# For Oak Ridge, Minnesotan Al Nier made a difference

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Recently, the Oak Ridge Institute for Continued Learning presented a series of classes on mass spectrometry achievements by scientists at Oak Ridge National Laboratory. The virtual classes were arranged by Bob Compton, a former ORNL physicist and a retired University of Tennessee physics professor. During one class, it was pointed out that a pioneer in mass spectrometry had important impacts on Oak Ridge during its Manhattan Project days. Carolyn Krause was curious and read brief biographies of Al Nier and oral history interviews with him on the internet. Here's what she found out.

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Those of us in tune with the history of Oak Ridge during the Manhattan Project have surely heard of Enrico Fermi and Ernest O. Lawrence, two Nobel laureates. Fermi created the world's first nuclear reactor and was ultimately responsible for the first continuously operated nuclear reactor (X-10 pile) at Clinton Laboratories, forerunner of the Graphite Reactor at ORNL. The pilot reactor's purpose was to demonstrate the technology for the production of plutonium needed for the second atomic bomb.

Lawrence invented the cyclotron, an apparatus in which charged atomic and subatomic particles are accelerated by an alternating electric field while circulating in a magnetic field. Then he developed the calutron for electromagnetic separations of uranium isotopes at Y-12 to provide fuel for the first atomic bomb.

Many of us are familiar with John Dunning, who pioneered the use of gaseous diffusion to enrich uranium, the process used at the K-25 plant in Oak Ridge to also supply uranium for the bomb. But how many of us know about Alfred O. Nier, who interacted with these three distinguished scientists and had an important impact on Oak Ridge, as well as the Manhattan Project?

Nier, born in St. Paul in 1911 to German immigrants, was a professor of physics at the University of Minnesota from which he earned his B.S., M.S. and Ph.D. degrees in electrical engineering and physics. (He was an advisor to ORNL retired physicist Joe McGrory.)

Nier built the highest-resolution mass spectrograph in the world in 1934, pioneering the development of uranium analysis mass spectrometers needed in large numbers later at all Manhattan Project sites. He was the first to use mass spectrometry to isolate uranium-235 from the other two uranium isotopes (U-234 and U-238), determine their relative abundances (U-235 makes up seven-tenths of one percent of ordinary uranium) and provide samples for a test that led to the discovery that U-235 was the isotope largely responsible for fission. And he invented the sector mass spectrometer now known as Nier-Johnson geometry.

As a postdoctoral fellow at Harvard University, Nier measured the relative abundances of the three uranium isotopes (in 1937 he found the ratio of U-238 to U-235 in natural uranium to be 139:1; the latest accepted value is 137.8:1). His 1938 publication of his measurements of uranium and lead isotopes were used by two scientists in the 1940s to estimate the age of the Earth (based on the fact that uranium decays at a known rate to form lead in rocks).

In April 1939, after the news about the discovery of nuclear fission in uranium pelted with slow neutrons was spreading like wildfire, Fermi was introduced to Nier by Nier's friend John Dunning at an American Physics Society conference in Washington, D.C. It was in a corridor between meetings—science also gets done during networking at conferences. Fermi told Nier he thought that U-238 might be responsible for fission but that Niels Bohr and Dunning, both at Columbia University, thought U-235 has this property. In fact, Dunning had bet Hans Bethe $10 that only U-235 was primarily responsible for fission.

Nier had built a mass spectrometer from parts in his Minnesota lab as an improvement over the first such instruments built in England by J. J. Thomson and Francis Aston. Their work was based on German physicist Wilhelm Wien's 1898 discovery that beams of charged particles could be deflected by a magnetic field. So, Fermi sent a letter to Nier asking him to separate the uranium isotopes and provide samples to Dunning. After an exchange of letters, Dunning and his chemist colleague Astrid von Grosse sent Nier dry uranium hexafluoride in a sealed-off glass bulb through express mail from New York in the fall of 1939.

Nier had a lot of trouble getting the positively charged uranium ions he wanted from this corrosive, volatile, sticky gas. So, he switched to the two gases he had used for the Harvard measurements—uranium tetrabromide and uranium tetrachloride.

In February 1940 in his Minnesota lab, Nier separated small amounts of concentrated fractions of the three uranium isotopes of masses 234, 235, and 238 and deposited the separated material on thin platinum substrates. On Friday, Mar. 1, he wrote a letter (on which he had pasted the uranium samples in the margin) and sent it to Dunning's Columbia University lab by air mail special delivery.

Dunning's team received the letter on Saturday afternoon and bombarded each sample with neutrons from the lab cyclotron and measured the emissions. Dunning awoke Nier on Sunday morning with a phone call announcing that the measurements showed that U-235, not U-238, is the isotope that readily fissions. Bethe lost the $10 bet. This finding was a critical step in deciding how to proceed on the atom bomb project.

Nier tried to separate uranium isotopes electromagnetically with his mass spectrometer without much success. Lawrence visited Nier's Minnesota lab and realized that his University of California at Berkeley facility was far better equipped.

In his 1968 book "Lawrence and Oppenheimer," Nuel Pharr Davis wrote that Lawrence had met in New York with Dunning, who said he wanted to try gaseous diffusion with 5000 separation stages to produce enriched uranium. Lawrence replied, "I think I ought to do something on my own. Magnetism and ion beams are in my field. I've got some big magnets on the hill at Berkeley and my new cyclotron's not built yet. My God, I'm going to try this mass spectrograph thing of Nier's."

In November 1941, Lawrence invited Nier to his Berkeley lab to help develop a hybrid of the cyclotron and mass spectrometer, which Lawrence later called a calutron (CALifornia University cycloTRON). "I spent two weeks there, coming home three days before Pearl Harbor Day," Nier said in an oral history interview for the University of Minnesota. "I helped them with the design of the 180-degree separator they installed in the cyclotron magnet. They had big pumps because of the cyclotron as well as high-voltage supplies for accelerating ions.

"They immediately began to get currents that were 100 or 1000 times as big as ours ever were able to get. They continued the development after I left and that led to the calutron. It was essentially a blown-up version of what I had here. It was my last direct association with trying to separate isotopes."

Borrowing from Nier's experience, Lawrence selected uranium tetrachloride as the feed gas for the Y-12 calutrons.

General Electric was given the contract to build hundreds of mass spectrometers based on Nier's prototypes and drawings for use at Manhattan Project sites. At the Oak Ridge Y-12 plant, mass spectrometry determined how much U-235 was increasing in the product relative to the more dominant U-238. Numerous mass spectrometers were sent to K-25 to do uranium analysis and to serve as helium leak detectors and line recorders that Nier invented as a scientist working for the Kellex Corporation of New York because of concerns about leaks at K-25.

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One potential problem at K-25 was that humid air might leak into the pipes carrying uranium hexafluoride (UF6) for separations of uranium isotopes by pumping UF6 gas through nickel barrier pores. If UF6 reacts with water, it forms uranyl fluoride ($UO_2F_2$) and hydrogen fluoride (4HF) that can plug up holes in the barrier.

According to Bill Wilcox's history of K-25, Nier's leak detector was a mass spectrometer tuned to detect helium, a very light, non-reactive gas that inflates party balloons and Goodyear blimps. "Leak testing at K-25 involved pumping all the air out of the piece of equipment being tested, and then 'spraying' a stream of helium gas over the outside," Wilcox wrote.

"The tiniest leak of helium through a weld or joint would be detected quickly and the exact place then marked for the repair crew to fix before testing again. Testing K-25's miles of pipes, thousands of pieces of equipment, and miles of copper tubing for the instrument panels required thousands of men and women. During 1945, the final year of getting K-25 ready for operation, the workforce grew to almost 12,000 with a large number involved in this vital leak testing and repair operation."

Another Nier mass spec invention used at K-25 was code-named the line recorder. During plant operation, 54 of the line recorders were used to detect any air gases, such as nitrogen and oxygen, that leaked into the cascade vacuum systems. Wilcox wrote that the women who monitored the line recorders were vital contributors to K-25's early operations. With Thomas Abbott, a GE engineer and executive, Nier made numerous visits to K-25 to guide the maintenance of the mass spectrometers.

After the war, Nier conducted research on geochronology, the upper atmosphere, noble gases and space science. He designed the miniature mass spectrometers used by the Viking Landers to sample the atmosphere of Mars. Named for him are the Martian crater Nier, the mineral nierite (tiny silicon nitride inclusions in meteorites) and the Nier Prize, awarded by the Meteroritical Society each year in recognition of outstanding research in meteoritics and closely allied fields by young scientists. Nier was elected a member of the National Academy of Sciences and the Royal Swedish Academy.

Active to the end of his life, Nier died on May 16, 1994, two weeks after being paralyzed in an automobile accident. This unsung hero is certainly worthy of recognition by Oak Ridgers for his contributions to the work of our city during the Manhattan Project.

BOX: How does mass spectrometry work? (optional)

The substance you want to study is placed in the ion source of the mass spectrometer. The substance is bombarded with a beam of electrons that turn the substance's atoms or molecules into charged particles called ions. The ions are accelerated out of the vacuum chamber by a strong electric field.

The singly charged ions are then passed through a magnetic field where they bend into an arc with the lighter ions making a smaller radius than the heavier ones. The ions are thus split into a mass spectrum, with each different type of ion bent a different amount according to its mass. The identities and relative amounts of the substance's components are shown in the spectrum on a monitor.

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Thanks to Carolyn for doing the research to bring Al Nier to our attention. I find it most interesting to see the interactions between Hans Bethe, and Enrico Fermi (both of whom are well known names) with Al Nier, of whom we in Oak Ridge know little. And even more so that he may well have separated the first uranium isotopes that led to the discovery that U-235 was the isotope best suited for fission. This discovery led to the creation of the electromagnetic separation method used at Y-12 which led to the successful separation of uranium for Little Boy, the first atomic bomb ever used in warfare that helped win World War II.

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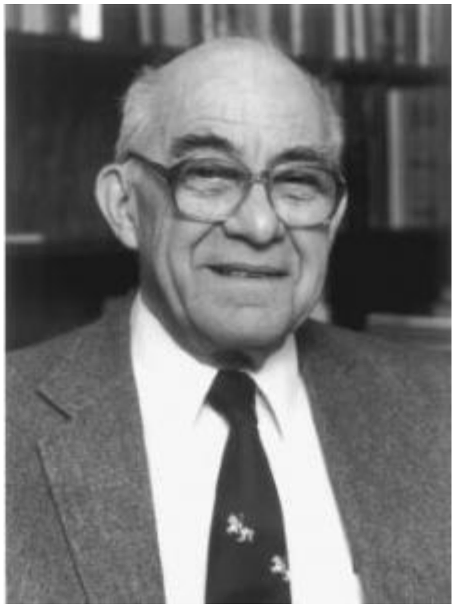

Alfred Nier


Al Nier at the blackboard