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Health Physics Survey of Trinity Site

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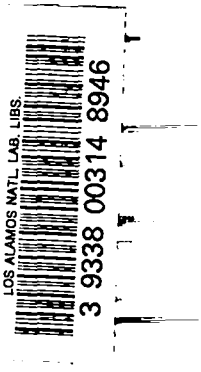

HEALTH PHYSICS SURVEY OF TRINITY SITE

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Frederic L. Fey, Jr.

ABSTRACT

More than 20 years after the first nuclear weapon test, a health physics survey of the site was made to determine whether it would be radiologically safe for the public to visit. It does not appear that anyone could receive any radiation injury through a visit to Trinity Site.

Introduction.

This report is an evaluation of Trinity Site based on a health physics survey made in March, 1967, during "Operation Sleeping Beauty."[1] This survey included: 1) monitoring of the entire site for whole-body exposure rates, 2) monitoring of samples of trinitite carried away from the site for gamma-exposure rates, 3) measurement of surface exposure rate from individual pieces of trinitite, 4) calculation of deposition of radioactivity in the body from injested trinitite, 5) analysis of soil samples, and 6) analysis of air samples taken in the area.

Trinity Site, where the first nuclear weapon was detonated on July 20, 1945, is in a semiarid region of south central New Mexico about 40 miles southwest of Socorro. At the time of this survey the Site was enclosed within the boundary of the White Sands Missile Range under the jurisdiction of the United States Army. The area referred to as Trinity Site is enclosed by a fence at a 1600-foot radius from ground zero. The team who detonated the Trinity bomb made use of other areas outside this fence such as the McDonald Ranch house, where the bomb was assembled, and other bunkers and underground chambers. However, these areas have been cleaned up, surveyed, and found to be free of any significant radioactivity.[2] Therefore, this report is concerned only with the area within the fence. The survey was to determine whether there would be any radiological hazard to any one from a visit to Trinity Site. This report includes the data collected during this survey, its evaluation, and the conclusion of the author as to the radiological safety of Trinity Site.

Whole-Body Exposure Rates at Trinity Site.

A pair of health physics surveyors criss-crossed the area, taking readings with Gieger-Mueller survey instruments. Near ground zero, gamma exposure rates as high as 3 mR/h were obtained. The exposure rate rapidly dropped off to below 1 mR/h at 100

yards from ground zero. Beyond this, the readings gradually tapered off to a low at the fence of 0.03 mR/h which is about an average background reading from natural causes such as cosmic radiation and radium in the soil.

The gamma radiation at Trinity Site comes from fission and activation products which were fused into the sand to form a green glassy substance called trinitite. Most of the gamma activity at present is caused by three isotopes: ^{137}Cs, ^{152}Eu, and ^{60}Co. The gamma exposure rate at any particular point is proportional to the amount and depth of trinitite in that area. Around ground zero, where the exposure rates are the highest, very little trinitite can be found on the surface. However, there is a layer of beaded trinitite about 6 in. below the surface. Shortly after the Trinity test a layer of uncontaminated soil was spread over the area around ground zero out to a distance of 25 yards. Beyond this distance, the density of trinitite lying on the surface increases out to about 1,200 feet where an attempt was made to bury the trinitite. Some of the mounds thus created may read as high as 1 mR/h due to the density of buried trinitite.

Gamma Exposure Rate from Trinitite.

In certain areas there are large quantities of trinitite on the surface. Most of these pieces have a surface area less than 5 cm^2; however, there are some as large as 25 cm^2. It is conceivable that a person visiting Trinity Site could pick up as much as 1 kg of trinitite in less than an hour. If he were to take this quantity of trinitite home, it would constitute a source of radiation.

Analysis of trinitite has indicated a gamma activity concentration of a few nCi/g. Therefore 1 kg of trinitite constitutes a maximum of 5 μCi of gamma activity. The gamma exposure rate from this amount of activity is about 5 μR/h at 1 meter, or 50 μR/h (0.05 mR/h) at 1 foot. These values are comparable to the normal background from natural causes.

Surface Exposure Rate from Trinitite.

In addition to the gamma exposure from trinitite, two less penetrating types of radiation, alpha and beta, must also be considered. Because of the presence of two prominent fission products, ^{90}Sr and ^{147}Pm, which emit beta particles but no gamma photons, the beta activity of trinitite is about twice the gamma activity. A gram of average trinitite contains about 10 nCi of beta activity. Since beta particles are not as penetrating as gamma photons, their energy is deposited in the first few millimeters of tissue. The maximum dose is received by the first layer of skin and is called the surface exposure.

To find out the maximum surface exposure rate possible from trinitite, measurements were made on the most active piece of trinitite that could be found; this was a rather dark piece weighing about 5 g and about 5 cm^2 in surface area. The beta activity of this piece, about 10 times greater than average, is about 0.5 μCi. An autoradiograph revealed that the activity was uniformly distributed over the surface of the smooth side.

This particular piece reads 5 mR/h in contact with an open shielded Gieger-Mueller probe, but this is by no means the surface exposure rate. To estimate the dose to the epidermis of a person holding this piece of trinitite, five very thin dosimeters were stacked on it and exposed to the beta and gamma for 2 weeks. These dosimeters are

5-mil-thick, 5-in.-diam, lithium fluoride impregnated teflon disks. Lithium fluoride is a thermoluminescent material which, upon heating, emits an amount of light proportional to the dose it has received. The five thermoluminescent dosimeters (TLD's) were backed with a piece of lucite to approximate the backscattering effect of tissue. The readings obtained are listed according to depth in Table 1.

TABLE I

RESULTS OF TLD EXPOSURE TO SURFACE OF TRINITITE

TLD No.	Depth (mils)	335 h Exposure (rads)	Exposure rate mrad/h
1	1st 5	36	108
2	5 - 10	26	78
3	10 - 15	20	60
4	15 - 20	16	48
5	20 - 25	14	42

The normal dead layer of skin is a minimum of 7 mg/cm^2 or about 3 mils thick. Therefore, the exposure rate to viable skin can be considered to be no more than 100 mrad/h from this particular piece of trinitite. Since this piece was 10 times more radioactive than the average, 10 mrad is about the maximum exposure rate available from at least 95% of the trinitite.

Deposition of Radioactivity in the Body from Ingested Trinitite.

Trinitite also contains an amount of unfissioned ^{239}Pu equal to the beta activity. The average piece contains about 10 μCi of ^{239}Pu per gram and has a surface count of 500 cpm (2π); however, this activity can not be removed by swiping. Since an alpha particle can not penetrate the dead layer of skin, the plutonium activity presents no external hazard.

To determine the hazard, if any, from ingested trinitite, a leaching experiment was carried out to see what percent of the activity in trinitite would become available under different circumstances. Two typical pieces of trinitite were selected, one ground fine, the other crushed into coarse granules. These two samples were first subjected to a leach with 100 ml of distilled water on a shaker at room temperature for 36 h. Then the same procedure was carried out with 0.1 M HCl. The results of this leach indicate the maximum amount of activity that could become available for uptake in the digestive system.[3] Finally, the remaining activity was removed by a 1 M HF-12 M HNO_3 extraction. The results of these analyses are recorded in Table II.

TABLE II

α, β, AND γ ACTIVITY IN TRINITITE

	Fine Ground (4.2 g) α dpm/g	β dpm/g	γ dpm/g
Water	<1	36	25
0.1 M HCl	2	348	198
1 M HF - 12 M HNO_3	16,800	26,400	10,700
Total Activity	16,800	26,800	10,900
	Coarse Ground (4.5 g)		
	α dpm/g	β dpm/g	γ dpm/g
Water	<1	9	<1
0.1 M HCl	<1	78	50
1 M HF - 12 M HNO_3	16,300	29,200	11,900
Total Activity	16,300	29,300	12,000

The availability $\left(\frac{\text{activity leached}}{\text{total activity}}\right)$ for each of the samples is recorded in Table III.

TABLE III

AVAILABILITY OF RADIOACTIVITY IN TRINITITE

	Water Leach Fine	Water Leach Coarse	0.1 HCl Leach Fine	0.1 HCl Leach Coarse
α	$<10^{-4}$	$<10^{-4}$	1.2×10^{-4}	$<10^{-4}$
β	1.3×10^{-3}	3.1×10^{-4}	1.3×10^{-2}	2.6×10^{-3}
γ	2.3×10^{-3}	$<10^{-4}$	1.8×10^{-2}	4.2×10^{-3}

It is obvious that the ^{239}Pu is held very tightly to the trinitite. The fraction of that available which reaches the critical organ, bone, is 7.4×10^{-5}.[4] Combining this figure with the maximum availability figure for α activity from Table III, the fraction of activity from trinitite ingested which is actually deposited in the bone is about 3×10^{-9}. Assuming the previously mentioned concentration of 10 nCi of ^{239}Pu per gram of trinitite, one would have to eat 1.3×10^{8} g of trinitite to produce the deposition of one maximum permissible body burden of 4 nCi. It is obviously impossible to reach even a small fraction of a maximum permissible body burden of ^{239}Pu by the ingestion of trinitite.

The beta and gamma activity is, however, considerably more available. The figures in Table III indicate that about 2% of the beta-gamma activity may become available for uptake. Of the Sr that becomes available for uptake, 9% is deposited in the bone.[4] Therefore, 0.2% of the ^{90}Sr found in trinitite will be deposited in the bone. Assuming the worst possible case, that all 10 nCi of beta activity in 1 g of trinitite is due to ^{90}Sr, then 0.02 nCi of ^{90}Sr per gram of ingested trinitite can be considered to be deposited in the bone. Since the maximum permissible body burden of ^{90}Sr for the public is 0.2 μCi, an ingestion of 10^{4} grams would result in the deposition of a maximum permissible body burden. Ingestion of this much trinitite is also inconceivable; therefore it can be concluded that there is no radiological hazard from the accidntal ingestion of trinitite.

Radioactivity in the Soil.

Soil samples from Trinity Site revealed varying amounts of alpha and beta-gamma activity. Samples from the original ground level near ground zero have an alpha 2π emission rate of 20 counts/cm²-min and may read as high as 8 mR/h in contact with an open-shield GM probe. To find out where the activity lies in the soil, two samples were divided according to particle size and analyzed for radioactivity. Soil sample S-2 was taken from the beaded trinitite layer near ground zero, and contained a large amount of trinitite mixed with sand. Sample S-5 was taken from the surface, about 10 yards out from ground zero. Each was sieved for 30 min on a mechanical shaker which resulted in the following fractionation:

Fraction No. 1 - Did not pass No. 10 mesh sieve (particle >2 mm)

Fraction No. 2 - Passed No. 10 mesh, not No. 20 (2 mm to 0.84 mm)

Fraction No. 3 - Passed No. 20 mesh, not No. 40 (0.84 mm to 0.42 mm)

Fraction No. 4 - Passed No. 4 mesh (<0.42 mm)

To find out how much radioactivity was contained in each fraction, a 2-g sample of each was ground to a fine powder. After addition of 50 ml of 12 M HNO_3 - 1 M HF, the samples were boiled for at least 3 h. This method has been found sufficient to remove at least 95% of the activity from samples of this type.[5] The solution was diluted to 100 ml, plated, and counted for alpha, beta, and gamma activity. The results are recorded in Table IV.

These results indicate that all the activity is contained in the trinitite. Fraction No. 1 of S-2 was nearly all trinitite, while Fraction No. 4 was mostly sand with only a few grains of crushed trinitite. Sample S-5 was mostly sand and gravel with a few small pieces of crushed trinitite.

TABLE IV

RESULTS OF HNO_3 - HF EXTRACTION

Sample	α dpm/g	β dpm/g	γ dpm/g
S2-1	24,600	67,400	36,500
S2-2	16,400	47,000	22,100
S2-3	6,800	19,000	12,500
S2-4	2,900	11,800	11,300
S5-1	300	200	3,600
S5-2	400	1,800	3,500
S5-3	150	600	3,000
S5-4	80	2,400	4,000

The fine, dusty portion of each sample contained very little trinitite and therefore very little radioactivity.

Radioactivity in Air.

To further verify that there is no alpha or beta-gamma activity in respirable size particles, several air samples were taken at various times at Trinity Site. While taking soil samples in areas where the 2π alpha emission rate was 20 counts/cm²-min a considerable amount of dust was stirred into the air. Air samples taken in this cloud revealed no long-lived radioactivity. Air samples were also taken during a dust storm, again without finding any airborne activity.

Summary and Conclusions.

The whole-body gamma-exposure rate at Trinity Site varied from a high of 3 mR/h near ground zero to a low of 0.03 mR/h. The whole-body exposure rate received by a person visiting Trinity Site would certainly average less than 1 mR/h. This is borne out by the fact that the two health physics surveyors, who spent at least 50 h within the fence over a two-week period, had no recordable exposure on the film dosimeters they were wearing. Since the threshold of the film is 0.020 rem, it can be reported that two men spending 50 h at Trinity Site received less than 20 mR. A person merely visiting Trinity Site would not have to wear a radiation dosimeter; however, a person, such as a guide, spending 40 h a week there should wear an accepted radiation dosimeter, and a record should be kept of any exposure received.

Unofficial visitors to Trinity Site will probably be asked not to remove any artifacts from the site. However, if someone did take away as much as a kilogram of trinitite, he would not be exposed to any greater radiation than would a person moving from New York to Colorado Springs.

The surface exposure rate from the most active piece of trinitite that could be found is 100 mrad/h. Since the minimum exposure for which there may be observable effects is 200 rad,[6,7] it appears that 2,000 h (83 days) of continuous contact with the skin may be sufficient to produce an effect. However, a biological system has the ability to repair 90% of radiation injury at the rate of 2.5% per day.[6] Calculations indicate that if this particular piece of trinitite were kept in continuous contact with an area of skin for one year, the "equivalent residual dose" would be 170 rad which is less than the 200-rad minimum. Radiation injury to the skin due to trinitite can be considered very unlikely, especially since the average piece of trinitite has less than 1/10 the activity of the one used in this example.

The deposition of radioactivity in the body due to ingestion of trinitite can not be considered a problem owing to the large amount it would be necessary to consume in order to deposit a maximum permissible body burden.

Soil and air samples taken at Trinity Site revealed that all the activity is contained in pieces of trinitite. There appeared to be no activity associated with

particles of respirable size.

After a thorough evaluation of the data gathered during a survey of Trinity Site, it does not appear that anyone could receive any radiation injury through a visit there. This includes the time spent at Trinity Site as well as irradiation from pieces of trinitite that might be carried away.

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