June 21, 2022
Slide notes to Oak Ridge history presentation at 79th HPC User Forum

Slide 1: Cover Slide

Slide 2: Oak Ridge map

- Contractors operate the sites for the Department of Energy.
- City of Oak Ridge is to the northeast
- ETTP – Formerly K-25 gaseous diffusion plant – URS and CH2M Hill (UCOR)
- Y-12 – Consolidated Nuclear Security (Bechtel, Leidos, Orbital ATK, SOC LLC, Booz Allen Hamilton)
- ORNL – University of Tennessee and Battelle

Slide 3: Chadwick and Groves

- James Chadwick born in England in 1891.
- Early 1900s studied physics & radioactivity at U. of Manchester with Ernest Rutherford, who discovered the atomic nucleus in 1911 and observed proton in 1919.
- 1914 – Traveled to Germany to study with Hans Geiger.
- World War I broke out and Chadwick spent four years in a prison camp (started science club; prisoners lectured to one another, experiments with radioactive toothpaste, tin foil, and wood)
- After war, returned to study with Rutherford at Cambridge's Cavendish Laboratory.
- 1932 – Published "The Evidence of a Neutron"

Slide 4: Hahn, Meitner, and Bohr

- 1878 – Lise Meitner born in Vienna
- 1906 – doctorate at U. of Vienna but could only be schoolteacher.
- 1907 – to Berlin seeking research opportunities, met chemist Otto Hahn
- 1912 – Kaiser Wilhelm Institute for chemistry established; position there.
- World War I – X-ray nurse
- After war – Head of a physics section at KWI
- After neutron discovered, scientists realized good probe of atomic nucleus.
- Meitner, Hahn, and chemist Fritz Strassmann began bombarding uranium and other elements with neutrons and ID'ing decay products.
- July 1938 – Meitner fled Nazis for Stockholm's Nobel Institute for Physics, maintained correspondence with Hahn
- December 1938 – Hahn and Strassman found barium in decay products.
- Meitner and nephew Otto Frisch theorized uranium might become elongated, like water droplet, thin in middle, till it split, driven apart by mutual electric repulsion of about 200 MeV (fitting result of E=mc2)

- Niels Bohr carried news to America; scientists quickly realized emission of enough secondary neutrons would cause chain reaction and enormous release of energy.

Slide 5: Einstein letter

July 12, 1939 – Leo Szilard and Eugene Wigner drove to see Einstein on Long Island to explain use of uranium for atomic bombs. Einstein: "I did not even think about that." Signed letter to Belgian ambassador (due to uranium ore in the Congo).

Aug. 2, 1939 – Szilard and Edward Teller visited Einstein with letter to FDR.

Oct. 11, 1939 – Einstein letter finally delivered to FDR. Two requests:

- Appoint someone you trust to be aware of progress, communicate with government departments, and secure uranium ore for the U.S.
- Speed experimental work limited to university and industrial labs at the time.

Also noted Germany had stopped shipments of uranium from Czech mines, perhaps because of research in Germany duplicating U.S. efforts.

Oct. 21, 1939 – Advisory Committee on Uranium, chaired by Lyman James Briggs, director of the Bureau of Standards (now called NIST)

Warren Buffett called it "the most important letter perhaps in the history of the United States."

Slide 6: Seaborg

Dec. 14, 1940 – Plutonium first produced and isolated by Glenn Seaborg. (Atomic Heritage story)

Slide 7: Chicago Pile

A reunion of atomic scientists in 1946 on the fourth anniversary of the first controlled nuclear fission chain reaction. Pictured in front of Bernard A. Eckhart Hall at the University of Chicago, from left (3rd row): Norman Hilberry; Samuel Allison; Thomas Brill; Robert G. Nobles; Warren Nyer; Marvin Wilkening; (2nd row): Harold Agnew; William Sturm; Harold Lichtenberger; Leona W. Marshall; Leo Szilard; (1st row): Enrico Fermi; Walter H. Zinn; Albert Wattenberg; Herbert L. Anderson. (Courtesy Life Magazine)

Dec. 2, 1942 – Chicago Pile I sustained criticality in a rackets court at the University of Chicago's Stagg Field, with 49 in attendance. Eugene Wigner brought a bottle of Chianti to celebrate.

- 40,000 graphite blocks
- 19,000 pieces of uranium
- 24-foot-square wooden framing
- Scientists from the Metallurgical Laboratory at University of Chicago.

Leona Woods received BS in Chemistry from the University of Chicago in 1938, at the age of just 19. After completing her graduate thesis, she was hired at Enrico Fermi's lab, and was present when Chicago Pile-1 went critical (age 23; she asked, "When do we become scared?").

- In July 1943, she married John Marshall, became pregnant with son, Peter. She wore baggy clothes to hide her pregnancy and keep working.
- After Fermi team relocated to Argonne, she helped oversee development of reactors at Hanford. On hand when B Reactor shut down ("poisoned" by Xenon-135); worked with rest of reactor team to resolve the problem.
- After the war, returned to Chicago, served as a fellow at the Institute for Nuclear Studies. Later worked in a number of laboratories studying particle physics, published more than 200 scientific papers and several books.

Middle row, second from left: **William Sturm** (1918-1999), U. of Chicago grad student. After the war, worked as a nuclear physicist at ORNL until 1956, then moved to Argonne where he served as assistant director of applied physics until his retirement.

Back row, second from right: **Warren Nyer**, physics undergrad at Chicago, later worked on X-10 Graphite Reactor.

Slide 8: Map of Manhattan Project sites

Slide 9: X-10 Graphite Reactor

Feb. 2-Nov. 4, 1943 – Construction of the X-10 Graphite Reactor.

- The design power was 1000 kW, but by blocking unused channels, reducing the amount of uranium near the center, and adding additional blowers, it was possible over time to increase it to 4000 kW.
- Nearly 2 grams of plutonium was produced in 2 months and shipped to Los Alamos, where tests revealed a high spontaneous fission rate of Pu-240. The neutrons emitted were concluded to be capable of causing premature detonation, an important discovery that had a major effect on the design of the plutonium bomb.
- The Pile was run to generate plutonium for processing until early 1945, producing total of 326 g.
- Smyth Report: “Clinton Laboratories have been invaluable as a training and testing center for Hanford, for medical experiments, pile studies, purification studies, and physical and chemical studies of plutonium and fission products.”

Slide 10: X-10, Y-12, K-25

Slide 11: War Ends!

Slide 12: Element discovery

In 1914, one year before he was killed in action during World War I, Henry Moseley, a brilliant 26-year-old British physicist whose work influenced the final order of elements in the Periodic Table, demonstrated that element 61 should exist between the rare earths neodymium and samarium. In 1941-42 American chemists tried to create element 61 but could not prove they had produced it.

In 1945, chemists Jacob Marinsky and Larry Glendenin, working at the Graphite Reactor under the leadership of Charles Coryell, produced element 61.

They did it both by uranium fission and by bombarding neodymium with neutrons from fissioning uranium in the reactor. Working in the nearby hot laboratory and chemistry building, they made the first chemical identification of two radioisotopes of element 61 by using ion-exchange chromatography.

Slide 13: Shull and Wollan

Ernest Wollan and Clifford Shull used a modified x-ray diffractometer installed at a beam hole of the Graphite Reactor. Their work established neutron diffraction as a quantitative research tool fostering scientific knowledge of crystallography and magnetism. (50-year History, p. 45)

History on SWC website:

In Manhattan Project, Wollan studied use of neutrons to measure nuclear materials. … Rumored to have taken x-ray diffractometer from Chicago at night. … In 1944, wrote a research proposal to measure the diffraction of neutrons using single crystals, leading to first powder diffraction measurements recorded using neutrons.

In 1946, impressed by Wollan's results, physicist Clifford Shull accepted his colleague's invitation to work alongside him at the Graphite Reactor to further develop the technique.

By 1955, they measured scattering patterns from more than 100 elements and 60 different isotopes. Achievements include first neutron Laue photograph [1]; first neutron radiograph; first direct evidence of antiferromagnetism and confirmation of the Neel model of ferrimagnetism [2,3]; first use of neutrons to determine the structure of hydrides [4]; and first measurement of magnetic moment distributions in 3d-electron alloys.

Slide 14: Isotopes

August 1946 – First official shipment of a radioisotope produced at a nuclear reactor, carbon-14, to Barnard Free Skin and Cancer Hospital in St. Louis. In first year, more than 1,000 shipments of 60 different radioisotopes for cancer treatment and as tracers for academic, industrial, and agricultural research.

1951 – Production of nickel-63 begins. Used in airport detectors. ORNL only source.

Today, ORNL produces, purifies, and ships more isotopes than any other place in the world—more than 300 isotopes used in medicine, research, industry and space exploration. Key areas include:

- actinide research, including recovery and use of berkelium-249, curium-248, and decay-enriched californium-251 in a variety of research applications such as super-heavy element discovery
- selenium-75 production for use as a gamma source in industrial radiography
- nickel-63 production for use in the detection of explosives or hazardous chemicals and vapors
- californium-252 production for industrial and research applications. ORNL supplies the majority of the work demand for this intense neutron emitter
- modeling and simulation for isotope production, including optimization of material usage, sensitivity and uncertainty quantification, and nuclear data investigations
- medical isotopes production and research

- recovery and dispensing of high purity actinium-225 from the decay of thorium-229 to medical facilities around the world for the treatment of cancer
- production and dispensing high purity thorium-227 and radium-223 for medical research and cancer treatment applications

Slide 15: Reactor School

1954 – Soon-to-be ORNL Lab Director Alvin Weinberg teaching at the Clinton Laboratories' Training School.

ORNL Review (https://www.ornl.gov/blog/ornl-review/oak-ridge-spreads-nuclear-knowledge): At the end of World War II, most people who knew anything about generating nuclear power were located at Manhattan Project sites like Oak Ridge.

At Clinton Laboratories' Training School convinced nuclear power was viable for naval propulsion; needed 100s of nuclear-savvy engineers.

In 1950, Rickover and ORNL research director Alvin Weinberg founded the Oak Ridge School of Reactor Technology, which offered 12-month intensive programs in reactor hazards analysis and reactor operations. The school produced nearly 1,000 graduates.

Rickover was put in charge of both the Navy's program to develop a nuclear-powered submarine and government's reactor development activities. With graduates from the Oak Ridge school playing key roles, the world's first nuclear submarine, Nautilus, was launched in 1954, and the Shippingport Atomic Power Station, the world's first full-scale nuclear electric power plant, went online in 1959.

1946-1961 – Aircraft Nuclear Propulsion Program received considerable funding and yielded diverse research results

Slide 16: Biology and Health Physics

Liane and Bill Russell

The Russells led a groundbreaking mammalian genetics and mutagenesis research program at ORNL that included the Mouse House, a colony of mutant mice used in genetics research. Liane Russell's findings on the vulnerability of embryos to radiation led to changes in radiological practices for women of child-bearing age. Mouse House discoveries include the roles of the X and Y chromosomes in mammals, including sex determination.

Eliot Volkin

"At the time of his experiment, in 1957, the foremost problem in biology was to figure out how the hereditary information encoded in DNA was used by living cells to synthesize the proteins that are their working parts."

https://www.nytimes.com/2003/08/02/us/lazarus-astrachan-78-conducted-rna-studies.html

"In several publications in 1958, Volkin and Lazarus (Larry) Astrachan thoroughly described the unusual properties of this RNA, which they termed DNA-like RNA. These were precisely the properties that Jacob and Jacques Monod sought to assign to the unstable intermediate (which they called X), necessary for the synthesis of galactosidase." – Alvin Weinberg letter to *Nature* (https://www.nature.com/articles/35107234)

"In 1956, Elliot 'Ken' Volkin (Figure 2) and Lazarus Astrachan used radioactive phosphorus to show that when *Escherichia coli* cells were infected with bacteriophage, radioactivity was found in an RNA fraction, the base composition of which was very different from the RNA normally produced by *E. coli* [31]. However, their experiment did not reveal anything about the function of the RNA, and Volkin and Astrachan's preferred interpretation was that this transitory form of RNA was a precursor to DNA. In 1958, Volkin and Astrachan found that while radioactive RNA appeared rapidly in bacteria after phage infection, if the isotope was added later, then more radioactivity was found in DNA than in RNA [32]. Their interpretation of these results again focused on how RNA might act as a precursor to the synthesis of DNA. Despite widespread interest in their results — Thomas Duke recalled that when they presented their findings at the 1956 FASEB meeting, the room was so packed he had to listen from the doorway [33], and in 1958 Volkin gave a talk at a conference session organized by Monod's group [9] — the interpretation of their finding as 'DNA-like RNA' obscured its true significance."

https://www.sciencedirect.com/science/article/pii/S0960982215006065#:~:text=The%20first%20suggestion%20that%20small,by%20Raymond%20Jeener%2C%20in%201950.&text=The%20first%20reports%20of%20what,Volkin%20and%20Astrachan%20in%201956.

Slide 17: Supercomputing

Right – Pioneering Argonne computer scientist Margaret Butler helps assemble the ORACLE computer with ORNL engineer Rudolph Klein. In 1953, ORACLE was the world's fastest computer, multiplying 12-digit numbers in .0005 seconds. Designed at Argonne, constructed at ORNL.

Left – ORACLE (Oak Ridge Automatic Computer and Logical Engine) could do 100 person-years of computing in 8 hours, the fastest and largest data storage computer on the planet at the time, with a peak rate of 14 kiloflops (1,000 floating-point operations per second). Original storage capacity of 1,024 words of 40 bits each; contained a magnetic-tape auxiliary memory.

Background

By 1948, researchers' computational needs could not be met either by the mechanical Friden and Marchant calculators that saw heavy use during World War II or the IBM card-programmed calculators used (primarily for business purposes) at K-25 and Y-12. ORNL also performed some calculations on Harvard's Mark 1 computer (an IBM Automatic Sequence Control Calculator), but in early 1949, P. R. Bell of the Physics Division and A. S. Householder and Lewis Nelson of the Math Panel were asked to examine the current development of high-speed computing machinery. This group's work led to the Oak Ridge Automatic Computer and Logical Engine (ORACLE), designed and constructed at Argonne by a team of Argonne and ORNL engineers. It used vacuum tubes, cost $350,000 (roughly $3.4 million today), and was briefly the fastest digital computer in the world. ORACLE was installed in October 1953 on the second floor of the recently completed Building 4500N, began operating in February 1954, and was retired from active service in the fall of 1962.

ORACLE was preceded by a digital computer called SPEC (Special Purpose Electronic Computer), designed and constructed as part of the Nuclear Energy for the Propulsion of Aircraft (NEPA) project, which was conducted by Fairchild Engine and Airplane Corporation for the Air Force. The NEPA project evolved into the Aircraft Nuclear Propulsion (ANP) project, which was a joint Air Force-AEC effort in which ORNL was heavily involved. SPEC was transferred from Fairchild to ORNL in 1953 and briefly (and confusingly) dubbed ORACLE (Oak Ridge Automatic Computer for Linear Equations), but it was very shortly thereafter superseded by the general-purpose ORACLE.

The first computing initiative at ORNL was created in 1947 by Alvin Weinberg.

In 1950, the lab acquired an automatic sequencing computer for its nuclear aircraft project. It was the first electronic digital computer in the South.

In 1954, ORACLE came online as the world's most powerful computer, with a peak rate of 14 kiloflops.

Over the next few decades ORNL expanded its computing power and resources with machines like:

- Cray MP-X in 1985
- Intel Personal SuperComputer 860 in 1989
- Intel Paragon XP/S 150 in 1995

In 2000, ORNL's IBM RS/6000 supercomputer broke the 1 trillion calculations per second mark.

In 2004, the Oak Ridge Leadership Computing Facility was established at ORNL, with a mission to build a supercomputer 100 times more powerful than the leading systems of the time.

In 2009, the TOP500 list ranked Jaguar as the fastest supercomputer in the world at 2.3 petaflops, or 2.3 quadrillion calculations per second.

Titan replaced Jaguar and was also ranked the fastest in the world by TOP 500 in 2012 at 27 petaflops, or 27 quadrillion calculations per second.

Titan remained America's fastest supercomputer until Summit came online in 2018 … making the lab once again home to the most powerful -- and smartest -- supercomputer in the world.

The 200-petaflop system performs 200,000 trillion calculations per second.

Slide 18: Weinberg quote

Slide 19: Discussion