everything he had into a thirty-beam source for Y-12, Groves ordered a crash barrier program, hoping to prevent K-25 from standing idle as the race for the bomb continued.

Help From the Navy

As problems with both Y-12 and K-25 reached crisis proportions in spring and summer 1944, the Manhattan Project received help from an unexpected source—the United States Navy. President Roosevelt had instructed that the atomic bomb effort be an Army program and that the Navy be excluded from deliberations. Navy research on atomic power, conducted primarily for submarines, received no direct aid from Groves, who, in fact, was not up-to-date on the state of Navy efforts when he received a letter on the subject from Oppenheimer late in April 1944.

Oppenheimer informed Groves that Philip Abelson's experiments on thermal diffusion at the Philadelphia Naval Yard deserved a closer look. Abelson was building a plant to produce enriched uranium to be completed in early July. It might be possible, Oppenheimer thought, to help Abelson complete and expand his plant and use its slightly enriched product as feed for Y-12 until problems with K-25 could be resolved.

The liquid thermal diffusion process had been evaluated in 1940 by the Uranium Committee, when Abelson was at the National Bureau of Standards. In 1941 he moved to the Naval Research Laboratory, where there was more support for his work. During summer 1942 Bush and Conant received reports about Abelson's research but concluded that it would take too long for the thermal diffusion process to make a major contribution to the bomb effort, especially since the electromagnetic and pile projects were making satisfactory progress. After a visit with Abelson in January 1943, Bush encouraged the Navy to increase its support of thermal diffusion. A thorough review of Abelson's project early in 1943, however, concluded that thermal diffusion work should be expanded but should not be considered as a replacement for gaseous diffusion, which was better understood theoretically. Abelson continued his work independently of the Manhattan Project. He obtained authorization to build a new plant at the Philadelphia Naval Yard, where construction began in January 1944.

Groves immediately saw the value of Oppenheimer's suggestion and sent a group to Philadelphia to visit Abelson's plant. A quick analysis demonstrated that a thermal diffusion plant could be built at Oak Ridge and placed in operation by early 1945. The steam needed in the convection columns was already at hand in the form of the almost completed K-25 powerplant. It would be a relatively simple matter to provide steam to the thermal diffusion plant and produce enriched uranium, while providing electricity for the K-25 plant when it was finished. Groves gave the contractor, H. K. Ferguson Company of Cleveland, just ninety days from September 27 to bring a 2,142-column plant on line (Abelson's plant contained 100 columns). There was no time to waste as Happy Valley braced itself for a new influx of workers.

The Metallurgical Laboratory

One of the most important branches of the far-flung Manhattan Project was the Metallurgical Laboratory (Met Lab) in Chicago, which was counted on to design a production pile for plutonium. Here again the job was to design equipment for a technology that was not well understood even in the laboratory. The Fermi pile, important as it was historically, provided little technical guidance other than to suggest a lattice arrangement of graphite and uranium. Any pile producing more power than the few watts generated in Fermi's famous experiment would require elaborate controls, radiation shielding, and a cooling system. These engineering features would all contribute to a reduction in neutron multiplication (neutron multiplication being represented by k); so it was imperative to determine which pile design would be safe and controllable and still have a k high enough to sustain an ongoing reaction.[35]

Pile Design

A group headed by Compton's chief engineer, Thomas V. Moore, began designing the production pile in June 1942. Moore's first goals were to find the best methods of extracting plutonium from the irradiated uranium and for cooling the uranium. It quickly became clear that a production pile would differ significantly in design from Fermi's experimental reactor, possibly by extending uranium rods into and through the graphite next to cooling tubes and building a radiation and containment shield. Although experimental reactors like Fermi's did not generate enough power to need cooling systems, piles built to produce plutonium would operate at high power levels and require coolants. The Met Lab group considered the full range of gases and liquids in a search to isolate the substances with the