Oak Ridge National Laboratory

Coordinates:

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Oak Ridge National Laboratory (**ORNL**) is a multiprogram science and technology national laboratory managed for the United States Department of Energy (DOE) by UT-Battelle. ORNL is the largest science and energy national laboratory in the Department of Energy system.[2] ORNL is located in Oak Ridge, Tennessee, near Knoxville. ORNL's scientific programs focus on materials, neutron science, energy, high-performance computing, systems biology and national security.

ORNL partners with the state of Tennessee, universities and industries to solve challenges in energy, advanced materials, manufacturing, security and physics.

The laboratory is home to several of the world's top supercomputers and is a leading neutron science and nuclear energy research facility that includes the Spallation Neutron Source and High Flux Isotope Reactor. ORNL hosts the Titan supercomputer; the Center for Nanophase Materials Sciences, the BioEnergy Science Center,[3] and the Consortium for Advanced Simulation of Light-Water Reactors.[4]

Oak Ridge National Laboratory

Established:	1943[1]
Director:	Thom Mason
Location:	Oak Ridge, Tennessee
Budget:	$1.65 billion[1]
Mission:	ORNL's scientific programs focus on materials, neutron science, energy, high-performance computing, systems biology and national security
U.S. patents since 2003:	292
Active technology licenses:	115
Staff:	4,400[1]
Website:	ornl.gov (http://ornl.gov)
Operated by:	UT-Battelle

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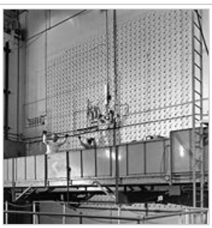
History



Workers load uranium slugs into the X-10 Graphite Reactor – now a National Historic Landmark, and part of Oak Ridge National Laboratory.

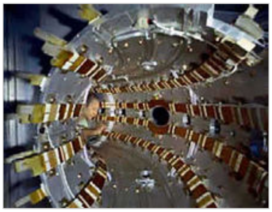
The town of Oak Ridge was established by the Army Corps of Engineers as part of the Clinton Engineer Works in 1942 on isolated farm land as part of the Manhattan Project.[5] In 1943 the "Clinton Laboratories" were completed, later renamed to the Oak Ridge National Laboratory.[5] The site was chosen for the X-10 Graphite Reactor, used to show that plutonium can be extracted from enriched uranium. Enrico Fermi and his colleagues developed the world's second self-sustaining nuclear reactor after Fermi's previous experiment Chicago Pile-1, the X-10 was the first designed for continuous operation.[6] After the end of World War II the demand for weapons-grade plutonium fell and the reactor and the laboratory's 1000 employees were no longer involved in nuclear weapons,[5][7] instead it was used for scientific research.[6] In 1946 the first medical isotopes were produced in the X-10 reactor, by 1950 almost 20,000 samples had been shipped to various hospitals.[6][7] As the demand for military science had fallen dramatically the future of the lab was uncertain. Management of the lab was contracted by the US government to Monsanto, however, they withdrew in 1947.[7] The University of Chicago assumed responsibility but withdrew shortly after, until in December 1947 Union Carbide and Carbon Co., which already operated two other facilities at Oak Ridge, took control of the laboratory and Alvin Weinberg was named Director of Research ORNL, and in 1955 Director of the Laboratory.[7][8]

In 1950 the Oak Ridge School of Reactor Technology was established with two courses in reactor operation and safety; almost 1000 students graduated.[7] Much of the research performed at ORNL in the 1950s was relating to nuclear reactors as a form of energy production both for propulsion and electricity; more reactors were built in the 1950s than the rest of the ORNL's history combined.[7] Through experiment X-10 was the first light water reactor, the most common type of nuclear reactor as of 2012.[9] The US Military funded much of the reactor development leading to the nuclear powered submarines and ships of the US Navy.[7] The US Army contracted portable nuclear reactors in 1953 for heat and electricity generation in remote military bases.[10] The reactors were designed at ORNL, produced by American Locomotive Company and used in Greenland, the Panama Canal Zone and Antarctica.[7] The United States Air Force (USAF) also contributed funding to three reactors; the lab's first computers; and its first particle accelerators.[7] ORNL designed and tested a nuclear powered aircraft in 1954 as a proof-of-concept for a proposed USAF fleet of long range bombers, although it never flew.[7][10] The provision of radionuclides by X-10 for medicine grew steadily in the 1950s with more isotopes available; ORNL was the only Western source of californium-252.[7] ORNL scientists lowered the immune systems of mice and performed the world's first successful bone marrow transplant.[7]

The core of the Molten Salt Reactor Experiment

In the early 1960s there was a large push at ORNL to develop nuclear powered desalination plants where deserts met the sea to provide water. The project called Water for Peace was backed by John F. Kennedy and Lyndon B. Johnson and presented at a 1964 United Nations conference but increases in the cost of construction and public confidence in nuclear power falling caused the plan to fail.[7][10] The Health Physics Research Reactor built in 1962 was used for radiation exposure experiments leading to more accurate dosage limits, dosimeters and improved radiation shielding.[7] In 1964 the Molten-Salt Reactor Experiment began with the construction of the reactor. It was operated from 1966 until 1969 (with six months down time to move from U-235 to U-233 fuel) and proved the viability of molten salt reactors while also producing fuel for other reactors as a byproduct of its own reaction.[7] The High Flux Isotope Reactor built in 1965 with the highest neutron flux of any reactor at the time.[7] It improved upon the work of the X-10 reactor producing more medical isotopes as well as allowing higher fidelity of materials research.[7] Researchers in the Biology Division studied the effects of chemicals on mice including petrol fumes, pesticides and tobacco.[7] In the late 1960s cuts in funding led to plans for another particle accelerator to be cancelled and the United States Atomic Energy Commission cut the breeder reactor program by two thirds leading to a downsizing in staff from 5000 to 3800.[7]

In the 1970s the prospect of fusion power was strongly considered sparking research at ORNL. A tokamak called ORMAK, made operational in 1971, was the first tokamak to achieve a plasma temperature of 20 million Kelvin.[11] After the success of the fusion experiments it was enlarged and renamed ORMAK II in 1973 however the experiments ultimately failed to lead to fusion power plants.[7] The US Atomic Energy Commission required improved safety standards in the early 1970s for nuclear reactors so ORNL



The inside of ORMAK, an early tokamak, was gold plated for reflectivity

staff wrote almost 100 requirements covering many factors including fuel transport and earthquake resistance. In 1972 the AEC held a series of public hearings where emergency cooling requirements were highlighted and the safety requirements became more stringent.[7] ORNL was involved in analysing the damage to the core of the Three Mile Island Nuclear Generating Station after the accident in 1979.[7] Also in 1972 Peter Mazur, a biologist at ORNL, froze with liquid nitrogen, thawed and implanted mouse embryos in a surrogate mother. The mouse pups were born healthy.[7] The technique is popular in the livestock industry as it allows the embryos of valuable cattle to be transported easily and a prize cow can have multiple eggs extracted and thus through *in vitro* fertilisation have many more offspring that would naturally be possible.[7] In 1974 Alvin Weinberg, director of the lab for 19 years, was replaced by Herman Postma, a fusion scientist.[7] In 1977 construction began for 6 metre (20 foot) superconducting electromagnets intended to control fusion reactions. The project was an international effort, three electromagnets were produced in the US, one in Japan, one in Switzerland and the final by remaining European states and experimentation continued into the 1980s.[7]

The 1980s brought more changes to ORNL, a focus on efficiency became paramount. An accelerated climate simulation chamber was built that applied varying weather conditions to insulation to test its efficacy and durability faster than real time.[7] Materials research into heat resistant ceramics for use in truck and high-tech car engines was performed, building upon the materials research that began in the nuclear reactors of the 1950s.[7] In 1987 the High Temperature Materials Laboratory was established where ORNL and industry researchers cooperated on ceramic and alloy projects. The materials research budget at ORNL doubled after initial uncertainty regarding Reagan's economic policy of less government expenditure.[7] In 1981 the Holifield Heavy Ion Research Facility, a 25 MV particle accelerator, was opened at ORNL. At the time, Holifield had the widest range of ion species and was twice as powerful as other accelerators attracting hundreds of guest researchers each year.[7] The Department of Energy was concerned with the pollution surrounding ORNL and it began clean-up efforts. Burial trenches and leaking pipes had contaminated the groundwater beneath the lab and radiation tanks were sitting idle, full of waste. Estimates of the total cost of clean-up were into the hundreds of millions of US dollars.[7] The five older reactors were subjected to safety reviews in 1987, ordered to be deactivated until the reviews were complete. By 1989 when the High Flux Isotope Reactor was restarted the US supply of certain medical isotopes was depleted.[7] In 1989 the former executive officer of the American Association for the Advancement of Science, Alvin Trivelpiece, became director of ORNL, he remained in the role until 2000.[7]

Areas of research

ORNL conducts research and development activities that span a wide range of scientific disciplines. Many research areas have a significant overlap with each other; researchers often work in two or more of the fields listed here. The laboratory's major research areas are described briefly below.

- Chemical sciences – ORNL conducts both fundamental and applied research in a number of areas, including catalysis, surface science and interfacial chemistry; molecular transformations and fuel chemistry; heavy element chemistry and radioactive materials characterization; aqueous solution chemistry and geochemistry; mass spectrometry and laser spectroscopy; separations chemistry; materials chemistry including synthesis and characterization of polymers and other soft materials; chemical biosciences; and neutron science.
- Electron microscopy – ORNL's electron microscopy program investigates key issues in condensed matter, materials, chemical and nanosciences.
- Nuclear medicine – The laboratory's nuclear medicine research is focused on the development of improved reactor production and processing methods to provide medical radioisotopes, the development of new radionuclide generator systems, the design and evaluation of new radiopharmaceuticals for applications in nuclear medicine and oncology.
- Physics – Physics research at ORNL is focused primarily on studies of the fundamental properties of matter at the atomic, nuclear, and subnuclear levels and the development of experimental devices in support of these studies.
- Population – ORNL provides federal, state and international organizations with a gridded population database, called Landscan,[12] for estimating ambient population. LandScan is a raster image, or grid, of population counts, which provides human population estimates every 30 x 30 arc seconds, which translates roughly to population estimates for 1 kilometer square windows or grid cells at the equator, with cell width decreasing at higher latitudes.[13] Though many population datasets exist, LandScan is the best spatial population dataset, which also covers the globe. Updated annually (although data releases are generally one year behind the current year) offers continuous, updated values of population, based on the most recent information. Landscan data are accessible through GIS applications and a USAID public domain application called Population Explorer.[14]

Energy

The laboratory has a long history of energy research; nuclear reactor experiments have been conducted since the end of WWII in 1945. Because of the availability of reactors and high performance computing resources an emphasis on improving the efficiency of nuclear reactors is present.[15][16] The programs develop more efficient materials, more accurate simulations of aging reactor cores, sensors and controls as well as safety procedures for regulatory authorities.[16]

The Energy Efficiency and Electricity Technologies Program (EEETP) aims to improve air quality in the US and reduce dependence on foreign oil supplies.[17] There are three key areas of research; electricity, manufacturing and mobility. The electricity division focuses on reducing electricity consumption and finding alternative sources for production. Buildings which account for 39% of US electricity consumption as of 2012, are a key area of research as the program aims to create affordable, carbon-neutral homes by 2020.[18] Research also takes place into higher efficiency solar panels, geothermal electricity and heating, lower cost wind generators and the economic and environmental feasibility of potential hydro power plants.[19][20][21]

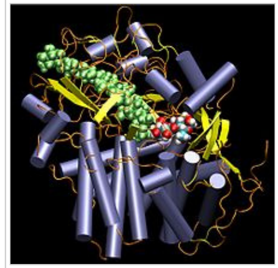
Fusion is another area with a history of research at ORNL, dating back to the 1970s. The Fusion Energy Division pursues short term goals to develop components such as high temperature superconductors, high-speed hydrogen pellet injectors and suitable materials for future fusion research.[22][23] Much research into the behaviour and maintenance of a plasma takes place at the Fusion Energy Division to further the understanding of plasma physics, a crucial area for developing a fusion power plant.[22][23] The US ITER office is at ORNL with partners at Princeton Plasma Physics Laboratory and Savannah River National Laboratory.[24] The US contribution to the ITER project is 9.09% which is expected to be in excess of US$1.6 billion throughout the contract.[25][26]

Biology

Oak Ridge National Laboratory's biological research covers genomics, computational biology, structural biology and bioinformatics.[27] The BioEnergy Program aims to improve the efficiency of all stages of the biofuel process to improve the energy security of the United States.[28] The program aims to make genetic improvements to the potential biomass used,[29] formulate methods for refineries that can accept a diverse range of fuels and to improve the efficiency of energy delivery both to power plants and end users.[30][31]

The Center for Molecular Biophysics conducts research into the behaviour of biological molecules in various conditions. The center hosts projects that examine cell walls for biofuel production,[32] use neutron scattering to analyse protein folding and simulate the effect of catalysis on a conventional and quantum scale.[33][34]

Neutron science



A simulation of CelS, a type of Cellobiohydrolase that hydrolises the glycosidic bonds of cellulose (cellulolysis)

There are three neutron sources at ORNL; the High Flux Isotope Reactor (HFIR), the Oak Ridge Electron Linear Accelerator (ORELA) and the Spallation Neutron Source. HFIR provides neutrons in a stable beam resulting from a constant nuclear reaction whereas ORELA and SNS produce pulses of neutrons as they are particle accelerators.[35][36] HFIR went critical in 1965 and has been used for materials research and as a major sources of medical radioisotopes since.[37] As of 2013, HFIR provides the world's highest constant neutron flux as a result of various upgrades.[38] As part of a US non proliferation effort the HFIR is scheduled to switch from highly enriched uranium (>90%, weapons grade) to low-enriched (3–4%) in 2020; the last reactor in the US to do so.[39] Berkelium used to produce the world's first sample of ununseptium was produced in the High Flux Isotope Reactor as part of an international effort.[40] HFIR is likely to operate until approximately 2060 before the reactor vessel is considered unsafe for continued use.[39]

The Spallation Neutron Source (SNS) is a particle accelerator that has the highest intensity neutron pulses of any man-made neutron source.[41] SNS was made operational in 2006 and has since been upgraded to 1 megawatts with plans to continue up to 3 megawatts.[38] High power neutron pulses permit clearer images of the targets meaning smaller samples can be analysed and accurate results require fewer pulses.[42]

Materials

A particulate filter housing for a regenerative burner made of CF8C Plus stainless steel

Oak Ridge National Laboratory conducts research into materials science in a range of areas. Between 2002 and 2008 ORNL partnered with Caterpillar Inc. (CAT) to form a new material for their diesel engines that can withstand large temperature fluctuations.[43] The new steel, named CF8C Plus, is based on conventional CF8C stainless steel with added manganese and nitrogen; the result has better high–temperature properties and is easier to cast at a similar cost.[43] In 2003 the partners received an R&D 100 award from *R&D magazine* and in 2009 received an award for "excellence in technology transfer" from the Federal Laboratory Consortium for the commercialisation of the steel.[43]

There is a high-temperature materials lab at ORNL that permits researchers from universities, private companies and other government initiatives to use their facilities. The lab is available for free if the results are published; private research is permitted but requires payment.[44] A separate lab, the Shared Equipment User Facility, is one of three DOE sponsored facilities with nano-scale microscopy and tomography facilities.[45]

The Center for Nanophase Materials Sciences (CNMS) researches the behaviour and fabrication of nanomaterials. The center emphasises discovery of new materials and the understanding of underlying physical and chemical interactions that enable creation of nanomaterials.[46] In 2012 CNMS produced a lithium-sulfide battery with a theoretical energy density three to five times greater than existing lithium ion batteries.[47]

Security

Oak Ridge National Laboratory provides resources to the US Department of Homeland Security and other defense programs. The Global Security and Nonproliferation (GS&N) program develops and implements policies, both US based and international, to prevent the proliferation of nuclear material.[48] The program has developed safeguards for nuclear arsenals, guidelines for dismantling arsenals, plans of action should nuclear material fall into unauthorised hands, detection methods for stolen or missing nuclear material and trade of nuclear material between the US and Russia.[48] The GS&N's work overlaps with that of the Homeland Security Programs Office, providing detection of nuclear material and nonproliferation guidelines. Other areas concerning the Department Homeland Security include nuclear and radiological forensics, chemical and biological agent detection using mass spectrometry and simulations of potential national hazards.[49]

High performance computing

Throughout the history of the Oak Ridge National Laboratory it has been the site of various supercomputers, home to the fastest on several occasions.[50] In the 1953 ORNL partnered with the Argonne National Laboratory to build ORACLE (Oak Ridge Automatic Computer and Logical Engine), a computer to research nuclear physics, chemistry, biology and engineering.[10][50][51] ORACLE had 2048 words (80 KiB) of memory and took approximately 590 microseconds to perform addition or multiplications of integers.[51] In 1969 X-10 was also equipted with an IBM 360/91 which was unique to ORNL. This mainframe contained many features not generally available until the 1980's. In 1995 ORNL bought an Intel Paragon based computer called the *Intel Paragon XP/S 150* that performed at 154 gigaFLOPS and ranked third on the TOP500 list of supercomputers.[50][52] In 2005 Jaguar was built, a Cray XT3 based system that performed at 25 teraFLOPS and received incremental upgrades up to the XT5 platform that performed at 2.3 petaFLOPS in 2009. It was recognised as the world's fastest from November 2009 until November 2010.[53][54]

Since 1992 the National Center for Computational Sciences (NCCS) has overseen high performance computing at ORNL. It manages the Oak Ridge Leadership Computing Facility that contains the machines.[55] In 2012 Jaguar was upgraded to the XK7 platform, a fundamental change as GPUs are used for the majority of processing, and renamed Titan. Titan performs at 17.59 petaFLOPS and holds the number 1 spot on the TOP500 list for November 2012.[56] Other computers include a 77 node cluster to visualise data that the larger machines output in the *Exploratory Visualization Environment for Research in Science and Technology* (EVEREST), a visualisation room with a 10 by 3 metre (30 by 10 ft) wall that displays 35 megapixel projections.[57][58] Smoky is a 80 node linux cluster used for application development. Research projects are refined and tested on Smoky before running on larger machines such as Titan.[59]

In 1989 programmers at the Oak Ridge National Lab wrote the first version of Parallel Virtual Machine (PVM), software that enables distributed computing on machines of differing specifications.[60] PVM is free software and has become the de facto standard for distributed computing.[61] Jack Dongarra of ORNL and the University of Tennessee wrote the LINPACK software library and LINPACK benchmarks, used to calculate linear algebra and the standard method of measuring floating point performance of a supercomputer as used by the TOP500 organisation.[50][62]

Facts and Figures

ORNL is managed by a limited liability partnership between the University of Tennessee and Battelle Memorial Institute known as UT-Battelle.

ORNL has a staff of about 4,600 full-time staff members, including 3000 scientists and engineers.[63] The laboratory annually hosts approximately 3,000 guest researchers[64] who spend two weeks or longer in Oak Ridge; about 25 percent of these visitors[65] are from industry. ORNL receives 30,000 visitors each year, plus another 10,000 precollege students.

ORNL funding exceeds $1.65 billion[63] annually; 80 percent of that amount comes from the Department of Energy, and 20 percent is from other federal and private customers. UT-Battelle, the laboratory's management and operating contractor, has provided more than $10 million in support of math and science education, economic development and other projects in the greater Oak Ridge region.

The laboratory occupies about 4,470 acres (18.1 km^2) of the 34,000-acre (140 km^2) Oak Ridge Reservation (ORR), which it shares with the East Tennessee Technology Park, the Y-12 National Security Complex, the Oak Ridge Institute for Science and Education, and the developing Oak Ridge Science and Technology Park. 20,000 acres (81,000,000 m^2) of the ORR, the Oak Ridge National Environmental Research Park, is an outdoor laboratory and a national user facility. It supports DOE-sponsored research in carbon cycling, ecosystem dynamics, global climate change, and remediation studies, as well as the research of numerous colleges, universities, and other state and federal agencies.

See also

- American Museum of Science and Energy
- Center for Nanophase Materials Sciences
- K-25 Gaseous Diffusion Plant
- Karl Z. Morgan
- National Transportation Research Center
- Sandia National Laboratory
- Spallation Neutron Source
- Y-12 National Security Complex
- Thorium Energy Alliance

References

1. ^ [a b c] "ORNL Fact Sheet" (http://www.ornl.gov/ornlhome/docs/fact.pdf) . Oak Ridge National Laboratory. 2012. http://www.ornl.gov/ornlhome/docs/fact.pdf. Retrieved November 15, 2012.
2. ^ "Oakridge.doe.gov" (http://www.oakridge.doe.gov/external/) . Oakridge.doe.gov. http://www.oakridge.doe.gov/external/. Retrieved 2012-07-14.
3. ^ "bioenergycenter.org" (http://bioenergycenter.org/) . bioenergycenter.org. http://bioenergycenter.org/. Retrieved 2012-07-14.
4. ^ "casl.gov" (http://www.casl.gov/) . casl.gov. http://www.casl.gov/. Retrieved 2012-07-14.
5. ^ [a b c] "Solving the Big Problems" (http://www.ornl.gov/ornlhome/ornl_brochure.pdf) . Oak Ridge National Laboratory. 2007. http://www.ornl.gov/ornlhome/ornl_brochure.pdf. Retrieved 11 November 2012.
6. ^ [a b c] Rettig, Polly (December 8, 1975). "X-10 Reactor, Graphite Reactor" (http://pdfhost.focus.nps.gov/docs/NHLS/Text/66000720.pdf) . National Register of Historic Places. http://pdfhost.focus.nps.gov/docs/NHLS/Text/66000720.pdf. Retrieved 11 November 2012.
7. ^ [a b c d e f g h i j k l m n o p q r s t u v w x y z aa ab ac ad ae af ag] "Swords to Plowshares: A Short History of Oak Ridge National Laboratory (1943–1993)" (http://www.ornl.gov/info/swords/swords.shtml) . Oak Ridge National Laboratory. April 8, 2006. http://www.ornl.gov/info/swords/swords.shtml. Retrieved 11 November 2012.
8. ^ "ORNL contractor gives $25K to Weinberg memorial effort" (http://www.oakridger.com/article/20110908/NEWS/309089996) . Oak Ridger. September 8, 2011. http://www.oakridger.com/article/20110908/NEWS/309089996. Retrieved November 16, 2012.
9. ^ "The Graphite Reactor" (http://www.ornl.gov/info/news/cco/graphite.shtml) . Oak Ridge National Laboratory. http://www.ornl.gov/info/news/cco/graphite.shtml. Retrieved 11 November 2012.
10. ^ [a b c d] "ORNL Review Timeline" (http://www.ornl.gov/info/ornlreview/v36_1_03/timeline/) . Oak Ridge National Laboratory. http://www.ornl.gov/info/ornlreview/v36_1_03/timeline/. Retrieved 11 November 2012.
11. ^ "Responding to Social Needs" (http://www.ornl.gov/info/ornlreview/rev25-34/chapter6.shtml) . *ORNL Review*. Oak Ridge National Laboratory. 2002. http://www.ornl.gov/info/ornlreview/rev25-34/chapter6.shtml. Retrieved January 22, 2013.
12. ^ "LandScan Home" (http://www.ornl.gov/landscan) . Ornl.gov. http://www.ornl.gov/landscan. Retrieved 2012-07-14.
13. ^ LandScan Home, ornl.gov (http://www.ornl.gov/sci/landscan/)
14. ^ "Populationexplorer.com" (http://www.populationexplorer.com/) . Populationexplorer.com. http://www.populationexplorer.com/. Retrieved 2012-07-14.
15. ^ "Fuel Cycle and Isotopes Division" (http://www.ornl.gov/sci/nsed/division_fcid.shtml) . Oak Ridge National Laboratory. http://www.ornl.gov/sci/nsed/division_fcid.shtml. Retrieved February 6, 2013.
16. ^ [a b] "Reactor and Nuclear Systems Division" (http://www.ornl.gov/sci/nsed/rnsd/) . Oak Ridge National Laboratory. http://www.ornl.gov/sci/nsed/rnsd/. Retrieved February 6, 2013.
17. ^ "Energy Efficiency and Electricity Technologies Program Fact Sheet" (http://www.ornl.gov/sci/ees/factsheets/fs_eere.pdf) . Oak Ridge National Laboratory. http://www.ornl.gov/sci/ees/factsheets/fs_eere.pdf. Retrieved February 6, 2013.
18. ^ "Program Areas - Building Technologies" (http://www.ornl.gov/sci/eere/research_building.shtml) . Oak Ridge National Laboratory. http://www.ornl.gov/sci/eere/research_building.shtml. Retrieved February 6, 2013.
19. ^ "Wind & Water Power Program" (http://www.ornl.gov/sci/eere/research_wind_hydro.shtml) . Oak Ridge National Laboratory. http://www.ornl.gov/sci/eere/research_wind_hydro.shtml. Retrieved 6 February 2013.
20. ^ "Geothermal Technologies" (http://www.ornl.gov/sci/eere/research_geothermal.shtml) . Oak Ridge National Laboratory. http://www.ornl.gov/sci/eere/research_geothermal.shtml. Retrieved 6 February 2013.
21. ^ "Solar Energy Technologies" (http://www.ornl.gov/sci/eere/research_solar.shtml) . Oak Ridge National Laboratory. http://www.ornl.gov/sci/eere/research_solar.shtml. Retrieved 6 February 2013.
22. ^ [a b] "Fusion Energy Division Fact Sheet" (http://www.ornl.gov/sci/nsed/factsheets/fs_fusion_energy.pdf) . Oak Ridge National Laboratory. http://www.ornl.gov/sci/nsed/factsheets/fs_fusion_energy.pdf. Retrieved 6 February 2013.
23. ^ [a b] "Fusion Energy Division" (http://www.ornl.gov/sci/nsed/division_fed.shtml) . Oak Ridge National Laboratory. http://www.ornl.gov/sci/nsed/division_fed.shtml. Retrieved 6 February 2013.
24. ^ "About US ITER" (https://www.usiter.org/about/) . US ITER. https://www.usiter.org/about/. Retrieved 6 February 2013.
25. ^ McGrath, Matt (June 17, 2009). "Fusion falters under soaring costs" (http://news.bbc.co.uk/1/hi/sci/tech/8103557.stm) . BBC. http://news.bbc.co.uk/1/hi/sci/tech/8103557.stm. Retrieved 6 February 2013.
26. ^ "ITER Procurement Sharing" (http://www.iter.org/procurementsharing) . ITER. http://www.iter.org/procurementsharing. Retrieved 6 February 2013.
27. ^ "Biological systems" (http://www.ornl.gov/ornlhome/biological_systems.shtml) . Oak Ridge National Laboratory. http://www.ornl.gov/ornlhome/biological_systems.shtml. Retrieved January 22, 2013.
28. ^ "BioEnergy Program – Our Role" (http://www.ornl.gov/sci/bioenergy/role.shtml) . Oak Ridge National Laboratory. http://www.ornl.gov/sci/bioenergy/role.shtml. Retrieved January 22, 2013.
29. ^ "BioEnergy Program – Biofeedstocks" (http://www.ornl.gov/sci/bioenergy/research_biofeedstocks.shtml) . Oak Ridge National Laboratory. http://www.ornl.gov/sci/bioenergy/research_biofeedstocks.shtml. Retrieved January 22, 2013.
30. ^ "BioEnergy Program – Refineries" (http://www.ornl.gov/sci/bioenergy/research_biorefineries.shtml) . Oak Ridge National Laboratory. http://www.ornl.gov/sci/bioenergy/research_biorefineries.shtml. Retrieved January 22, 2013.
31. ^ "BioEnergy Program – Product Delivery" (http://www.ornl.gov/sci/bioenergy/research_product.shtml) . Oak Ridge National Laboratory. http://www.ornl.gov/sci/bioenergy/research_product.shtml. Retrieved January 22, 2013.
32. ^ "Biophysical origins of biomass recalcitrance to hydrolysis" (http://cmb.ornl.gov/research/bioenergy) . Oak Ridge National Laboratory. http://cmb.ornl.gov/research/bioenergy. Retrieved January 23, 2013.
33. ^ Parks, Jerry M.. "Enzymatic Mechanisms of MerA and MerB" (http://cmb.ornl.gov/research/enzyme-catalysis/mera-merb) . Oak Ridge National Laboratory. http://cmb.ornl.gov/research/enzyme-catalysis/mera-merb. Retrieved January 23, 2013.
34. ^ Saharay, Moumita. "Catalytic Mechanism of Cellobiohydrolase, CelS, on Cellulose Degradation" (http://cmb.ornl.gov/research/enzyme-catalysis/cels) . Oak Ridge National Laboratory. http://cmb.ornl.gov/research/enzyme-catalysis/cels. Retrieved January 23, 2013.
35. ^ "Neutrons at ORNL" (http://neutrons.ornl.gov/about/) . Oak Ridge National Laboratory. http://neutrons.ornl.gov/about/. Retrieved January 21, 2013.
36. ^ Koehler, P. E.. "The Oak Ridge Electron Linear Accelerator Pulsed Neutron Source" (http://www.phy.ornl.gov/nuclear/orela/) . Oak Ridge National Laboratory. http://www.phy.ornl.gov/nuclear/orela/. Retrieved January 21, 2013.
37. ^ "The High Flux Isotope Reactor at ORNL" (http://neutrons.ornl.gov/facilities/HFIR/) . Oak Ridge National Laboratory. http://neutrons.ornl.gov/facilities/HFIR/. Retrieved January 21, 2013.

38. ^ [a] [b] "Neutron Review" (http://neutrons.ornl.gov/media/pubs/pdf/2010neutronreview.pdf) . Oak Ridge National Laboratory. April 2011. http://neutrons.ornl.gov/media/pubs/pdf/2010neutronreview.pdf. Retrieved January 22, 2013.
39. ^ [a] [b] Munger, Frank (May 8, 2012). "ORNL's High Flux Isotope Reactor may be last reactor to convert to low-enriched fuel" (http://blogs.knoxnews.com/munger/2012/05/will-ornls-high-flux-isotope-r.html) . Knox News. http://blogs.knoxnews.com/munger/2012/05/will-ornls-high-flux-isotope-r.html. Retrieved January 21, 2013.
40. ^ Cabage, Bill. "International team discovers element 117" (http://www.ornl.gov/ornlhome/news_items/news_100407.shtml) . Oak Ridge National Laboratory. http://www.ornl.gov/ornlhome/news_items/news_100407.shtml. Retrieved January 22, 2013.
41. ^ "Spallation Neutron Source" (http://neutrons.ornl.gov/facilities/SNS/) . Oak Ridge National Laboratory. http://neutrons.ornl.gov/facilities/SNS/. Retrieved January 22, 2013.
42. ^ "Spallation Neutron Source First Of Its Kind To Reach Megawatt Power" (http://www.sciencedaily.com/releases/2009/09/090929181816.htm) . Science Daily. October 1, 2009. http://www.sciencedaily.com/releases/2009/09/090929181816.htm. Retrieved January 22, 2013.
43. ^ [a] [b] [c] "New Steel Advances Engine Exhaust System" (http://www.ornl.gov/sci/cf8cplus/pdf/09-G01217_Steel.pdf) . US Department of Energy. February 2010. http://www.ornl.gov/sci/cf8cplus/pdf/09-G01217_Steel.pdf. Retrieved January 19, 2013.
44. ^ "What We Do" (http://www.html.ornl.gov/what.shtml) . Oak Ridge National Laboratory. http://www.html.ornl.gov/what.shtml. Retrieved January 20, 2013.
45. ^ "Shared Research User Facility" (http://www.ornl.gov/sci/share/) . Oak Ridge National Laboratory. http://www.ornl.gov/sci/share/. Retrieved January 20, 2013.
46. ^ "SCIENCE AT THE CNMS" (http://cnms.ornl.gov/about_cnms/about_cnms.shtm) . Oak Ridge National Laboratory. http://cnms.ornl.gov/about_cnms/about_cnms.shtm. Retrieved January 22, 2013.
47. ^ "High Energy Lithium-Sulfur Batteries" (http://cnms.ornl.gov/news/Liang_AdvFuncMat_2012.shtm) . Oak Ridge National Laboratory. June 2012. http://cnms.ornl.gov/news/Liang_AdvFuncMat_2012.shtm. Retrieved January 20, 2013.
48. ^ [a] [b] "Global Security & Nonproliferation Programs Mission Factsheet" (http://www.ornl.gov/adm/directorates/gsd/factsheets/GS&N%20Fact%20Sheet.pdf) . Oak Ridge National Laboratory. http://www.ornl.gov/adm/directorates/gsd/factsheets/GS&N%20Fact%20Sheet.pdf. Retrieved January 23, 2013.
49. ^ "Department of Homeland Security Programs – Key Competencies" (http://www.ornl.gov/adm/directorates/gsd/dhs_compentencies.shtml) . Oak Ridge National Laboratory. http://www.ornl.gov/adm/directorates/gsd/dhs_compentencies.shtml. Retrieved January 23, 2013.
50. ^ [a] [b] [c] [d] Brouner, Jennifer; McCorkle, Morgan; Pearce, Jim; Williams, Leo (2012). "ORNL Review Vol. 45" (http://www.ornl.gov/info/ornlreview/v45_3_12/Review_v45n3.pdf) . Oak Ridge National Laboratory. p. 1. http://www.ornl.gov/info/ornlreview/v45_3_12/Review_v45n3.pdf. Retrieved November 2, 2012.
51. ^ [a] [b] Weik, Martin H.. "BRL Report 1961" (http://ed-thelen.org/comp-hist/BRL61-o.html#ORACLE) . *Army Project No. 5803-06-002*. Ballistic Research Laboratories. http://ed-thelen.org/comp-hist/BRL61-o.html#ORACLE. Retrieved 8 November 2012.
52. ^ "XP/S-MP 150" (http://www.top500.org/system/172576) . TOP500. http://www.top500.org/system/172576. Retrieved January 8, 2013.
53. ^ Dunlap, Darren (November 16, 2006). "'Jaguar' Rises on TOP500 Listing" (http://www.redorbit.com/news/technology/734453/jaguar_rises_on_top500_listing/) . Knoxville News-Sentinel. http://www.redorbit.com/news/technology/734453/jaguar_rises_on_top500_listing/. Retrieved 9 November 2012.
54. ^ "ORNL's Jaguar Claws its Way to Number One" (http://top500.org/lists/2009/11/press-release) . TOP500. November 13, 2009. http://top500.org/lists/2009/11/press-release. Retrieved 9 November 2012.
55. ^ "National Center for Computational Sciences" (http://computing.ornl.gov/nccs.shtml) . Oak Ridge National Laboratory. http://computing.ornl.gov/nccs.shtml. Retrieved January 19, 2013.
56. ^ "Oak Ridge Claims No. 1 Position on Latest TOP500 List with Titan" (http://www.top500.org/blog/lists/2012/11/press-release/) . TOP500. November 12, 2012. http://www.top500.org/blog/lists/2012/11/press-release/. Retrieved November 15, 2012.
57. ^ Munger, Frank (January 1, 2013). "ORNL visualization lab gets $2.5M makeover, adds 3D" (http://www.knoxnews.com/news/2013/jan/01/ornl-visualization-lab-gets-25m-makeover-adds-3d/) . Knox News. http://www.knoxnews.com/news/2013/jan/01/ornl-visualization-lab-gets-25m-makeover-adds-3d/. Retrieved January ,2013.
58. ^ "Lens" (https://www.olcf.ornl.gov/computing-resources/lens/) . Oak Ridge Leadership Computing Facility. https://www.olcf.ornl.gov/computing-resources/lens/. Retrieved January 19, 2013.
59. ^ "Smoky" (https://www.olcf.ornl.gov/computing-resources/smoky/) . Oak Ridge Leadership Computing Facility. https://www.olcf.ornl.gov/computing-resources/smoky/. Retrieved January 19, 2013.
60. ^ "PVM 3 USER'S GUIDE AND REFERENCE MANUAL" (ftp://ftp.jlab.org/pub/coda/docs/pdf/manuals/pvm_guide.pdf) . Oak Ridge National Laboratory. September 1994. p. 1. ftp://ftp.jlab.org/pub/coda/docs/pdf/manuals/pvm_guide.pdf. Retrieved 10 November 2012.
61. ^ "PVM: Parallel Virtual Machine" (http://www.csm.ornl.gov/pvm/) . Computer Science and Mathematics Division, Oak Ridge National Laboratory. December 5, 2011. http://www.csm.ornl.gov/pvm/. Retrieved 10 November 2012.
62. ^ "The Linpack Benchmark" (http://www.top500.org/project/linpack) . TOP500. http://www.top500.org/project/linpack. Retrieved 10 November 2012.
63. ^ [a] [b] "ORNL.gov" (http://www.ornl.gov/ornlhome/docs/fact.pdf) (PDF). http://www.ornl.gov/ornlhome/docs/fact.pdf. Retrieved 2012-07-14.
64. ^ "ORNL.gov" (http://www.ornl.gov/ornlhome/user_facilities.shtml) . ORNL.gov. http://www.ornl.gov/ornlhome/user_facilities.shtml. Retrieved 2012-07-14.
65. ^ "ORNL.gov" (http://www.ornl.gov/ornlhome/visiting.shtml) . ORNL.gov. http://www.ornl.gov/ornlhome/visiting.shtml. Retrieved 2012-07-14.

External links

- Oak Ridge National Laboratory (http://www.ornl.gov/) Official website

35.933333°N 84.316667°W (http://toolserver.org/~geohack/geohack.php?pagename=Oak_Ridge_National_Laboratory&params=35.933333_N_-84.316667_E_region:US_typ

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