The History of the Twentieth Century
Episode 450
"The Gadget"
Transcript

[music: Fanfare]

What we were trying to do was build a new laboratory in the wilds of New Mexico with no initial equipment except the library of Horatio Alger books or whatever it was those boys in the Ranch School read, and the pack equipment that they used going horseback riding, none of which helped us very much in getting neutron-producing accelerators.

Los Alamos physicist John Manley.

Welcome to *The History of the Twentieth Century*.

[music: Opening War Theme]

Episode 450. The Gadget.

The last time I talked about the Manhattan Project was back in episode 391, so it's time to get caught up.

The Manhattan Project is the unofficial name usually used to describe the American project to build an atomic bomb. This project was given a high priority and a lot of money, because there was a great fear among the Western Allies that the Germans were already working on an atomic bomb, and indeed it was likely they had a head start.

You know and I know that the Germans gave up on researching an atomic bomb, on the grounds that the cost in resources needed elsewhere in the war effort was too great, and they viewed it unlikely that such a bomb could be produced before the end of the war anyway. And they were quite correct, on both counts.

But the Western Allies didn't know any of that; they thought it prudent to assume the worst about the prospects of Germany developing an atomic bomb.

Since no one knew which approach to building an atomic bomb was the right one, the Americans chose to pursue multiple projects at once, hoping one of them would pan out. This is one of the reasons the project was so expensive.

The US military took control of a large parcel of land in rural eastern Tennessee and built the Oak Ridge National Laboratory. Because Oak Ridge was in Tennessee, a former Confederate state, Southern Democrats in Congress insisted the facility be segregated.

One of the projects conducted at Oak Ridge was the construction of a reactor to produce plutonium. It was designated X-10 and constructed by the DuPont Corporation. The leadership at DuPont well remembered how their company had been labeled the "merchants of death" for their role in producing munitions during the last war, so DuPont agreed to a contract that covered the company's costs, plus a nominal profit of one dollar. That way no one could say they got rich from the atomic bomb, because you see, back in those days business leaders worried about their images and did not want to appear too greedy or indifferent to the welfare of society at large. Hard to imagine, I know, but that's how it was.

Construction of X-10 began in February 1943, and the reactor began producing plutonium a year later. These early samples of plutonium were sent to Los Alamos for research use.

Once researchers established the proper procedures for producing plutonium, DuPont's president, Walter Carpenter, expressed concern over siting a plutonium production facility so close to the city of Knoxville, just 20 miles away and with a population of around 120,000 in 1943. To address this, the US government took over a much larger stretch of land in central Washington State, which would become the Hanford Engineer Works and produce the plutonium that would be used in the bomb.

A second project at Oak Ridge, designated Y-12, was developed to separate the isotope U-235, which would be needed in an atomic bomb, from U-238. Y-12 would separate the isotopes using electromagnetism. They developed a device called a calutron; the name was coined in honor of California University, where Ernest Lawrence developed it.

The calutron worked like this: First, the elemental uranium had to be chemically converted to uranium tetrachloride and heated until the compound became gaseous. Individual molecules were then ionized, accelerated to a high velocity in an electric field, then passed through a magnetic field, which bent the path of the ionized molecules. Molecules containing U-235 would bend a little farther, because the molecule had slightly less mass. This caused the stream of molecules to split into two beams: one containing U-235 and the other U-238.

The construction of the huge electromagnets needed in the calutrons for project Y-12 required thousands of tons of copper, a material in very short supply because of other wartime needs. Eventually, the engineers figured out they could use silver wire instead. The project borrowed from the silver reserves of the United States Treasury, about 14,000 tons in all. The silver wire was gradually replaced with copper wire and returned to the Treasury after the war.

By this time, Y-12 had become so big that it needed over 2,000 operators to monitor the calutrons. Oak Ridge recruited local women for this job they were officially known as "cubicle operators" but informally known as the "Calutron Girls." They were trained on how to operate the equipment, but were never told what the machines were producing.

The first samples of enriched uranium, about 15% U-235, were sent to Los Alamos in March 1944. These samples were not nearly enriched enough to be useful in a bomb, but Los Alamos needed them for research purposes. By June 1944, Y-12 was producing uranium enriched to 89%, which was sufficient to build an atomic bomb.

A third project, dubbed K-25, used gaseous diffusion to separate the isotopes. This involved producing gas molecules that contained uranium atoms, then passing them through a permeable membrane. Lighter molecules pass through a membrane more readily, so the gas on the other side would have a slightly higher concentration of U-235 atoms.

The most challenging aspect of this process was producing a compound containing uranium atoms that was gaseous at room temperature. There was only one known compound that fit the bill: uranium hexafluoride, but uranium hexafluoride was also extremely corrosive.

A fourth project, which they called S-50, employed thermal diffusion. This process took advantage of the fact that when you chill a gaseous mixture, the heavier molecules tend to drop to the bottom of their container and the lighter ones rise to the top. This process also required uranium hexafluoride.

None of these processes could produce bomb-grade uranium, at least not in the early days, but the same sample could pass through the process multiple times, until it reached the desired enrichment. For that matter, you can run your uranium samples multiple times through all three processes.

And that brings me to Los Alamos, the main topic of today's episode. I already told you the story of the site selection as well as the choice of Robert Oppenheimer as head of the operation. Los Alamos was given the code name "Site Y," since Oak Ridge had already been designated "Site X." Later the Hanford site would be called "Site W." There was no "Site Z" in the Manhattan Project, as far as I know, although there is one in the *Halo* games.

I suppose that's not relevant, is it?

Robert Oppenheimer loved the desert country, but not everyone else did. I already quoted to you physicist John Manley's recollection of the place. Leo Szilard declared, "Nobody could think straight in a place like that. Everybody who goes there will go crazy."

Housing was built in the form of cheap barracks not intended to last beyond the end of the war. They were heated with coal stoves. The University of California agreed to operate the project, while Oppenheimer traveled the country in an effort to recruit scientists. General Leslie Groves, the military man supervising the project wanted the researchers to be commissioned into the

United States Army as a condition of working at Los Alamos, but many of the scientists Oppenheimer wanted balked at that idea.

Oppenheimer persuaded Groves to allow civilian scientists to work at Los Alamos. The price for this concession was a barbed-wire fence around the site and careful military monitoring of any communications with the outside world. Many of the researchers at Los Alamos were refugees from fascism in Europe and to them this arrangement bore an uncomfortable resemblance to a concentration camp.

Physicist Richard Feynman, a graduate student at the time, was recruited by Oppenheimer to work on the project. His wife Arline used to buy blank, all-white jigsaw puzzles, write her husband a letter on a completed puzzle, then disassemble it before mailing it to him, in order to annoy the security people, who were required to read all mail into or out of Los Alamos before it was delivered.

Meanwhile, on the other side of the Pacific Ocean, in Tokyo, a committee of Japanese scientists funded by the Imperial Navy held a series of colloquia to consider the possibility of a Japanese atomic bomb. By this time, it was well known among senior Japanese military officers that the United States was probably working on an atomic bomb, and that the American project was benefitting from the arrival of Jewish scientists fleeing the Nazis in Europe.

Initially, the Imperial Navy's interest was in nuclear propulsion for its ships, but as they became aware of the American program, they began to examine the bomb question, hence these colloquia. These Japanese scientists concluded that such a bomb was feasible, but the practical problems were overwhelming. First, Japan would somehow have to acquire and process hundreds of tons of uranium ore. Second, a facility would have to be built to separate the U-235 isotope. They estimated such a facility would require half of Japan's copper production and a tenth of the nation's electric power capacity.

They concluded that it would take a minimum of ten years to produce a Japanese atomic bomb. They further concluded that neither Germany nor the United States could spare the necessary industrial capacity to develop and produce an atomic bomb before the end of the war. Not for the first time, the Japanese had badly underestimated American industrial capacity.

Based on these scientists' conclusions, the Navy terminated the study and put their physicists to work on a more practical and pressing problem: radar. Even so, the Navy did allocate ¥600,000 to the University of Kyoto to build a cyclotron.

A month later, in April 1943, Los Alamos conducted its own lecture series to explain to its newly arrived scientists exactly what they were working on. In stark contrast to the Tokyo symposia, the Los Alamos lectures, delivered by physicist Robert Serber, explained to newly arrived researchers what the purpose of the project was, expressed confidence that an atomic bomb was feasible, and summarized what had been learned so far.

Serber's lectures were both exciting and startling to the new arrivals. Their previous work had been highly compartmentalized and they'd had only vague suspicions of what precisely they had been working on. Now they were getting the full picture for the first time, and it was exhilarating. Serber in his lectures was one of the first to refer to the atomic bomb as "the gadget," an informal codename that quickly caught on. It is possible that the nickname originated with Robert Oppenheimer. Serber's lectures were committed to a book consisting of 24 pages of typewritten, mimeographed notes from these lectures that was distributed to later arrivals to help them get up to speed. This notebook became known as the *Los Alamos Primer*.

There were a number of questions that needed investigation. One was the critical masses of uranium and plutonium. The theoretical physicists had rough estimates, but more precise figures would be necessary in order to build a bomb. The bomb would need to contain at least a critical mass of one or the other element, but more than one critical mass would likely be necessary. Once the atomic explosion began, the energy would vaporize the radioactive material in a tiny fraction of a second. And blow it apart, thus ending the chain reaction. Serber predicted that only a small percentage of the radioactive material would actually be converted into energy.

The issue was one of efficiency. If the amount of radioactive material was too small, it would blow itself into pieces before you got the truly big explosion you were looking for. They called this outcome a *fizzle*. Now, even a fizzle would be a pretty big explosion, comparable to a conventional bomb, and it certainly would destroy the bomb mechanism, meaning that the enemy would not have the opportunity to capture and study the device, even if it was a fizzle, so that was good news.

On the other hand, if you put too much radioactive material in one bomb, that would be an inefficient use of a scarce commodity: U-235 or Pu-239, both of which were being slowly produced in large, expensive facilities literally an atom at a time.

In July 1943, a speck of plutonium, about 200 milligrams, produced at Berkeley, arrived at Los Alamos. Small as it was, this sample represented virtually the entire world's supply of plutonium at the time, and small as it was, Los Alamos researchers were able to use it to determine the rate of neutron production in Pu-239 and found it to be somewhat greater than U-235. This was experimental confirmation of what the theoretical physicists had already predicted: that Pu-239 was indeed capable of spontaneous fission and could be used in a bomb. Plutonium could, in fact, produce more powerful bombs than uranium could.

And what about this "critical mass" thing? I discussed this before, but as a review, critical mass is the mass of uranium or plutonium large enough to produce the neutron chain reaction that would cause an atomic explosion. Every time a nucleus of an atom of uranium or plutonium fissions, it releases neutrons. Some of these neutrons are absorbed into other atoms and cause them to fission as well. If the average number of neutrons that get absorbed is less than one, nothing much happens. If the average number is more than one, you get a chain reaction. The material goes critical, more and more atoms split, more and more energy is released, and you have your atomic bomb.

This average number of neutrons absorbed depends on the size and shape of the sample, since neutrons that escape from the radioactive material altogether won't get absorbed. So a certain quantity of uranium might go critical if it is shaped into a sphere, but not if the same quantity is rolled out into sheet metal. Generally, when we speak of critical mass, we mean the minimum mass sufficient to start a chain reaction in a spherical sample.

If you think about what I just said, you'll begin to get a feel for how to build an atomic bomb. In essence, the trick is to include a critical mass of uranium or plutonium in a shape that won't go critical plus a mechanism that will change its shape into one that *will* go critical when the bomb is triggered.

How would you accomplish that? At Los Alamos in 1943, this was the question that was least well understood. People were drawing all sorts of sketches of possible mechanisms for triggering an atomic bomb, but there was one idea which was obvious and fairly simple.

Suppose you put together a sphere of uranium or plutonium of critical mass, except that you keep a cylindrical hole in it that keeps the material subcritical. Now suppose you have a separate plug of the same material sized to fit into the hole. Now build your bomb so that when it detonates, an explosive charge slams that plug into the hole. The sphere is now complete, it reaches critical mass, and you get a huge explosion.

Several of the scientists and engineers at Los Alamos came up with this idea, independently and very early on. It got the most attention, and the researchers at Los Alamos felt confident something like this could be achieved.

But the simplified explanation I just gave you glosses over some serious problems. First and foremost, you need precise information about critical masses and how the shape of the material affects them. Once you have that worked out, you next have to figure out a way of getting that plug into that hole fast enough and with enough force behind it that you will get the full explosion you're looking for and not a disappointing fizzle, in which the incipient chain reaction blows the plug right back at you before the full explosion can happen.

To avoid that second problem, you'd need to fire that plug into the sphere with sufficient force and speed that the bomb explodes before the plug gets blown back.

[music: Domenico Scarlatti, *Sonata in B-flat Major*.]

In 1943, the gun with the highest muzzle velocity in the United States Army arsenal was the M1, which was still in development at the time. The M1 was designed to be the Army's heaviest anti-aircraft gun. It was 120mm caliber and could fire a 50-pound shell to an altitude of nearly 60,000 feet, or 18,000 meters, which is why they called it the "stratosphere gun."

To achieve that kind of altitude requires a high muzzle velocity, as you can imagine. A shell fired from an M1 exited the muzzle at a velocity of 3,100 feet per second, which is just shy of one kilometer per second. This velocity was just enough to ensure that even Pu-239, which produced neutrons at a faster rate than U-235, would reach critical mass before it fizzled.

So imagine this as a first approximation of an atomic bomb: first, a sphere of uranium is welded to the muzzle of an M1. Second, a uranium plug is loaded into the gun. Third, the gun fires, shooting the plug into the hole. Fourth, boom. Atomic explosion.

As I said, this idea came up very early in the deliberations at Los Alamos, but as is usually the case, the devil is in the engineering details. An M1 gun is too heavy to carry in an aircraft, for starters. That seemed an insurmountable problem until someone recognized that the barrel of an M1 is thick and heavy because it has to fire as rapidly as once every five seconds, so it needs durability. The gun in the gadget only had to work once.

That could get the gadget down to a weight that a heavy bomber could manage, but there was also the matter of the weapon's unusual shape. To incorporate the barrel of the gun, the bomb would have to be 17 feet long, though it wouldn't need to be very wide. These are proportions quite different from a conventional bomb and inspired the scientists at Los Alamos to dub this design the "Thin Man." The name was inspired by a 1934 detective novel by Dashiell Hammett titled *The Thin Man*, featuring a retired detective named Nick Charles and his wife, heiress and socialite Nora Charles. In the novel, Nick comes out of retirement to solve one more mystery.

MGM adapted *The Thin Man* into a film with the same title, released the same year, and cast William Powell and Myrna Loy as Nick and Nora Charles. The film was a huge success and was nominated for four Academy Awards including Best Picture, but went 0 for 4. The winner of Best Picture that year was *It Happened One Night*, the film that made Frank Capra a name, and which I already talked about.

Hollywood being Hollywood, the film's success guaranteed sequels; five of them in all. Dashiell Hammett never wrote another Nick Charles novel, though he did contribute to the screenplays of a couple of the sequels. Please note that the "thin man" in the title of the original novel refers to the missing person Nick Charles is hired to find. The novel describes Nick himself as overweight, but since William Powell was a rather tall, slender, dapper man, film audiences took "the thin man" as a reference to his character. The studio was happy to run with this idea, since it allowed them to use the words "thin man" in the title of every one of the sequels.

When the gang at Los Alamos began their design work, there had already been four Thin Man films released, with two more to come, so the name "Thin Man" would have been very familiar.

Anyway, as I was saying, by slimming down the gun, they'd managed to reduce the weight of the bomb down to a load a heavy bomber could actually carry, but the Thin Man's unusual shape still posed a problem. One solution might be to carry the bomb under the plane, but that increased the risk of the bomb getting damaged, or even lost, before the bomber reached the target, so the Army opposed that idea. In 1943, there was only one bomber in service in the Allied air forces that had a bomb bay capable of accommodating the Thin Man. That bomber was the British Avro Lancaster. The odds that the United States Army would put together the biggest and most complex weapons development program ever attempted, create a novel weapon with unimaginable destructive force, an invention sure to become a pivotal moment in the history of warfare, and then use a British bomber to deliver it were approximately equal to the odds the bomb would be delivered by a squadron of flying pigs.

Fortunately for Army pride, there was a suitable American bomber in development: the B-29 Superfortress, which I've already talked about. In 1943, the B-29 was behind schedule due to a number of design problems that had to be tracked down and corrected, but one of the first B-29s produced was sent to Los Alamos for the folks there to study. They determined that the B-29 could deliver a Thin Man bomb, but only with special modifications.

The design of the Thin Man was simple and obvious. There was little doubt the principle was sound and it would likely work. The problems were more on the engineering side: building a mechanism that would reliably fire the plug into the sphere and putting it inside a practical case that would fit inside a B-29 and had the proper aerodynamics to fall straight and true once it was released.

In July 1944 came shocking news. The first samples of plutonium produced in the experimental X-10 reactor at Oak Ridge had arrived at Los Alamos for study. It didn't take much study to discover a serious problem. The earlier tiny samples came from a cyclotron, which only produces small quantities of plutonium. The huge X-10 reactor, which was built to produce much larger quantities, bombarded the U-238 with a lot more neutrons.

A nucleus of U-238 can absorb a neutron, emit two beta particles, and become a nucleus of Pu-239. But a nucleus of Pu-239 can also absorb a neutron to become Pu-240. The theoreticians hypothesized this reaction, but here for the first time was the real thing. The plutonium from the X-10 reactor included a significant quantity of Pu-240. The Hanford reactor, being even larger, could be expected to produce plutonium with an even larger percentage of Pu-240.

This was bad because Pu-240 nuclei undergo fission and release neutrons at a faster rate than Pu-239, and the bottom line is that even the 3,100 feet per second muzzle velocity of the Thin Man gun would not be enough to get that plug into the sphere before the Pu-240's rapid release of neutrons melted the plug and produced a fizzle. To accelerate the plug to the required velocity would require a much longer gun than the 17-foot gun in the Thin Man. The bomb would have to be impossibly long.

Pu-240 is an isotope, which means, as in the case of uranium, the two isotopes cannot be separated by chemical processes. It would require thousands more calutrons like the ones operating at Oak Ridge, with the added complications that plutonium is more dangerous to work with and the two isotopes differed by only one mass unit, rather than the three mass units that make the difference between U-235 and U-238, which meant the process would be that much more difficult and time consuming.

It appeared that plutonium was a dead end, and that all the labor, all the construction, and all the time and money that had gone into plutonium production had been wasted. Robert Oppenheimer, in despair, contemplated resigning. He was talked out of it with the argument that his resignation would delay production of the atomic bomb, which would lengthen the war and lead to huge numbers of avoidable deaths.

There was a silver lining to this dark cloud. If plutonium was no longer under consideration as the energy source for an atomic bomb, that meant the long cannon in the Thin Man bomb design could be shortened. It was only as long as it was to accommodate the properties of plutonium. With plutonium out of the picture, the bomb could be more compact in design and conventional in appearance. This new, modified version of the design would soon acquire the nickname "Little Boy."

As for plutonium, well, was there some way to salvage this situation? Maybe.

One year earlier, shortly after the Los Alamos facility opened, a physicist named Seth Neddermeyer attended one of those early lectures organized to get the Los Alamos scientists up to speed on the project. The speaker was an explosives expert there to review some of the explosives issues involved in the Thin Man design. In the course of the lecture, he made the pedantic point that the Los Alamos physicists kept referring to the firing of pieces of uranium at each other as "explosions." The technically correct word, he pointed out, was "implosion."

That started Neddermeyer thinking. Others at Los Alamos were also playing around with alternative design possibilities that involved, say, firing two chunks of nuclear material at each other, or even firing multiple wedges of nuclear material from various angles that would meet at a central point and go critical.

Neddermeyer's idea was a little different. Suppose you made a spherical core with a hole in the middle. This core could be subcritical because of its shape, but if you crushed it, say by surrounding it with conventional explosives and setting them off all at once, it would be forced into a sphere that would go critical and explode.

Neddermeyer did some preliminary work on this idea and concluded that it could be more efficient than the Thin Man gun. The Thin Man was a one-dimensional solution, Neddermeyer told his colleagues. Two dimensions would be better, and his implosion idea, being three dimensional, would be better still.

His colleagues were skeptical. Oppenheimer compared it to squeezing a handful of water. All that would happen would be the water squirting out between your fingers. Neddermeyer's idea could only work if you could detonate explosives in such a way as to create a perfectly spherical shock wave. You're talking about applying high explosives as if they were a precision instrument, like performing surgery with a meat cleaver.

Oppenheimer was dismissive at first, but on reflection decided someone at Los Alamos should do at least some preliminary work to see if the idea was feasible, and told Neddermeyer he was now in charge of a group that would begin some experiments.

Two months later, in September 1943, Neddermeyer was supervising a group of fifty working the problem. That month, the renowned Hungarian-American mathematician John von Neumann visited Los Alamos and pitched in by helping to develop a mathematical model of a spherical implosion.

In April 1944, Neddermeyer's group was still working on the implosion idea when the plutonium isotope problem was uncovered. Neddermeyer's idea, if it could be made practical, would work even with Pu-240 and promised a much more powerful bomb than Little Boy.

If it could be made practical. Suddenly, making a practical implosion device advanced from a fringe research investigation to the Manhattan Project's highest priority.

We'll have to stop there for today. We'll have to stop there for today. I thank you for listening, and I'd like to thank Neal and Jesse for their kind donations, and thank you to Kyle for becoming a patron of the podcast. Donors and patrons like Neal and Jesse and Kyle help cover the costs of making this show, which in turn keeps the podcast available free for everyone always, so my thanks to them and to all of you who have pitched in and helped out. If you'd like to become a patron or make a donation, you are most welcome; just visit the website, historyofthetwentiethcentury.com and click on the PayPal or Patreon buttons.

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And I hope you'll join me next week, here on *The History of the Twentieth Century*, as we consider Germany's secret weapons projects. The Germans had ended work on the atomic bomb, but they had a few other ideas up their sleeves. The Wonder Weapons, next week, here, on *The History of the Twentieth Century*.

Oh, and one more thing. One of the theoretical physicists working at Los Alamos was a 35-year-old Jewish-Hungarian émigré born Teller Ede in Budapest, but was known after his naturalization in the United States as Edward Teller.

Teller was friends with Enrico Fermi, and during a conversation in 1942, Fermi wondered aloud about the possibility of using an atomic fission detonation to trigger an even more powerful hydrogen fusion bomb. Teller described to Fermi the reasons why he thought such a bomb was impossible, yet he couldn't get the idea out of his head.

He became something of a gadfly at Los Alamos, dismissive of the atomic bomb as too simple, even though no one had yet built one. He urged that work begin at once on a hydrogen fusion bomb, which he referred to as "the Super." Oppenheimer and the other leading scientists at Los Alamos dismissed the idea as probably impossible, and even if it was possible, it would take too long to develop.

In March 1944, Teller was assigned to lead a team that would work on mathematical modeling of the implosion device, but he quickly became bored with the project. Three months later, his enthusiasm notably lacking, Teller was removed from that project and assigned to lead a group that would work on the Super, his passion project. But Oppenheimer was correct; by the end of the war, Teller and his group had not even convincingly demonstrated that the Super was possible, let alone proposed a practical design.

Still, Teller would not give up on the idea. But that is a story for another episode.

[music: Closing War Theme]