The RaLa/Bayo Canyon Implosion Program

1. Introduction

The RaLa/Bayo Canyon
Implosion Experiments

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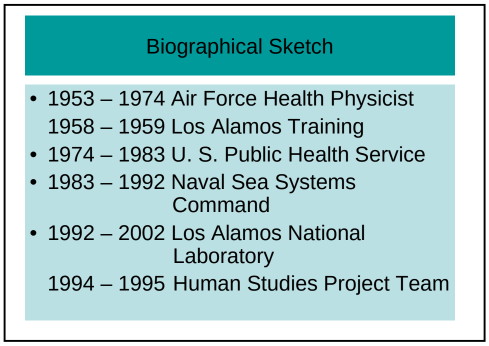
Figure 1. The RaLa/Bayo Canyon Implosion Experiments

A. Biographical Sketch



Biographical Sketch

- 1953 – 1974 Air Force Health Physicist
  1958 – 1959 Los Alamos Training
- 1974 – 1983 U. S. Public Health Service
- 1983 – 1992 Naval Sea Systems Command
- 1992 – 2002 Los Alamos National Laboratory
  1994 – 1995 Human Studies Project Team

Figure 2. Biographical Sketch

I am a very retiring person. I **retired** from the Air Force in 1974 after 21 years. I **retired** from Civil Service in 1992 after serving 9 years with the Public Health service and 9 years as the Navy's Deputy Director of it Nuclear weapons Radiological Controls program. I **retired** from Los Alamos National Laboratory in 1992 after 10 years.

In 1958, as a First Lieutenant in the Air Force Medical Service Corps, I was assigned to the Los Alamos Scientific Laboratory (now the Los Alamos National Laboratory) for one year of on-the-job training in health physics and nuclear weapon design. Three days after arrival I found myself at the Nevada Test Site for the Operation Hardtack II above ground nuclear weapon tests that concluded October 31, 1958. When I returned to Los Alamos I moved from one facility to another learning accelerator safety, critical assembly safety, personnel dosimetry, bioassay, and all other aspects of health physics. I also spent about six weeks in nuclear weapons engineering.

One of my assignments was to provide field monitoring support to the project call RaLa, the use of radioactive lanthanium-140 to diagnose nuclear weapon implosion. From 1944 to 1962 the Los Alamos Scientific Laboratory (now Los Alamos National Laboratory - LANL) conducted 254 experiments that used radioactive ^{140}La as a diagnostic tool to determine implosion

In 1994, DOE opened up a Pandora's Box with the release of records that pertained to human radiation exposure experiments that had been conducted under the Manhattan Engineering District and the Atomic Energy Commission. I was asked to join LANL's Human Studies Project Team to respond to the allegations of wrong doing.

One of my jobs was to head a three man team to write a report on the LANL's "Intentional Releases of Radiation" that had occurred at Los Alamos. These releases were from the 254 implosion tests in Bayo Canyon that used radioactive lanthanum to diagnose implosion.

2. Background.

Until the summer of 1944, the designers of both the uranium and plutonium bombs, focused on developing a gun-type device in which a sub-critical mass of fissile material, backed by a propellant explosive, was fired down the gun barrel into a second sub-critical mass. Together, the two sub-critical masses became supercritical, producing a nuclear explosion of about 15 KT (15,000 tons of HE equivalent yield) (Figure 3).

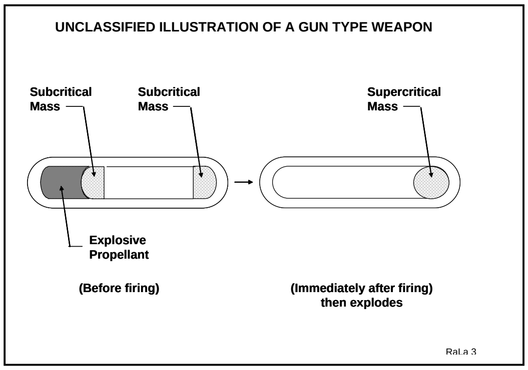


Figure 3. Gun type weapon

The gun-type assembly was relatively straightforward compared to the implosion technique that would eventually have to be used for the plutonium bomb.

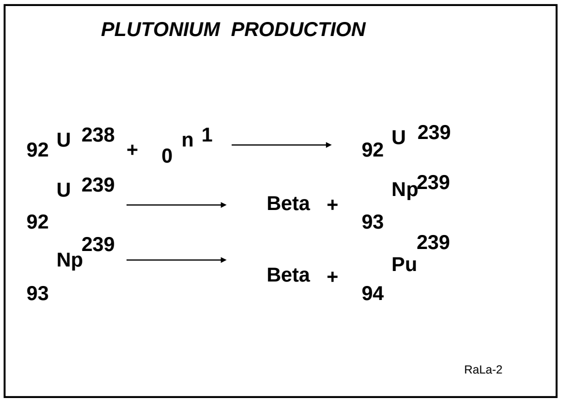
Until the instant of full assembly, the number of neutrons in the gun-type assembly had to be kept to an absolute minimum. Because the gun assembly is a slow process compared to the speed of a nuclear explosion, neutrons threatened to set off a partial explosion to early and cause a "fizzle" before super-criticality was achieved.

This was not a problem with ^{235}U because it does not spontaneously fission, the natural tendency of some heavy atomic nuclei to split (fission) producing neutrons.

Initially, both the uranium bomb ("Little Boy") and the plutonium bomb ("Thin Man") were gun type designs. However, the presence of ^{240}Pu in weapons grade plutonium (WgPu) forced the development of the more complicated implosion bomb ("Fat Man") because ^{240}Pu spontaneously fissions with the release of neutrons.

3. Plutonium Production

Plutonium-239 is produced in a nuclear reactor by bombarding uranium-238 with neutrons. The uranium-238 atoms are transformed via neutron capture into neptunium-239 which beta decays to plutonium-239.



$${}_{92}U^{238} + {}_{0}n^{1} \longrightarrow {}_{92}U^{239}$$

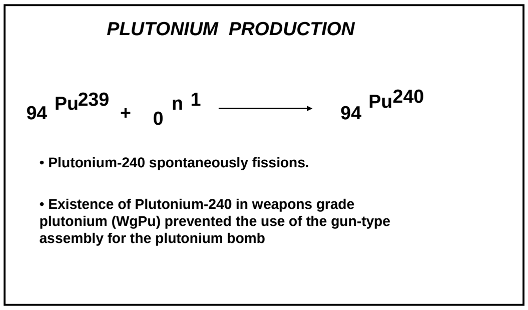
$${}_{92}U^{239} \longrightarrow \text{Beta} + {}_{93}Np^{239}$$

$${}_{93}Np^{239} \longrightarrow \text{Beta} + {}_{94}Pu^{239}$$

Figure 4. Plutonium production.

As the inventory of plutonium-239 increases so does the probability that plutonium-239 atoms will capture neutrons to form plutonium-240 (Figure 5). Plutonium-240 has a relatively high spontaneous fission rate creating unwanted neutrons.

Figure 6 shows the isotopic mixture of weapons grade plutonium. Note that at zero years of age, when the WgPu is first separated from the uranium fuel, the



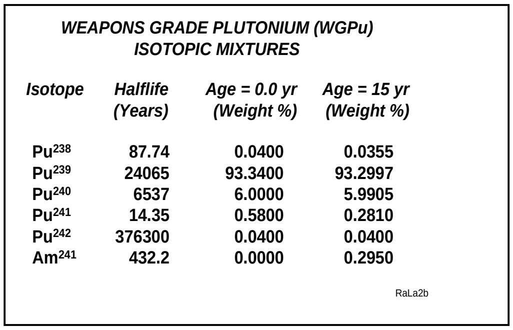
PLUTONIUM PRODUCTION

$${}_{94}Pu^{239} + {}_{0}n^{1} \longrightarrow {}_{94}Pu^{240}$$

- Plutonium-240 spontaneously fissions.
- Existence of Plutonium-240 in weapons grade plutonium (WgPu) prevented the use of the gun-type assembly for the plutonium bomb

Figure 5. Plutonium-240 production.

^{240}Pu content is about 6 percent.



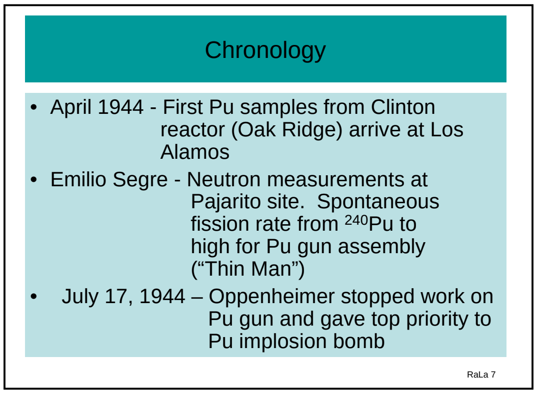
WEAPONS GRADE PLUTONIUM (WGPu)
ISOTOPIC MIXTURES

Isotope	*Halflife (Years)*	*Age = 0.0 yr (Weight %)*	*Age = 15 yr (Weight %)*
Pu^{238}	87.74	0.0400	0.0355
Pu^{239}	24065	93.3400	93.2997
Pu^{240}	6537	6.0000	5.9905
Pu^{241}	14.35	0.5800	0.2810
Pu^{242}	376300	0.0400	0.0400
Am^{241}	432.2	0.0000	0.2950

RaLa2b

Figure 6. Weapons Grade Plutonium Isotopic Mixtures

When the first very small samples of plutonium arrived from the Clinton reactor in Oak Ridge, Tennessee (Oak Ridge National Laboratory) in mid-April 1944 (Figure 7) Emilio Segre's group at Los Alamos were alarmed when they found the spontaneous fission rate of ^{240}Pu to be much higher than predicted - a rate far too high for the plutonium gun assembly ("Thin Man"). These neutron measurements were so delicate that the counting rates were of the order of a few events per day. The neutron emission rate proved to be too high for the "Thin Man" gun assembly to work. This was a major crisis because it would be physically impossible to assemble a sufficiently supercritical mass of plutonium in a gun- type weapon before the neutron chain reaction began (pre-initiation).



Chronology

- April 1944 - First Pu samples from Clinton reactor (Oak Ridge) arrive at Los Alamos
- Emilio Segre - Neutron measurements at Pajarito site. Spontaneous fission rate from ^{240}Pu to high for Pu gun assembly ("Thin Man")
- July 17, 1944 – Oppenheimer stopped work on Pu gun and gave top priority to Pu implosion bomb

RaLa 7

Figure 7. Chronology

By July 1944, Los Alamos had to accept failure of "Thin Man." The whole investment in plutonium production facilities at Clinton, Tennessee (now Oak Ridge National Laboratory) and at Hanford, Washington was in jeopardy of having been wasted unless you could figure some way to assemble plutonium fast enough that the spontaneous fission neutrons would not set it off prematurely.

General Groves, Commanding Officer of the Manhattan Engineering District, ordered an increased effort to develop a faster assembly process – implosion. This resulted in a major reorganization and size increase in the laboratory.

4. Implosion Assembly

The only alternative was implosion. In the implosion assembly, a sub-critical shell of fissionable material (weapons grade plutonium (WgPu)) is compressed inward by the blast from a symmetrical array of high explosives (Figure 8).

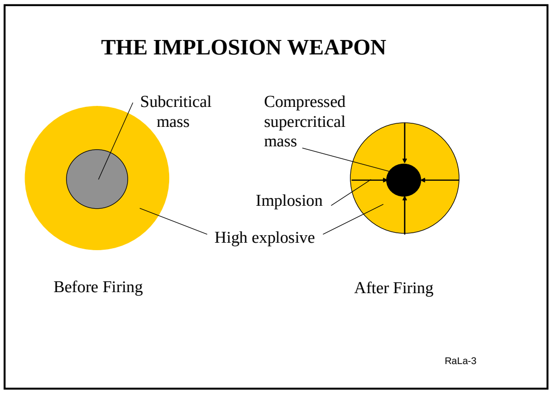


Figure 8. Implosion Assembly

The process would occur so rapidly that spontaneous fission neutrons would not have time to interfere with the nuclear explosion. All detonators have to fire within a microseconds of each other.

On July 17, 1944, Oppenheimer, the Los Alamos Director, stopped work on the plutonium gun assembly and gave top priority to the development of the plutonium implosion bomb. One year later, on July 16, 1945, the first implosion bomb was tested successfully at the Trinity Site in Alamogordo, New Mexico. A truly remarkable feat because in 1944 very little was known about implosion technology. The implosion “gadget" ended up with a sphere of explosives 5-feet in diameter that surrounded the plutonium sphere and therefore bore the code name of “Fat Man.” The “Fat Man” bomb weighted 10,300-lbs.

Bayo Canyon

The place that was chosen for the RaLa implosion experiments was Bayo Canyon which was located north east of the Los Alamos townsite (Figure 9). The facility installed in there was designated TA-10 but generally was referred to as the Bayo Canyon Site. Its layout is shown in Figure 10. The principle structures included a radiochemistry building for La-140 separation (TA 10-1), A personnel building (TA 10-21), four firing sites (TA 10 -1, 2, 3, and 4), and detonation control buildings (TA 10-13 &15) that contained the firing and recording instrumentation.

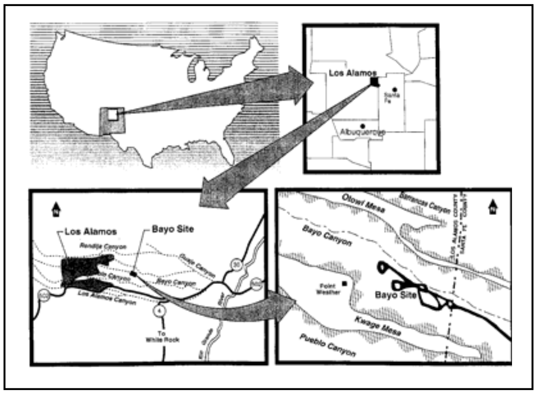


Figure 9. Maps of Los Alamos & Bayo Canyon.

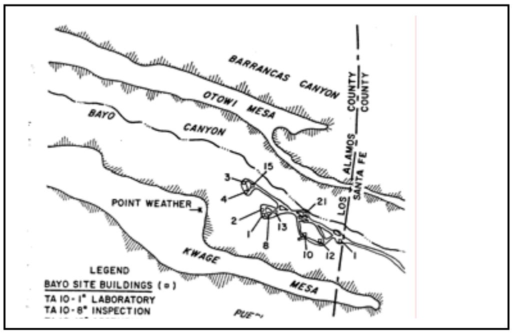


Figure 10. Bayo Canyon

The facilities were constructed in Bayo Canyon in 1943 and were used until 1961 for experiments relating to the development of the implosion weapon.

The ^{140}La sources were prepared in the radiochemistry building (TA-10-1) where ^{140}La was separated from its parent ^{140}Ba. A total of 254 implosion experiments were conducted and a total of 250,000 Ci of ^{140}La were released to the atmosphere.

5. Implosion Diagnostics

Implosion was an entirely new assembly method and techniques had to be devised to determine if, when you put high explosive around a metallic sphere and detonated it, it would implode uniformly because absolute uniform compression of the plutonium sphere was necessary to create a nuclear explosion.

On November 1, 1943, Robert Serber conceived of a novel method for diagnosing implosion based on placing a gamma ray source at the center of a spherical implosion assembly (Figure 11) rays would travel outward radically, through both the collapsing metal shell and the high explosive. Because increasing compression of the metal caused the gamma rays to be increasingly absorbed, the emerging gamma rays, monitored by detectors placed around the device would provide information on density changes in the collapsing sphere of metal.

6. Radioactive lanthanum-140

Radiolanthanum-140, having a 40-hour half life and a strong gamma emission at 1.6 Mev was soon found to be a suitable source. The gamma energy and abundance per decay is: 0.49 Mev (46%); 1.60 Mev (96%).

^{140}La has a specific activity of 5.57 x 10^5 Ci/g. Thus a nominal 1,000 Ci La-140 source has a mass of about:

1,000 Ci ÷ 5.6 x 10^5 Ci/gm = 0.18 x 10^{-2} grams = 0.0018 grams =1.8 mg

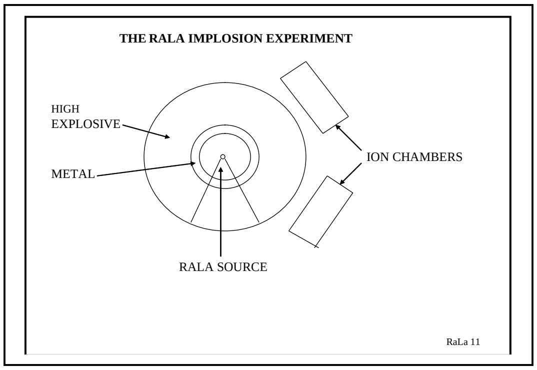


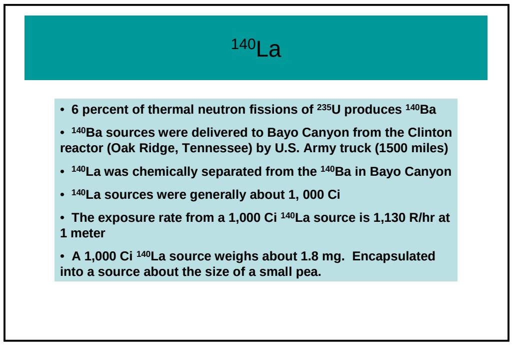
Figure 11. The RaLa Implosion Experiment.

The exposure rate from a 1 Ci ^{140}La source is 1.13 R/hr at one meter. The exposure rate from a nominal 1,000 Ci source used in these experiments is:

(1,000 Ci) (1.13 R/hr per Curie) = 1, 130 R/hr at 1 meter or about 11,000 R/hr at one foot.

However, up to 2,300 Curies were used in a single shot (2,590 R/hr at one meter).

Surrogate metals such as depleted uranium were generally used as the substitute for plutonium in these tests. In the final assembly, detonated on July 16, 1945, plutonium was used, of course.



^{140}La

- 6 percent of thermal neutron fissions of ^{235}U produces ^{140}Ba
- ^{140}Ba sources were delivered to Bayo Canyon from the Clinton reactor (Oak Ridge, Tennessee) by U.S. Army truck (1500 miles)
- ^{140}La was chemically separated from the ^{140}Ba in Bayo Canyon
- ^{140}La sources were generally about 1, 000 Ci
- The exposure rate from a 1,000 Ci ^{140}La source is 1,130 R/hr at 1 meter
- A 1,000 Ci ^{140}La source weighs about 1.8 mg. Encapsulated into a source about the size of a small pea.

Figure 12. Physical properties of ^{140}La

A. Where did the La-140 come from?

About 6 percent of the thermal fissions of ^{235}U produce an isotope of mass number 140. The 140 chain is ideal as the ^{140}I (Half life – 0.86 sec), ^{140}Xe (Half life – 13.6 sec) and ^{140}Ce (Half life – 64 sec) isotopes quickly decay to ^{140}Ba with a half life of 13 days. ^{140}La beta decays to stable ^{140}Ce. All of the other barium isotopes have very short half lives and decay away before the uranium fuel elements can be removed from the reactor for barium and plutonium extractions. This provides a convenient "cow" for producing its daughter ^{140}La which has a half-life of 40 hours. This is analogist to the molybdenum-99 "cows" used in nuclear medicine to obtain technetium-99m that is used in a variety of medical diagnoses.

Beginning in 1944 irradiated uranium fuel elements used in the production of plutonium at the Clinton, Tennessee atomic pile were chemically processed to extract the fission product ^{140}Ba. The ^{140}Ba was loaded into a heavily shielded "pig" welded to the deck of a 2-1/2 ton army truck. Two Army personnel then drove the truck non-stop to Los Alamos (a distance of about 1500 miles) where the barium/lanthanium mix was processed separating the ^{140}La.
The sources were stored in this shed (Figure 13) until it was time for ^{140}La separation. This is probably the most famous picture in all of remote handling. This is Kurt Freidlander and Norma Gross in January 1945 bringing a 1,000 Ci of lanthanum out of its storage shed.

Figure 13. ^{140}Ba source being removed from storage shed.

In Bayo Canyon the barium cow was milked to extract pure ^{140}La which was encapsulated in a sphere about the size of a small pea (1/8 diameter).

Figure 14. Large source handling.

Here is an example of the rather crude but effective means for handling high activity sources. The sources were stored in wells and the manipulator allows a man to get some separation to lower his exposure. Actually this pit was used to stored calibration sources.

The encapsulated ^{140}La source was placed in a shielded cask in the back of a truck and transferred to the implosion test assembly. Prior to source incursion, four Rossi ionization chambers were placed about the test assembly (Figure 15).

Figure 15. Implosion assembly with ionization chambers.

When I participated in these tests in 1959, the ion chambers had been replaced by 20-5 gallon liquid scintillation detectors (Figure 16). When the test took place the explosion destroyed the detectors in a few microsecond or so, so all the data had to be collected in a very short time. The flash from the ignition of 100 gallons of liquid scintillator ignition was brilliant as most of the experiments were conducted early in the morning.

The gamma detectors would measure the photon intensity about the device as a function of time. If implosion is uniform about the device the photon intensity would fall off uniformly due to the increase in density of the imploding material and resulting gamma ray absorption (Figure 17).

Figure 17 shows the decrease in percent transmission of the gamma rays as a function of time. The measurements were first made with Rossi ionization chambers. All four curves in Figure 17 are virtually the same indicating uniform compression. The total lapse time for this event as 95 microseconds – 52 microseconds or **43 microseconds**.

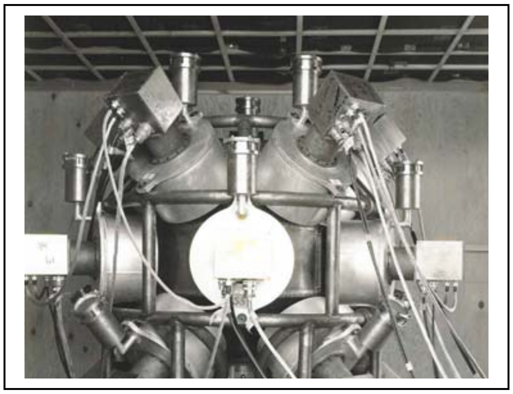


Figure 16 . Implosion assembly with scintillation detectors.

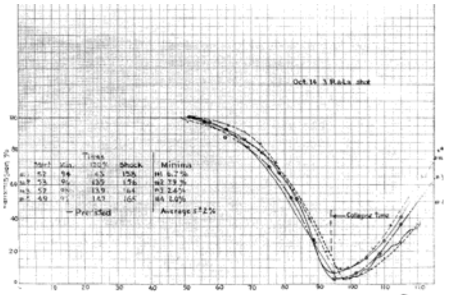


Figure 17. Decrease in percent transmission versus time (in microseconds)

The first RaLa shot was fired on September 22, 1944.

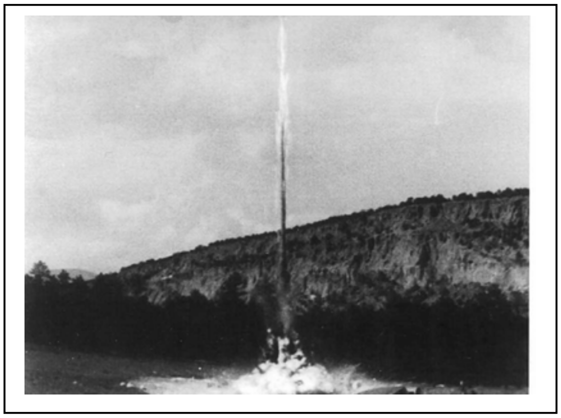


Figure 18. RaLa shot.

Radiological concerns

One can easily see that the ^{140}La "milking" process was fraught with danger. The highest exposures that occurred at Los Alamos during this period were to the chemists that prepared the sources. There were no "hot cells" as we know them today. There was no mechanical manipulation behind leaded glass and heavy shields. Work was done behind lead brick shadow shields. Radiation exposures were reduced somewhat through the use of handling tongs (Figure 19)

Many of these devices became the prototypes of the mechanical handling tongs that would be used in radioisotope laboratories.

In an attempt to control exposures, the H-1 (Health Physics) group set a limit of 500 mrem for the source preparation activity. This was exceeded occasionally and one occasion a 2 rem exposures occurred on source preparation day.

By the fall of 1944 radiolanthanum extraction had been put on a working basis and fast enough ionization chambers had been produced. The RaLa firing program got under way in Bayo Canyon on October 14, 1944. The first shots were fired by mulipoint Pimacord systems, and the results were erratic. Five months later in February 1945 electric detonators became available and the results immediately improved. RaLa became the most important single experiment affecting final bomb design. This principle advantage of this technique was that the data gave an average of the compression as a function of time.

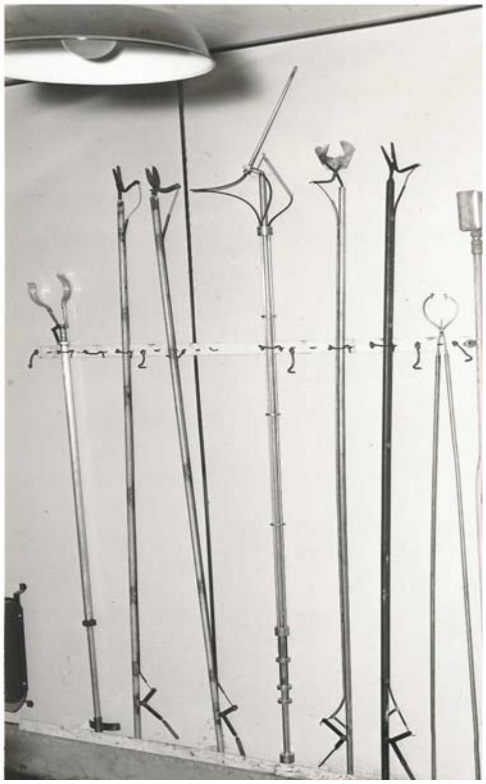


Figure 19. Remote handling tools.

Five months later, on July 16, 1945, the Trinity shot was fired. On August 9, 1945, Fat Man was dropped on Nagasaki. On August 10, 1945 the Japanese began surrender negotiations.

The time from the day the gates of Los Alamos opened, so the scientists could begin work there, until the Trinity shot was fired was 27 months 16 days.

7. ^{140}La Fallout

This slide is a dispersion model for a 1,600 Ci ^{140}La source. The experiments were generally conducted when the winds were to the north. However, at times wind shifts occurred in the early morning hours and on occasion the plume went toward the Los Alamos town site or toward the access road to Los Alamos. Occasionally exposure rates of 5-10 mR/hr were measured along the access road and automobiles had to be stopped for a period of time.

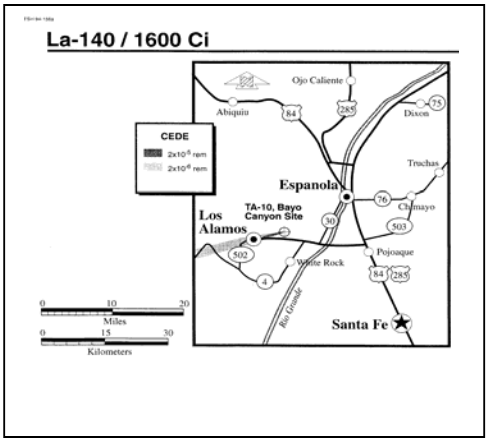


Figure 20. Fallout pattern from a 1,600 Ci ^{140}La source