Uranium Gaseous Diffusion: The Secret Behind the Atom Bomb - and the Peaceful Use of Nuclear Energy

(As published in The Oak Ridger's Historically Speaking column the week of August 16, 2021)

The K-25 History Center opened first the last week in February 2020. I was unable to be there as Fanny and I had been invited to Vail, Colorado, for a very special "Roundtable" resulting from a most unique tour I was asked to provide for four couples in 2019. It was an amazing experience where 20 people who had unusual professional experiences that the host chose to bring together. We were honored to be among those invited.

While the new museum, which is open again now, is an excellent museum and provides some exceptional exhibits telling the history of the K-25 Gaseous Diffusion Plant in Oak Ridge, TN, there is a much larger story of gaseous diffusion. Gordon Fee approached me asking if we might gather a group who knew that broader history.

Gordon wanted to create something that the public could easily understand. Such things as the "Toll Enrichment" effort, the contribution to the United States Nuclear Navy, the contribution to nuclear reactors for electrical power, and the Cold War.

Gaseous Diffusion has produced the nation's highly enriched uranium for our nuclear weapons and the US Nuclear Navy. Nuclear reactor fuel has also been produced using gaseous diffusion.

Our first contact was Steve Polston, who was at one time the Manager of the Paducah Gaseous Diffusion Plant and now retired. Steve agreed to help and took on the task of producing a draft document. We also included Jim Rushton, Ralph Donnelly, John Shoemaker and finally an exceptional writer who has expertise taking technical information and editing it into language the general public can better understand, Alan Brown.

The document, produced here in Historically Speaking, has been provided to the K-25 History Center for consideration in creating a video or exhibit conveying the broader history of gaseous diffusion. We include it here to document the history in its original form.

***

Gaseous diffusion is a complicated technology that helped end World War II, powered the U.S. Navy's nuclear fleet, and helped generate more than 10 percent of the world's electricity. One of the most closely guarded American secrets of WW II, the process separated the most common form of uranium, U-238, from the much rarer isotope, U-235, that produces energy when split.

What is Gaseous Diffusion?

The concept behind gaseous diffusion is easily understood: separate the two uranium isotopes by weight. All uranium atoms have 92 protons, but U-238 has 145 neutrons, giving it an atomic weight of 238. U-235 has three fewer neutrons than U-238, which accounts for its lower atomic weight (235).

To take advantage of this difference, the engineers and scientists developed the gaseous diffusion process. They started by turning uranium into a gas by reacting it with fluorine. This formed uranium hexafluoride, the only uranium molecule volatile enough to behave as a gas at room temperatures.

Then they pumped the gas through a diffusion barrier, a thin, tubular metal membrane with millions of nanoscale holes (diameters equal to 1/5000 thickness of sheet of paper) perforating its surface. Because the U-235 gas molecules were 1.3 percent lighter than those containing U-238, they moved slightly faster and were more likely to contact and diffuse through the barrier's pores and into a chamber on the other side. This created a second stream of uranium hexafluoride that was very slightly richer in U-235 than the stream that went straight through the pipe without diffusing.

Uranium Gaseous Diffusion: The Secret Behind the Atom Bomb - and the Peaceful Use of Nuclear Energy

(As published in The Oak Ridger's Historically Speaking column the week of August 16, 2021)

To create a stream of gas rich enough in U-235 to use in fission, this process was repeated thousands of times. The equipment to do that was housed in the K-25 Plant at Oak Ridge, Tenn., the first U.S. gaseous diffusion facility. When it opened in 1945, the mile-long, U-shaped, four-story-high plant was the largest roofed building in the world. It was followed by the Paducah, Ky., facility in 1952 and the Portsmouth, Ohio, unit in 1955. These three gaseous diffusion plants formed what is known as the U.S. gaseous diffusion complex.

Gaseous Diffusion Was Built Using Incredible Technologies in the 1940's

Nuclear fission was only one year old when the U.S. government began formulating plans to develop an atomic bomb. In 1938, two German chemists, Otto Hahn and Fritz Strassman, and a physicist, Lise Meitner, of the Kaiser Wilhelm Institute in Berlin discovered that bombarding U-235 atoms with neutrons would split the atoms and release massive amounts of energy. It was clear to many physicists that this reaction could produce a weapon of incredible power, and that Nazi Germany had the lead in developing it. In 1939, several leading U.S. physicists, including Albert Einstein, wrote a letter warning President Franklin Roosevelt of the danger. Their intervention led the President to launch to Manhattan Project to develop an atomic bomb.

The development of the mass spectrometer, which measured the weight of individual atoms, helped prove the existence of isotopes, atoms with the same number of protons but different numbers of neutrons. By 1938, scientists knew that some uranium isotopes underwent fission, but they did not know which one. That year, American physicist Alfred Nier at the University of Minnesota used the technique to identify U-235 and show that there is only one U-235 atom for every 139 atoms of U-238. This 139:1 ratio occurs no matter where in the world uranium is mined and is the reason uranium must be enriched.

Uranium hexafluoride is one of the most reactive and highly corrosive gases known. Unchecked, it would have eaten away the thousands of miles of steel piping in the Oak Ridge K-25 gaseous diffusion plant. To prevent this, researchers developed a nickel-plating process that protected the pipes. Similar coatings were later used to protect equipment in chemical and food processing plants as well as jet engines.

The first use of Teflon was to prevent uranium hexafluoride from leaking in gaseous diffusion plants. Teflon was discovered in 1938 by a DuPont scientist looking for a new fluorine-based refrigerant. This fluorine polymer so highly inert, it appeared slippery. It was used to seal thousands of diffusion pipes and valves, preventing dangerous uranium gas from escaping into the environment. To produce Teflon, engineers first had to develop a process to mass-produce fluorine, which is used today in a wide range of Teflon and other industrial products.

The diffusion barrier was the Manhattan Project's single greatest technical challenge. To make gaseous diffusion work, the diffusion barrier had to allow only some uranium fluoride molecules to pass while blocking most of the others. This meant finding a way to produce millions of 10-25-nanometer holes only slightly larger than the uranium hexafluoride molecules themselves. The pores ran through an ultrathin metal tube that still needed high mechanical strength. The holes also had to resist corrosion and plugging by any contaminants in the gas stream.

***

Next, we will look at the details of the history of gaseous diffusion relative to the Cold War, the Nuclear Navy, Nuclear Power Reactors, and even an international venture. It is our firm conviction that the public should know the broader history of gaseous diffusion and our fear is that it is in danger of being lost.

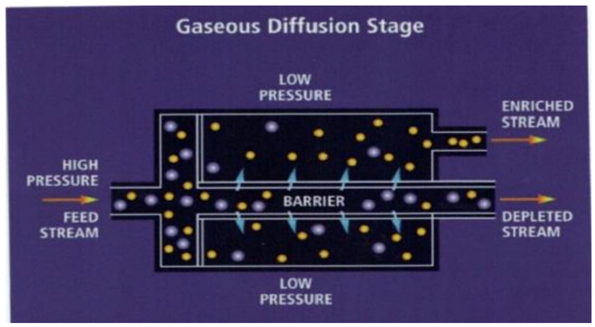
The excellent K-25 History Center and work to be completed by the Department of Energy Environmental Management that includes a viewing platform, marking the huge K-25 Building footprint with a dozen

Uranium Gaseous Diffusion: The Secret Behind the Atom Bomb - and the Peaceful Use of Nuclear Energy

(As published in The Oak Ridger's Historically Speaking column the week of August 16, 2021)

wayside markers will complete a major heritage tourism destination at the East Tennessee Technology Park's Heritage Center.

We are pleased to provide this broad history of gaseous diffusion.



Gaseous Diffusion model