rier more readily than molecules of a heavier one, this approach proposed to produce by myriad repetitions a gas increasingly rich in uranium-235 as the heavier uranium-238 was separated out in a system of cascades. Theoretically, this process could achieve high concentrations of uranium-235 but, like the electromagnetic method, would be extremely costly. British researchers led the way on gaseous diffusion, with John R. Dunning and his colleagues at Columbia University joining the effort in late 1940.

Centrifuge

Many scientists initially thought the best hope for isotope separation was the high-speed centrifuge, a device based on the same principle as the cream separator. Centrifugal force in a cylinder spinning rapidly on its vertical axis would separate a gaseous mixture of two isotopes since the lighter isotope would be less affected by the action and could be drawn off at the center and top of the cylinder. A cascade system composed of hundreds, perhaps thousands, of centrifuges could produce a rich mixture. This method, being pursued primarily by Jesse W. Beams at the University of Virginia, received much of the early isotope separation funding.[10]

Liquid Thermal Diffusion

The Uranium Committee briefly demonstrated an interest in a fourth enrichment process during 1940, only to conclude that it would not be worth pursuing. This process, liquid thermal diffusion, was being investigated by Philip Abelson at the Carnegie Institution. Into the space between two concentric vertical pipes Abelson placed pressurized liquid uranium hexafluoride. With the outer wall cooled by a circulating water jacket and the inner heated by high-pressure steam, the lighter isotope tended to concentrate near the hot wall and the heavier near the cold. Convection would in time carry the lighter isotope to the top of the column. Taller columns would produce more separation. Like other enrichment methods, liquid thermal diffusion was at an early stage of development.[11]

Limited Government Funding: 1940

The Uranium Committee's first report, issued on November 1, 1939, recommended that, despite the uncertainty of success, the government should immediately obtain four tons of graphite and fifty tons of uranium oxide. This recommendation led to the first outlay of government funds—$6,000 in February 1940—and reflected the importance attached to the Fermi-Szilard pile experiments already underway at Columbia University. Building upon the work performed in 1934 demonstrating the value of moderators in producing slow neutrons, Fermi thought that a mixture of the right moderator and natural uranium could produce a self-sustaining chain reaction. Fermi and Szilard increasingly focused their attention on carbon in the form of graphite. Perhaps graphite could slow down, or moderate, the neutrons coming from the fission reaction, increasing the probability of their causing additional fissions in sustaining the chain reaction. A pile containing a large amount of natural uranium could then produce enough secondary neutrons to keep a reaction going.

There was, however, a large theoretical gap between building a self-generating pile and building a bomb. Although the pile envisioned by Fermi and Szilard could produce large amounts of power and might have military applications (powering naval vessels, for instance), it would be too big for a bomb. It would take separation of uranium-235 or substantial enrichment of natural uranium with uranium-235 to create a fast-neutron reaction on a small enough scale to build a usable bomb. While certain of the chances of success in his graphite power pile, Fermi, in 1939, thought that there was "little likelihood of an atomic bomb, little proof that we were not pursuing a chimera."[12]

The National Defense Research Committee

Shortly after World War II began with the German invasion of Poland on September 1, 1939, Vannevar Bush, president of the Carnegie Foundation, became convinced of the need for the government to marshall the forces of science for a war that would inevitably involve the United States. He sounded out other science administrators in the nation's capital and agreed to act as point man in convincing the Roosevelt administration to set up a national science organization. Bush struck an alliance with Roosevelt's closest advisor, Harry Hopkins, and after clearing his project with the armed forces and science agencies, met with the President and Hopkins. With the imminent fall of France undoubtedly on Roosevelt's mind, it took less than ten minutes for Bush to obtain the President's approval and move into action.[13]