

NEUTRON COUNTERS, PLUTONIUM HEMISPHERES, AND WELDER'S GLASSES: REMINISCENCES OF THE MANHATTAN PROJECT

— by L. Worth Seagondollar, former President of Sigma Pi Sigma. This is the text of a talk which was given at North Carolina State University.

FEATURE



I went to Los Alamos, NM, halfway through graduate school at the University of Wisconsin in 1944. In the previous decade, an Englishman [James Chadwick, 1932] discovered the neutron, then an Italian [Enrico Fermi] had a bright idea, let's do something really unique with this new particle for nuclear bombardment. Let's take the heaviest element and bombard it with neutrons. By this time it had been established that the main thing that happens when you shot neutrons at something was the 'invader reaction.' Neutrons go in, electrons go out. When you do that, that increases your positive charge by one point. And Fermi was successful in producing new elements. He was overly successful. He produced not just one new element but a whole bunch of them. The way you determine when you get a new element when you bombarded it with neutrons and get beta particles out, is that you looked for radioactivity that is different from the radioactivity of the uranium 238 which was the primary isotope for uranium. And he did find new half lives—too many of them!

He explained this by saying that in his bombardment of U238 he had produced some element 93, but that element 93 had been hit by neutrons and this produced element 94, and element 94 was hit by neutrons which produced element 95, and so forth. There was a German chemist and physicist [Lise Meitner] who didn't like Fermi's chemistry. She proposed that what really had happened was that the uranium nucleus had been hit by a neutron, a compound nucleus had been formed, and the extra energy that was in that compound nucleus went into causing this thing to simply come apart. In other words—fission. But there's no reason to believe the fragments would always be the same, there could be lots of them, and this could explain what Fermi had observed.

A little bit later, in December 1938, a pair of German chemists [Hahn and Strassman] repeated Fermi's experiment, shooting neutrons into uranium, and going through the chemistry to separate out the residual radioactive nuclei. One of the things they found, without any doubt whatsoever, was a lighter element—I think it was bromine, but I won't swear to that. There was no question that the uranium nucleus was being split into smaller fragments.

Also, if you look at stable nuclei, if you start with the light nuclei you have the same number of protons and neutrons—roughly—as you go up. But as you go to heavier and heavier

nuclei, due to the Coulomb energy of the repulsion between the protons, you begin to find that the stable nuclei are neutron-rich, they have more neutrons than protons. When you get into the heavy stuff, the lower end of the radioactive material, the number of neutrons is far greater than the number of protons. For instance, in uranium 238 you have 92 protons and 146 neutrons. When this splits into smaller stuff, you get elements such as 40 and 52 to make up the 92 protons of uranium. But, in the elements 40 and 52 the ratio of neutrons to protons is much higher [than it was in U]. There was the conclusion that these fragments would be intensely radioactive, these are not stable nuclei.

These fragments would be neutron-rich. Somewhere along the line it was realized that there would be about three neutrons come out as a result of this splitting. Along this same line, probably Lise Meitner calculated the Q value in the splitting of uranium, and the answer was approximately 200 million electron volts. If you compressed 200 MeV in the palm of your hand you wouldn't even feel it, but if you think of it in terms of the dimensions of the particles which are producing this 200 MeV, and now you've got some extra neutrons, maybe you can get a chain reaction. Maybe you can get a large number of these uranium nuclei to split. And if so, then you will get a macroscopic amount of energy.

Well, so what? If you take a gasoline molecule and completely oxidize it, you get something on the order of two or three electron volts. This is a big long-chain molecule. Compared to a uranium nucleus it's a huge thing. But now if you want to oxidize this gasoline on a macroscopic scale, take a bucket, fill it half-full of gasoline, half full of liquid oxygen, light a match, and the building probably is gone. [laughter] This is first-rate rocket fuel. This is what you get with the large numbers of atoms on the macroscopic scale, where on the scale of the individual atoms you get only 2 or 3 eV. And here we're talking about 200 million eV per atom of uranium.

And so there is a possibility of getting a chain reaction, of getting a tremendous energy release from this. This was in December 1938. The next year Hitler goes into Poland and World War II starts. One can make the argument that this was not a particularly good time for fission to have been discovered as far as the world was concerned.

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Soon thereafter some Norwegian underground people radioed to their counterparts in England that for some reason the Germans were modifying the output of a fertilizer plant in Norway. Fertilizer is valuable stuff during wartime—you need your crops. Why would the Germans be modifying this? They seemed to be modifying it so they could get a small amount of stuff called ‘heavy water’ out of it. And the Norwegian underground did not know what this meant. They radioed to the British, the British talked to the Americans. The only known value of heavy water at that time was to slow neutrons down. Why would you want to slow neutrons down? The fission cross-section—the probability of fission—depends highly on the energy of the neutron. There was a man who I think at the time was chairman of the physics department at Chapel Hill, or he may have gone on from there by that time [John Wheeler], he and Niels Bohr made a calculation assuming the uranium nucleus was a liquid drop.[1] And now that you feed energy into this drop, how does the energy get dissipated? If it causes oscillations inside the liquid drop, if the oscillations are great enough, it can separate into two fragments, like the way an amoeba separates. This is the liquid drop counterpart of the fission process. Then they utilized what information they had at that time about the fission process for U235. When you shot neutrons into U the only thing that happens is not fission, there can be other things happening, such as gamma-ray reactions. The neutron goes into the nucleus, it excites it, and the excess energy is got rid of by electromagnetic radiation. They took what information they had, and came to a very definite conclusion: that the amount of material from which you could make a nuclear explosion, the so-called critical mass, for U238 was infinite, but the critical mass for U235 was somewhere below a hundred kilograms, they did not know exactly where it was.

What do I mean by critical mass? Suppose you have a little chunk of say U235, or later plutonium 239; you have a BB-size, and you shoot a neutron in, what’s the most probable thing that will happen? It will go right on through, it won’t even touch any of the nuclei. But if by chance that neutron hit a U235 nucleus, and it undergoes fission, then you get your 200 MeV, and about three extra neutrons. What’s the most probable thing that will happen to these three extra neutrons? They’d go right on out, they’ll miss also. So, if you want to increase the probability of one nucleus detonating, then three more—you don’t need three more, just one more to continue the process—then you put more and more nuclei out there to intercept those neutrons. If you get a big enough chunk, a neutron comes in, you get a fission, three neutrons come out, one or more causes more fission, and so forth. The minimum size you can have to give a probability of this chain reaction being continued, is what’s called the ‘critical mass.’ Its calculation depends on the cross-section for fission reactions of neutrons hitting U235 or U238. After all, this is just a bunch of theorists talking about a liquid drop. But you need some U235 and U238 which you can bombard with neutrons and measure what comes out; you can mea-

sure the probability of the various reactions—the gamma production, n - α reaction, whatever it may be.

Well, for a long time they had mass spectrometers in which you put in a material, and you ionize it, and the ions are accelerated electrostatically and go through various electric fields and magnetic field and they finally end up on a little metal electrode at the end of this thing. This had been done with U235 and U238 and they get an electrical signal for 238 and 235, and they find that they’ve got 139 times as much U238 as they do U235. But nobody had produced quantities of [U235,] what they needed were macroscopic quantities of it. Mass spectrograph looked like the best way to go. They turned to the best mass spectroscopy laboratories in the world. There were two of them. One was in Berlin. They probably would not be very cooperative. [laughter] The other was a guy named Al Near at the University of Minnesota, and Near ran his mass spectrometer on uranium, 24 hours a day for 30 days. And he not only got signals, but got microscopic quantities of U238 and U235. It was sent down to Los Alamos, where neutrons were shot in and cross-sections were measured.

After you get a considerable amount of information of this type, you can calculate the critical mass for uranium 235 and 238. I remember a speaker’s colloquium where Feynman was talking and he said, “What’s gonna happen if we accidentally get a critical mass of U235 or Pu-239 together? What are we gonna lose? A beaker? Gonna lose a laboratory room? The eastern half of New Mexico?” At that time nobody really knew.

Well, they had two Van de Graaf generators, a Cockroft-Walton generator, and a cyclotron, all of them measuring nuclear cross-sections. This information was being handled by theorists as quickly as they could. I remember that the man under whom I got my PhD later after the war, Hank Barschall, was putting together the first half-kilogram of U235, and the fellow who was making the calculation of what the critical mass was, somewhere in the neighborhood of 50 kilograms, said to him, “Can you wait, let me go home, let me get away from this thing before you put it all together.” He was confident of his calculation, but errors can occur! [laughter]

I had nothing to do with the measurement of the critical mass of uranium 235. I was on the three-man team that experimentally measured the critical mass of plutonium 239. I was low man on the totem pole and I can prove this. Hal Hansen, who was the group leader for this project, had the 8am to 4pm session; Carl Bailey had the 4pm to midnight shift; and I had the midnight to 8am shift. This proves where you stand in this particular organization I think. [laughter]

We had set up equipment to measure what was called the “neutron multiplication ratio” from the world’s supply of plutonium. Basically what we had was a radioactive source which was inside a one-inch diameter sphere and it was a mixture of polonium and beryllium and some other things. The neutron energy was somewhere in the neighborhood of 3.2 MeV. You

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want to pull these neutrons down, and take advantage of the fact that the fission cross section is higher for slower neutrons of lower energy. This is why they put moderators in nuclear reactors, to slow the neutrons down. When the neutrons finally hit the uranium or plutonium, they have a higher probability of causing a fission.

We had this one-inch sphere and the Allied world's supply of plutonium in terms of two hemispheres, which would fit over this one-inch sphere. The first one was roughly an eighth of an inch thick. We had two counters set up a meter away from this thing in the center. Each counter counted neutrons essentially in the middle [of the range] of the neutron's energy, from about 30 keV up to 10 MeV neutron energy; the variation of these counters went from about 90 percent up to 100 percent then back down to about 97 percent. They were the most consistent neutron energy detectors that anybody knew of at that time.

Basically the idea was we took this sphere here with nothing around it, and these two counters out here measured the number of neutrons counted per minute. We did this for weeks on end. We knew what that little ball was putting out. Then when the plutonium became available, the two plutonium hemispheres, we put them around it. Now there are two key things I should mention. One is, you have a guy sitting behind you. He may be in civilian clothes, he may be in military clothes, but he's a plutonium guard—he has a snub-nose .38; he doesn't have a holster, he carries the .38 in his hand all the time. I first met him—I happened to be the first in the laboratory when the plutonium arrived and I walked over to our equipment and heard this deep voice behind me: "Would you please stand still." I thought this was kinda unusual and I'm afraid I didn't; I turned around and looked and there was this big fellow with this .38 pointing at me. The guy was an ex-professional wrestler, he doesn't need the gun [laughter], but still we got to know each other quite well, we were together eight hours a day. His job was to see that that plutonium stayed where it was, or if it went somewhere he went with it, and you had better have a good explanation of why it was going somewhere.

We put the one-eighth-inch shell around the ball and counted neutrons. What we were looking for was an increase in the number of neutrons due to the three-neutrons per fission that were occurring whenever fission occurred. What we started out plotting was what we are going to call a "multiplication ratio." We plotted count rate vs. the mass of the plutonium we were using. And when we started out with zero mass we got a first count rate. When we put this one-eighth-inch shell across it, we got as far as we could tell the same count rate as with the bare ball. When we had worked about three days on this, the plutonium was taken away from us, back to the laboratory where a friend of ours was in charge of taking the protective cover off it. Plutonium is a rather unusual material. It oxidizes rapidly. In an atmosphere of air, when you cut a slice of it, it will turn brown then black then fragments start being there and the fragments will blow off. Now they estimated that if you got a microgram of these fragments in your lungs that part of your

lung would have to be surgically removed. So this stuff had to be prevented from oxidizing. So it had a thin metallic coating over it. I think it was silver, but I don't recall where I got this information. But at any rate, when we finished with this thin layer and it was sent back to the metallurgical laboratory where a friend of ours—actually his wife was a friend of my wife—was in charge of taking the coating off, remelting this down. Meanwhile more plutonium had come down from Hanford, cast into a thicker shell. And when that was done, it came back to us and we had some more and maybe this time we got a slightly higher count rate. And this was done over and over again. And so what we were getting was the multiplication ratio.

We anticipated that it would go up like this, and it would go up very rapidly, ultimately to infinity when we got to the critical mass. And how far we wanted to go on this was a little bit uncertain. So we started plotting one over the multiplication ratio, and then what we would expect to get was a curve like this and when the multiplication ratio was infinite why one over the multiplication ratio would be zero and we had a little more confidence in determining where that was. We did this over and over and over again as more plutonium became available. We got to where we estimated that we were at 98 percent of the critical mass.

Meanwhile, our laboratory was being duplicated in a deep canyon nearby. Los Alamos is a town on a high plateau. There are some deep canyons nearby. And our equipment was being duplicated in this real deep canyon, with the idea that if there was an accident—heaven forbid—that the walls of the canyon would funnel the explosion up away from the town. We didn't do the 100 percent measurement. A fella named Lewis Post did it. I had known Louie Post for some time because he and we had been sharing some radioactive sources. I've seen Louie sit with this one-inch ball in his lap. I wouldn't do that, believe me. [laughter] He was not really bothered by radioactivity. At any

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Delivering the plutonium core to the McDonald ranch house to assemble the bomb for the Trinity test.

Credit: Los Alamos National Laboratory, courtesy AIP Emilio Segrè Visual Archives

rate, in his experiment he completed the 100 percent measurement.

Meanwhile, down in southern New Mexico they were setting up a test place to set off the first plutonium device. Now you've got a problem: you want to have a critical mass or even a super-critical mass together to make an explosion, but you don't want to have a critical mass together before the time when you want the explosion. The first idea on this was the so-called "gun assembly." Basically what they did was take a three-inch artillery piece, a 90mm anti-aircraft gun which put out a shell at 3000 ft/s. The idea was you have half of your radioactive material on the end of the brass cartridge in the shell. The other piece is out here and you're gonna shoot it in, you're gonna hit it. You don't want to miss so you screw it onto the end of the gun. Somebody got the bright idea you better evacuate the air out of the barrel, otherwise you're liable to have the shell go down a ways and turn around and come back. [laughter] This was the basic idea and there really wasn't any question that it would work.

Unfortunately—and thank God it was realized early enough—when you separate the plutonium 239 chemically from uranium you also get a little bit of plutonium 240, which is a spontaneous neutron emitter. So if you use this in the gun assembly, while this shell is going down the barrel at 3000 ft/s, part of the plutonium is emitting neutrons. What you want to do in an assembly is have the sub-critical assembly, have them go together, and then have a trigger mechanism. The trigger mechanism—I'm not sure of this but I think it was one of these one-inch balls—had a mixture of powered beryllium and polonium in it. The polonium was covered by some kind of material so that the alpha particles put out by the polonium would not get through the covering. But now you put one of those balls in here, and you slam into it, you'll mash it. The polonium would lose its covering, putting out alpha-particles which hit the beryllium which will put out a big burst of neutrons. And this, as far as I know, is the basic idea of the neutron trigger that was used in both the gun barrel assembly, and the implosion device which I'll talk about in a little bit.

The feeling was that the number of spontaneous neutrons coming out of Pu-240 was so great that the thing would probably go off before you crush the trigger mechanism. You would get either no real nuclear explosion or just barely a nuclear explosion. So the gun assembly was not so suitable for plutonium. Plutonium is unusual in that it has six different metallic phases. Harold Smith, head of the metallurgical division, was asked a question, "Is plutonium good for anything other than nuclear weapons," and he thought a bit and then he suddenly grinned from ear to ear and said, "Yeah—it's good for training young metallurgists. There is nothing else that is as nasty as plutonium and nothing else has as many different metallic phases." [laughter]

Well, the basic idea was to have the plutonium in one of those metallic phases where the atoms are the farthest apart.

Under these conditions, a certain size would still not be critical. But then if you do something to put these atoms closer together, then you can make that assembly critical. How can you do this? The idea was to use inward-directed explosion, a so-called implosion. They had known about shaped chemical charges for a long time; in the bazookas that were developed early in World War II, a little device that sat on a soldier's shoulder and he could kill a tank with this thing. A rocket comes out, there is an explosive charge on the end of it, there's a contact detonator; the explosive material is designed in such a shape that the explosive shock wave goes out in a small cone and boy it just drills a hole through the tank and goes around inside. So shaped chemical charges had been known for a long time.

The basic idea was "let's have a non-critical sphere, and we surround it with explosives." I think the pattern of different kinds of explosives was like the pattern on a soccer ball. Each one of these explosive devices was a shaped charge, and the direction of the explosive shock wave that comes out is not a flat plane, it is a curve, and the curve is exactly the outer radius of the sphere. The idea was to set all of these off at the same time, all of these shock waves would come in and compress the sphere, get it down to where the spacing between the nuclei was small enough that it would then make a critical mass. This is a much more complicated thing [than the gun barrel design]. One of the reasons is, if you have a high explosive and you detonate it, due to the energy of the trigger, the burning rate of the explosive will be quite high at first. But it goes down in a foot or so; the burning rate of the explosive goes down, and the rate of the explosion is propagated drops off quite rapidly.

To test the instruments that were going to be used at the Alamogordo test, they had put a hundred tons of high explosive, stacked it up in boxes. These were cubic-foot boxes of high explosives and in each there was a detonator in the middle. The electrical signal that was to go to those detonators, would arrive at all of them within a microsecond of the same time. So this 100 tons of high explosive would explode essentially simultaneously, there would be no low-energy burning. A friend of mine saw this thing from nine miles away, and he said it was set off at dawn to aid in the photographic process. He said that it looked like the sun came up halfway, then went back down. That's from nine miles away. I know nothing about the shock wave or the sound from that blast, I wasn't there for it.

The complications of the implosion technique—they had a heck of a time getting all the electrical signals to arrive within a microsecond. There are declassified pictures of this first [nuclear] device that was set off from the top of a hundred-foot high oil well tower. The whole device was about six feet in diameter. I know personally that the plutonium in the middle was about the size of a softball. I know this because I was in Enrico Fermi's office talking to him alone. You may wonder why a middle graduate student was talking to Fermi in his office alone. That's because I came back from lunch one day and a

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Enrico Fermi

Credit: AIP Emilio Segrè Visual Archives, Crane-Randall Collection

friend said “Fermi wants you to call him.” I made a remark, “I suppose God’s after me too,” and was told, “No, the man wants you to call him.” So I called him and he asked me to come up. It turns out that the other two guys who were on that experiment were already down in southern New Mexico setting up the test arrangements and he wanted to talk to somebody who had actually made the cross-section measurements. It took me about five minutes to realize that he was asking me questions that were real simple questions, basically to get me to calm down and talk intelligently. [laughter] [Pauses:] I had a tremendous respect for that man. After about fifteen minutes of talking he shut the door, and he goes over to the blackboard, he writes—and I used to know what those numbers were, but I tried hard to forget them—but there wasn’t any question, this was the size of the sphere that would make a critical mass of plutonium. You can’t forget numbers very easily. I would not have gone into Russia for any amount of love or money. I have successfully forgotten those numbers, which he gave in kilograms. But that was our 98 percent, about the size of a softball.

Because of the complications, maybe the explosion’s not gonna work, we would have the chemical explosion but not the nuclear explosion, which would leave two billion dollar’s worth of plutonium scattered all over the desert, which would result in the darndest mining operation you ever saw. To avoid this, they had a steel tank, called “Jumbo.” It was about 12 feet in diameter and I think about 30 feet long, and I was told that the walls of the tank were about 18 inches thick. A few years ago my wife and I went back down there again and I saw the remains of Jumbo. This was a huge steel tank, made in an Ohio steel yard, shipped by boat down to New Orleans, then shipped by train over a route where there were tall bridges, then put on a rugged trailer [with 64 wheels] and pulled it out there into the New Mexico desert. They hung it up vertical with a steel framework

made of 18-inch I-beam, reinforced with concrete. This is what they were going to set it off in. All the electrical leads would have to go through insulators into it, and by May or June 1945 the decision was made that the probability of problems with the lead-ins which complicated putting the bomb into this steel tank probably were more than the probability that the darn thing wouldn’t work out in the open.

So they set the bomb off on top of this 100-foot-high tower. It was set off this high because if it were used against a city in Japan it would be set off at a high altitude. There are two reasons for this. One is that if it goes off down low, it does very intense damage in the local region, but if it goes off up higher, the shock wave spreads out and will take care of everything for a much larger radius, and is by far a much more effective weapon at destroying a city. The other is, undoubtedly there is going to be radioactivity, and this is a new element of warfare, and they wanted to minimize the flak that the United States would get for spreading radioactivity around.

Well it was set off on this 100-foot oil well tower. I and probably 200 other people were leaning up against a bank that had been part of a water runoff containment that ranchers had built. When it rained, which wasn’t very often, the water would run in there and he would have it trapped for some time. The bank was about four feet tall, inclined at maybe a 45 degree angle. There were two of these tanks and out there nine miles away was this oil well tower. It had a 300 watt light bulb on the top of it which you could see quite clearly from nine miles away. I can remember leaning up against this thing and figuring, “Well, whatever happens is just going to have to come over this bank first,” and I was figuring the cosine of the angle for nine miles and four feet. We had been warned at noon before that day there was a lunch with discussions afterwards about many things. Most of the things that were discussed we already knew. For one thing, we learned someone was betting it was going to be about 5000 tons of TNT.

We got to the bunker about three o’clock in the morning, and we were leaning up against this bank and the countdown began. For a long time nothing happened. Basically it was supposed to go off around four in the morning, it didn’t get off until about five thirty, primarily because there were supposed to be two B-29s Superfortresses within about 40 miles of us to take pictures from there. It turned out there were storm clouds and US Army regulations said you could not take B29’s into storm clouds. Over the FM radio system we had loudspeakers everywhere. We could hear this Air Force colonel who was in charge of the two planes explaining to this civilian that he didn’t know—the civilian was very calm and confident and seemed to have considerable authority—the civilian was urging him to go ahead but the colonel kept talking about Army Air Corps regulations—it was a rather interesting dialog that went on for about 30 or 40 minutes until finally one of the planes got close enough to where they were supposed to be that Oppenheimer decided to

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go ahead with the countdown. We had been warned at this luncheon by a Colonel who was the head medical man for the Manhattan District. He said "There's a number of things you should be aware of tomorrow morning. One of them is that it may go off and the wind may shift. The radioactive dust cloud may come directly towards you in which case there will be plenty of alarm over the public address system and they will tell you whether to go to parking lot A or parking lot B. If it says 'go to A,' go to A, do not go to B. There are different roads going out of them and anybody going to the wrong one trying to drive a vehicle out will be shot. It may be that the radioactive dust cloud will blow in the direction of the Oscaloosa Mountains; there will be no danger from that. There still could be real danger to the retina of your eye from looking at the blast. We strongly recommend that you get the strongest sunglasses you can get your hands on and be looking in the opposite direction. From the reflected light you decide when and if you want to turn around and look. We thought about this at Los Alamos before we drove down. I recall I had a case of acetylene torch welder's goggles. The more he talked the dimmer those goggles got. I noticed they had a welding shop and that afternoon I went over and traded the whole box of goggles for five pieces of blue glass that go on an electric arc welder's helmet. And five of us took one-foot-square pieces of cardboard, cut a little rectangle in it, and taped the blue glass to it. These were our sunglasses. We thought they were pretty good. We had looked at a 100 watt, old-fashioned carbon light bulb the night before, and you could barely see the outline of the carbon filament.

Well when the countdown came I was looking in the opposite direction and I counted thousand-one, thousand-two, up to thousand-fifteen and turned around and looked. My first reaction was "you darn fool you forgot the blue glass." I was looking through the blue glass but there wasn't any trace of blue in what I was seeing, it was just a whiteout. The ball of fire touched the ground and was about its own diameter above the earth and this goes on up. The clouds overhead parted. By far the most impressive thing was that it was like looking at a photographer's flash bulb. The sound was like heavy rolling thunder. I come from the Midwest and I have heard a lot of thunder. Out there you get some real blasts of thunder. What I heard there at Alamogordo was not as loud a thunder that I heard in Kansas; but when you stop and think about it, you're all familiar with counting seconds after you see the lightning; it takes five seconds the sound to travel a mile. And this had come a minimum of nine miles. So it was a very noisy thing.

The shock wave—I don't know whether it got there before the sound wave did or not. It was sort of like standing in an open door and somebody slams the door.

A couple of hours after the explosion there were two tanks that were supposed to go out and see what the damage had been. One of them had only a minimum amount of lead on it, with several periscopes so they could look out. It had radiation measuring devices on the outside and on the inside. Fermi and two

others were in this tank and they left first. He was gonna go as far out as he could, observing what had happened. I was standing by a loudspeaker by a guy named William Penny who was a demolition expert. One of the most important pieces of equipment out there as far as Fermi was concerned—we had some wooden boxes that were one meter cubed and they were glued together except for one side, and there was a piece of plywood going down the middle, and another piece of plywood here, and another piece of plywood here, and so forth, you see you're getting a smaller and smaller area. They had glued heavy paper over these boxes, the idea being that if the pressure goes atmospheric that will be a very small amount of breakage. If it was more than that then there would be more breakage. These things were arranged in a row where the tank was going to go down. And we heard Fermi radioing back what they were seeing. When he was two miles away, and radioed that the overpressure—the pressure of the blast over atmospheric—was five pounds per square inch. The demolition expert said, "Oh my god," he was not aware that such pressures could be developed at that distance.

I'll wind this up by saying that a friend of mine had the job of putting up instruments on meteorological balloons close to the oil well tower, which was vaporized. But he talked somebody into giving him a jeep and going back down there and looking for these things. And I guess I was the first person he ran into, and he said "do you want to go along?," and I said sure I wanted to go along. So I got to go down there about 30 days after the blast. What I saw was pretty horrifying. That heavy-duty, hundred-foot-high oil well tower was gone, vaporized. There still were some fragments of it down near the ground embedded in the concrete. The crater itself—I was amazed at how small it was. But what was really horrifying was outside the crater itself. The desert had been melted, it was now a green glass, very highly radioactive, we pulled back from it as far away as we could.

I found later that the yield of this bomb was described as something like 17 kilotons. The thermonuclear fusion people set off their first bomb on the island of Eugelab in the Pacific. It was in a building, it was not in a hundred-foot-high tower, there are photographs of the equipment, maybe it was 20 feet above the concrete slab. The crater that was caused by it was very large. This was on an island about a mile and three-quarters long and about three quarters of a mile wide. The blast made a crater a mile wide on the ocean floor.[2]

Thank you for this chance to recall some personal experiences with you today.[applause]

[1] N. Bohr and J.A. Wheeler, "The Mechanism of Nuclear Fission," *Phys. Rev.* 56, Sept. 1, 1939, pp. 426-435.

[2] This was the "Mike" test, the first hydrogen bomb. See "Working (and Not Working) on Weapons," by Kenneth W. Ford, *Radiations*, Spring 2005, pp. 5-7.

