Manufacturing%20Success%20Stories.pdf

[102] From *Perfect Powder: Ames Laboratory's Processes Perfect Metal Powders for Manufacturing*, Inquiry, Ames Laboratory, 2016 (Issue 1), https://alvideo.ameslab.gov/Inquiry/2016-1/files/assets/common/downloads/publication.pdf

EXPEDITED EBOLA DETECTION

Year: 2014[103]

Laboratories Involved: Sandia[104]

During the 2014 Ebola epidemic, reducing the amount of time Liberians who suspected they had Ebola spent waiting in large, open waiting rooms called Ebola treatment units was critical to controlling the outbreak. Sandia modeled and analyzed the West Africa nation's blood sample transport system from the treatment units to diagnostic labs and made recommendations to improve turnaround time. Sandia's solution minimized the amount of time that people were together in these open Ebola treatment units, so that somebody with a less serious illness wasn't infected by an Ebola victim.

Sandia's modeling also showed the fastest options for transporting blood samples from patients, many in remote jungles, to diagnostic labs. Sandia was additionally involved in modeling the potential need for quarantine, the effects of various changes to the global air transportation network, and even the resilience of the U.S. hospital system to Ebola cases.[105]

Link: https://newsreleases.sandia.gov/ebola_award/

[103] From *Sandia Honored for Fighting Ebola, Analyzing Emerging Biotechnologies*, Sandia National Laboratories, 2017, https://newsreleases.sandia.gov/ebola_award/
[104] From *Sandia Honored for Fighting Ebola, Analyzing Emerging Biotechnologies*, Sandia National Laboratories, 2017, https://newsreleases.sandia.gov/ebola_award/
[105] From *Sandia Honored for Fighting Ebola, Analyzing Emerging Biotechnologies*, Sandia National Laboratories, 2017, https://newsreleases.sandia.gov/ebola_award/

RECOVERED RARE EARTH ELEMENTS

Year: 2016[106]

Laboratories Involved: Ames[107]

Since 2016, Ames National Laboratory has been working on acid-free dissolution recycling (ADR) and chemical recovery of rare earth elements (REE), critical materials found in magnets in e-waste. REE magnets are critical components for electronic items such as cell phones and hard disk drives and clean energy technologies like offshore wind turbines. The demand for REE magnets is expected to increase significantly; however, their supply chain is not always reliable, partly due to the limited supply sources of REEs.

There are extensive benefits to recycling REE magnets – if done correctly, it can be an environmentally preferable solution, and it tackles challenges surrounding accessibility of REEs. In 2018, researchers received two R&D 100 awards for using oxidative dissolution to remove REEs from existing waste. By utilizing a water-based solution, the team developed a process that was more adaptable for recycling REEs, which cut down on REE losses in landfills and allowed for less reliance on mining.

Link: https://www.energy.gov/eere/ammto/articles/acid-free-dissolution-recycling-second-chance-rare-earth-elements

[106] From *Acid Free Dissolution Recycling: A Second Chance for Rare Earth Elements*, Department of Energy, 2023, https://www.energy.gov/eere/ammto/articles/acid-free-dissolution-recycling-second-chance-rare-earth-elements
[107] From *Acid Free Dissolution Recycling: A Second Chance for Rare Earth Elements*, Department of Energy, 2023, https://www.energy.gov/eere/ammto/articles/acid-free-dissolution-recycling-second-chance-rare-earth-elements

RAPIDLY RESPONDED TO COVID PANDEMIC

Year: 2020[108]

Laboratories Involved: All of Them![109]

The National Virtual Biotechnology Laboratory (NVBL) was established in March 2020 to address challenges associated with the COVID-19 crisis. The NVBL brought together the broad scientific and technical expertise of the Department of Energy (DOE)'s 17 national laboratories to address medical supply shortages, discover potential drugs to fight the virus, develop and verify COVID-19 testing methods, and model disease spread and impact across the nation.

Within just a few months, NVBL teams produced innovations in materials and advanced manufacturing that mitigated shortages in test kits and personal protective equipment (PPE), creating nearly 1,000 new jobs. They used DOE's high- performance computers and light and neutron sources to identify promising candidates for antibodies and antivirals. Researchers used artificial intelligence and high-performance computing to produce near-real-time analysis of data to forecast disease transmission, stress on public health infrastructure, and economic impact. Through NVBL, DOE contributed significantly to the nation's COVID response, demonstrating the critical impact of the national laboratories.[110]

Link: https://science.osti.gov/-/media/nvbl/pdf/NVBL_Brochure.pdf

[108] From *National Virtual Biotechnology Laboratory: R&D for Rapid Response to the COVID-19 Crisis*, Department of Energy, 2021, https://science.osti.gov/-/media/nvbl/pdf/NVBL_Brochure.pdf
[109] From *National Virtual Biotechnology Laboratory: R&D for Rapid Response to the COVID-19 Crisis*, Department of Energy, 2021, https://science.osti.gov/-/media/nvbl/pdf/NVBL_Brochure.pdf
[110] From *National Virtual Biotechnology Laboratory: R&D for Rapid Response to the COVID-19 Crisis*, Department of Energy, 2021, https://science.osti.gov/-/media/nvbl/pdf/NVBL_Brochure.pdf

BUILT WORLD'S LARGEST DIGITAL CAMERA

Year: 2024[111]

Laboratories Involved: Brookhaven, Lawrence Livermore, SLAC [112]

The 3,200-megapixel Legacy Survey of Space and Time (LSST) Camera was built by a team led by SLAC to help observe our universe in unprecedented detail. Over ten years (starting in 2025), it will generate an enormous trove of data on the southern night sky that researchers will mine for new insights into the universe. That data will aid in the quest to understand dark energy, which is driving the accelerating expansion of the universe, and the hunt for dark matter, which makes up around 85% of the matter in the universe.

The camera is roughly the size of a small car and weighs around 3 metric tons, and its front lens is over five feet across – the largest lens ever made for this purpose. The camera's focal plane is made up of 201 individual custom-designed sensors, and it is so flat that it varies by no more than a tenth the width of a human hair.[113]

Link: https://www6.slac.stanford.edu/news/2024-04-03-slac-completes-construction-largest-digital-camera-ever-built-astronomy

[111] From *SLAC Completes Construction of the Largest Digital Camera Ever Built for Astronomy*, SLAC National Accelerator Laboratory, 2024, https://www6.slac.stanford.edu/news/2024-04-03-slac-completes-construction-largest-digital-camera-ever-built-astronomy

[112] From *SLAC Completes Construction of the Largest Digital Camera Ever Built for Astronomy*, SLAC National Accelerator Laboratory, 2024, https://www6.slac.stanford.edu/news/2024-04-03-slac-completes-construction-largest-digital-camera-ever-built-astronomy

[113] From *SLAC Completes Construction of the Largest Digital Camera Ever Built for Astronomy*, SLAC National Accelerator Laboratory, 2024, https://www6.slac.stanford.edu/news/2024-04-03-slac-completes-construction-largest-digital-camera-ever-built-astronomy