Alex McArther

Kevin Boyle

English 102

Research Paper

25 November 2010

The Manhattan Project: The Story of a Letter and a Bomb

Without revolutionary points in science and technology, mankind would not be where it is today. Such points are marked by desperation and discovery, enigma and enlightenment, fear and fame, as well as a place in history. Some are marked as triumphs of industry, or great periods of creativity. Others are remembered for a horrifically negative impact they had on people. The Manhattan Project conjures up all of these images, and it had a remarkable story first marked by early discovery.

The modern idea of the true form of an atom arose after Ernest Rutherford developed the modern concept of the nucleus. He proved this idea by literally blowing positive particles off of atoms of nitrogen in an experiment, fundamentally changing them into oxygen (The Nobel Foundation). His experiment proved that atoms of individual elements are comprised of the same fundamental particles. The idea that followed evolved into an atomic model comprised of a positive nucleus, surrounded by negative particles. This model left a question to be asked though, “Why can one element be exactly the same as another, but weigh a different amount?” This question led to discovery of the neutron; a subatomic particle crucial to nuclear science.

After this great discovery, nuclear physics faced a surge in research, as eager scientists bombarded atoms with pieces of other atoms in particle accelerators. This rise in interest arose from the 1938 discovery in Berlin that atoms could be literally split in two by fast moving particles (Office of History and Heritage Resources). This process would soon become known as “nuclear fission”, and as Albert Einstein theorized, this process would release tremendous quantities of energy (Office of History and Heritage Resources). Some elements, as a byproduct of fission emitted secondary neutrons, which in simplified terms meant that one atom could be fissioned to send out more neutrons which would fission more atoms, creating a chain reaction. All it would require was an element composed of the right amount of neutrons to facilitate this chain reaction. As tests conducted by scientists at Columbia University found, only a particular variation of Uranium, Uranium-235, emitted the neutrons in the particular fashion required to fuel a nuclear chain reaction (Gosling 4). Uranium-235 differed from standard uranium in that it had a different number of neutron in its structure. The only problem with Uranium-235 (hereby referred to as U-235) was that it was rare – only 1 in 140 parts of Uranium were U-235 (Gosling 4). As difficult as procuring the specific kind of uranium required would be, it would be equally difficult to persuade government officials to support a nuclear project.

As the war was looming over the horizon in late 1939, two men in particular began to fear the attainment of the atomic bomb by Nazi Germany. These men were Leo Szilard and Albert Einstein who personally sent a letter to President Roosevelt to plead for American efforts toward nuclear physics, just as interest in nuclear physics was beginning (Office of History and Heritage Resources). The result of this effort would be the Advisory Committee on Uranium, which would first meet October 21, 1939 (Office of History and Heritage Resources).An effort was also made by Vannevar Bush, who was the president of the Carnegie Foundation at the time, to appeal to President Roosevelt to develop a “National Defense Research Committee”, whose job would be in part to fund a limited nuclear program (Gosling 6). He would be successful.

This new committee headed by Vannevar Bush would reconsolidate the Advisory Committee on Uranium in June 1940, and eliminate military participation in the committee (Gosling 6). Worries still remained on the feasibility of a nuclear project however. By June 1940 there was still no efficient means to filter raw uranium into the usable U-235. Four practical methods existed for filtration. They were electromagnetic filtration, centrifugal filtration, gaseous diffusion, and liquid thermal diffusion (Gosling 6).

The electromagnetic method worked by firing a beam of charged Uranium particles through a magnetic field, which would deflect the individual Uranium particles differently depending on their atomic weights. Since the desired type of uranium, U-235 was lighter than the vastly more common type, U-238, Uranium could be separated in this manner. However, according to the Department of Energy, a single mass spectrometer used by the electromagnetic method in 1940 would have taken twenty-seven thousand years to produce 1 gram of solid U-235 (5). At this point other methods were still on the table, since the electromagnetic method was very time consuming.

Centrifugal filtration is performed by filling a centrifuge with Uranium Hexafluoride, a gas composed of one part Uranium and six parts Fluorine, then running the centrifuge (Federation of American Scientists). Due to the subtle differences in weight between Uranium Hexafluoride made with normal Uranium and Uranium Hexafluoridemade with U-235, the normal uranium compound would be pushed to the outside of the centrifuge, while the desirable U-235 compound would be pushed to the inside. By running the same mixture through hundreds or thousands of centrifuges, a mixture of Uranium Hexafluoride with high U-235 content could be made. This process would also evidently be time consuming. Nonetheless, the time problem would become obvious in all of the methods.

Gaseous Diffusion was very similar to the Centrifuge Method. Uranium Hexafluoride gas would be passed through a barrier, which would allow more U-235 through than U-238, the common less useful variant (Gosling 6). This idea was founded on the physics principle that lighter molecules (such as Uranium Hexafluoride made with U-235) would be more likely to pass through a porous barrier than the heavier molecules. Since it relied on similar ideas as the Centrifuge method, the Gaseous Diffusion method suffered some of the same problems -- notably high cost and time requirements (Gosling 6).

The fourth of the methods of filtration was called liquid thermal diffusion, and it also worked using Uranium Hexafluoride. In this case, liquid Uranium Hexafluoride would be pressurized inside a sort of doughnut-shaped cylinder. The inner walls would be cooled while the outer were heated. Thus, the inner walls would attract the lighter U-235 variant and push it toward the top of the cylinder while the outer walls would attract the heavier U-238 and push it downward -- all due to common convection (Office of History and Heritage Resources). Since none of the four ideas seemed to be the best by 1940, Vannevar Bush decided to fund and work with all of them simultaneously (Office of History and Heritage Resources).

At the same time, important work for the bomb was also being done by a team led by Glenn Seaborg. By preparing a sample of Neptunium, another man-made element, his team could procure Plutonium via the decay of the Neptunium (Lagowski 268). Before this point, Plutonium's relatively short half-life meant virtually none of it existed in nature. They did not know it yet, but Seaborg and his team had just synthesized an element with properties similar to U-235 -- properties that made it perfect for a bomb.

Up until this point, U.S. nuclear efforts were mostly a decentralized pastiche of research done by people all over the country. This would change after a crucial report was done by the MAUD committee in July 1941. The MAUD committee who wrote the report was a committee of scientists organized in England with the sole purpose to discuss the development of a nuclear weapon (Office of History and Heritage Resources). Since they held particular credibility as well known scientists in their fields with both the heads of the National Defense Research committee, as well as with the president, their findings would be especially crucial as to whether or not the efforts to produce a weapon would move forward. The MAUD report stated that "...the scheme for a uranium bomb is practicable and likely to lead to decisive results in the war..." as well as the belief that "[uranium weapon research] be continued on the highest priority and on the increasing scale necessary to obtain the weapon in the shortest possible time" (MAUD Committee). Vannevar Bush would be able to use this report to form the Manhattan Engineer District of the Army Corps of Engineers, with the blessings of President Roosevelt (Lagowski 58).

Meanwhile, research was done to see if a sustainable fission reaction was even possible. To prove this fact, an effort was spearheaded by Enrico Fermi to build the first man made nuclear reactor (Lagowski 86). Fermi's revolutionary "nuclear pile", CP-1, was basically spheres of uranium surrounded by blocks of graphite, "egg-shaped, 22 feet (6.7 m) high, 26 feet (7.9 m) across, and contained 6 tons of uranium oxide encased in 250 tons of graphite"(Karam, 435). This reactor was revolutionary in two regards: First, it definitively did its job -- it proved a self sustaining fission reaction was possible, second, the reactor would produce plutonium which was potentially a better material for a bomb than U-235; a material already difficult to attain. Plutonium was different in this regard. Since it is a completely different element from Uranium, it could be separated by far cheaper and far less time intensive chemical means.

This meant that there were now two possible methods to acquiring a nuclear weapon: using conventional Uranium 235 produced by electromagnetic filtration, centrifugal filtration, gaseous diffusion, or liquid thermal diffusion, or using Plutonium produced in nuclear piles. By the end of 1942, President Roosevelt assigned Colonel Leslie Groves as the official head of the Manhattan project, and gave him full authorization to build the bomb (Office of History and Heritage Resources). Groves quickly jumped into action by grabbing up critical locations in Tennessee and Washington for producing U-235 and Plutonium respectively, naming J. Robert Oppenheimer as the scientific director, and securing a research and development lab in Los Alamos, New Mexico (Office of History and Heritage Resources). These important efforts would have to occur simultaneously to complete the weapon by 1945, the expected completion date.

Oak Ridge, Tennessee was the decided location for large-scale U-235 production. After seeing the results of current research, Groves decided to pursue electromagnetic and gaseous diffusion for enriching the Uranium. At the Oak Ridge facility, he would construct two plants -- "Y-12" and "K-25" for the different methods of enrichment. The sheer size of the plants, along with the short deadline made construction difficult. The Oak Ridge facility alone would have to house some 13,000 people near the site, later revised to 40-45,000 people (Gosling 20). Materials were also a problem, especially in the case of the Y-12 electromagnetic plant which was forced to use "almost 15,000 tons" of the U.S. Treasury silver bullion for the magnets instead of copper due to war shortages (Office of History and Heritage Resources).

By the time it was completed, the Oak Ridge facilities would be using a sixth of the entire U.S. electrical output. Unfortunately, even by the time it was completed, it was plagued with problems. The K-25 did not fare much better, only able to produce "slightly enriched" uranium (Office of History and Heritage Resources). Due to the worries about producing enough uranium in time to be helpful another plant, "S-50", a thermal diffusion type plant, was constructed. S-50 suffered from the same chronic problems as K-25, so new plans for U-235 would have to be drawn up. Luckily, by late 1944 efficiency at Oak Ridge was improving. By reprocessing the partially enriched output of S-50 and K-25 in the now much more efficient Y-12 plant, Los Alamos was able meet the Uranium requirements for the bomb (Gosling 22).

The facility in Hanford, Washington faced challenges of its own. Major scientific breakthroughs were required before the facility could even be built, since Plutonium had only just been isolated by late 1942. At the same time, a new type nuclear pile would need to be built to generate the raw plutonium for the facility to process. The first real effort at this was X-10 in Oak Ridge. The primary difference between this facility and its initial predecessor, Fermi's CP-1, was that X-10's uranium "fuel" was purpose designed to be removed and refined, while CP-1 was simply a proof of concept -- a sort of mock reactor just to see if the idea worked at all, whose uranium fuel was impractical to remove (Office of History and Heritage Resources). By 1944, the Hanford facility was already under construction, even without the plans for the nuclear pile or methods for processing the plutonium finalized. These problems would be ironed out over the course of 1944, and by September 27 1944, the first rod was inserted into the first Reactor at the Hanford facility. Aside from a few technical problems, most notably a "xenon poisoning" problem that shut down the reactor every few hours, the Hanford facility worked as it should, and by December 1944 more than one reactor was producing workable quantities of plutonium (Office of History and Heritage Resources). With adequate amounts of both plutonium and U-235, all that was left was to get the scientists together to design the bomb.

After Groves settled on Los Alamos as the main center for research and development of the bomb, J. R. Oppenheimer got to work gathering staff for the project. In the process of recruiting he was able to gather some important scientists, such as Enrico Fermi and Niels Bohr (Calvo 489). In return for the services of some scientists, particularly Robert Bacher and Isidor Rabi, Oppenheimer and Groves promised that the facility would stay in civilian hands (Gosling 37). With a wide array of scientists, including Nobel laureates, research on the production of the actual weapon began. Still, numerous difficulties remained.

Several questions plagued the development process of the bomb, such as "exactly how much uranium or plutonium is needed for a bomb", or "what is the most effective design for a nuclear bomb?" The essential question was, "what is needed to create the most efficient nuclear chain reaction?" A nuclear weapon is fundamentally different from a conventional explosive. The Department of Energy describes it in terms of a dynamite stick and a conventional explosive. They explain that, "[a] stick of dynamite is capable of exploding.... [w]hen its cap or detonator sets it off, it explodes. A [fully armed nuclear weapon] is not only capable of sustaining a chain reaction; it is incapable of not doing so. No percussion cap is necessary. Nobody lights a fuse" (Department of Energy 21). This means that the bomb will explode the instant it is fully assembled. Therefore, the question for Oppenheimer and his team was how they were to deliver an unassembled bomb, which would complete its assembly a moment before its intended detonation. The scientists came up with two possibilities: a gun type weapon, or an implosion type weapon.

The gun type weapon works just like a conventional gun. It simply fires a slug of uranium or plutonium into another, much larger chunk of uranium or plutonium the second the bomb is supposed to detonate. This means the bomb is technically not assembled until the moment the slug hits the large mass -- the same moment the bomb explodes. This was the simple form of nuclear weapon, so the general consensus was that no test would need to be done for the Uranium bomb that used this method(Gosling 43). This worked fine when U-235 was used, but Plutonium was so unstable that it would have to be used in impossibly pure samples to work in this manner without significant risk of pre-detonation, which simply meant the bomb would have a far smaller explosion than it should have. This left only one method of detonating a plutonium bomb -- implosion, an untested and experimental idea (Department of Energy 21).

The engineering efforts for building the bombs were extensive after the theoretical work was out of the way, around February 1945 (Gosling 43). Weapon designs would need to be rushed to the specialists so construction could commence, and a plutonium weapon finished in time to test, since it was so experimental. Difficulties were numerous during this time, ranging from extremely short deadlines such as the plutonium bomb test planning for only five months for construction start to finish, and complete inexperience on the metallurgist's part in working with plutonium. They would have to quickly develop methods for working with the new metal by the time it arrived in May (Gosling 43). Luckily for those building the bomb, the plants at Oak Ridge and Hanford had come through, producing enough material for at least one of each bomb in time for usage against Japan (Office of History and Heritage Resources).

The year was 1945. It was July. President Roosevelt had just unexpectedly passed away and was succeeded by Harry S. Truman. Germany had recently surrendered, and Japan was teetering on the brink of defeat. The decisive weapon would be the nuclear bomb, and it would be tested July 16th, 1945. Ground Zero for the aptly named "Trinity test" was arranged to be in the Alamogordo Bombing Range, where relatively level land, few people, and stable weather would all be beneficial to the test (Department of Energy 32). By the time the bomb was to be tested, most of the scientists were confident enough that it would work that they were literally placing down bets on what the explosive yield of the device would be (Department of Energy 44).

Finally the time came, and at 5:30 in the morning on that July 16th, the first man-made nuclear device detonated with an explosive yield equivalent to 18,000 tons of TNT, over ninety times the mere 200 tons of that Oppenheimer himself bet upon (Department of Energy 44). The characteristic shape that the resulting cloud produced would be remembered for decades as the symbol for the dangerous power of the nuclear bomb. At this point there were now two atomic weapons ready for deployment against Japan.

The results of the development of these two nuclear bombs are well recorded in history. The first weapon, Little Boy, a uranium gun-type bomb was dropped on Hiroshima, Japan on August 6th, 1945. This bomb weighed nearly 5 tons, detonated with the force of over 15,000 tons of TNT, and its total death toll over the course of five years exceeded 200,000 men, women, and children (Gosling 43). The second nuclear weapon, Fat man, was the plutonium implosion-type bomb dropped on August 9th on Nagasaki, Japan, after the U.S. Potsdam declaration demanded unconditional surrender or another nuclear bombing. This nuclear weapon weighed approximately the same as Little Boy, while delivering the equivalent of 21,000 tons of TNT worth of force, and over the course of several decades killing 140,000 people (Gosling 44).

It is truly a scientific marvel that the world's true ignorance of nuclear physics could be the opening scene of a decade, while the widespread advancement of military and nonmilitary usages of such technology be the closing act of that same decade. From just one letter and a small effort by a group of endeavoring scientists spawned an enormous effort, in secret, whose industry would rival the automobile industry (and employ about as many people) at its peak (Gosling 44). In under four years a new element was synthesized in microscopic quantities, researched, and eventually produced in large enough quantities to fuel a nuclear arsenal. While the deaths from this dangerous technology are a tragedy for mankind, the development of such technology is truly a high point in the scientific advancement of mankind.

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