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# RECENT ONSITE GAMMA MEASUREMENTS AT THE TRINITY TEST SITE AND A COMPARISON TO TRINITITE SAMPLES

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## ABSTRACT

The world's first nuclear device was detonated on 16 July 1945 near Alamogordo, New Mexico. The device, called "The Gadget," was placed on a 100-foot steel tower and detonated with a yield of about 20 kilotons. The desert soil was drawn into the fireball, melted and mixed with radioactive debris, and rained down to form a green glass that would be named "Trinitite". This material was heavily scavenged by mineral collectors, and in 1952 most of the remaining material in the crater was bulldozed and buried. Visible particles of Trinitite near ground zero are very sparse; however, the soil still retains some radioactivity.

During a recent visit to the site we collected spectra at several locations near ground zero using a mechanically-cooled high-resolution gamma spectroscopy system. We report results from these measurements, as well as laboratory measurements of Trinitite samples and glass samples obtained from nuclear detonation sites in Nevada and Semipalatinsk.

## *IN SITU* MEASUREMENTS

A visit to the Trinity site in August 2010 presented an opportunity to take high-resolution gamma ray spectra *in situ* to determine the presence of residual radioactive isotopes. The wind at the time of detonation blew the fallout northeast from ground zero. Using a NaI identiFINDER we confirmed that the highest remaining radioactivity is in this direction. Six locations with the strongest signals were then measured using a higher-resolution Ortec microDetective. Figure 1 shows a typical measurement in progress.

The *in situ* spectra were dominated by $^{152}$Eu, as shown in Figure 2. $^{137}$Cs and $^{154}$Eu were visible in all spectra, and $^{60}$Co was visible in some of them. The radioisotopes $^{152}$Eu ($T_{1/2}$=12.7 years) and $^{154}$Eu ($T_{1/2}$=8.5 years) were generated by neutron irradiation of natural europium in the soil, $^{137}$Cs ($T_{1/2}$=30.1 years) was a fission product from the nuclear detonation, and $^{60}$Co ($T_{1/2}$=5.3 years) was produced mainly by irradiation of steel structures. Many shorter-lived isotopes are no longer visible. We observed 7.8 – 37.6 Bq/cm$^2$ of $^{152}$Eu, 1.0 – 7.4 Bq/cm$^2$ of $^{137}$Cs, 0.1 – 3.4 Bq/cm$^2$ of $^{154}$Eu, and 0.0 – 0.4 Bq/cm$^2$ of $^{60}$Co at the various measurement locations.

Figure 1. *In Situ* measurements at the Trinity Site using an identiFINDER and an Ortec microDetective. The obelisk in the background marks Ground Zero, where remnants of the steel tower are still visible today.

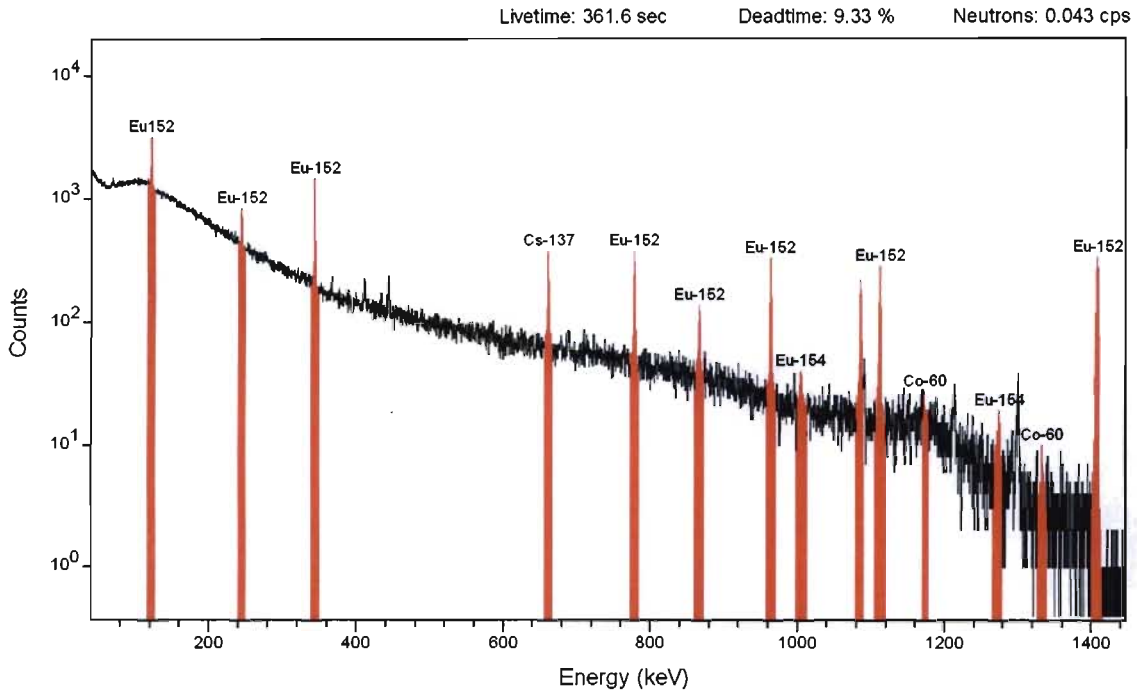


Figure 2. *In Situ* spectrum showing signature peaks of $^{152}$Eu, $^{137}$Cs, $^{154}$Eu, and $^{60}$Co.

Surprisingly, no signature of $^{241}$Am was visible in any of the *in situ* spectra, even though most published measurements of Trinitite samples (and our own measurements below) report a strong $^{241}$Am signature. $^{241}$Am is a daughter of $^{241}$Pu, a component of the nuclear fuel, and we had fully expected to see a residue in the soil. One possible explanation is

that the soil contained little remaining Trinitite, and the observed soil radioactivity is due mostly to neutron-irradiated subsoil that was not drawn into the fireball. The americium appears to have been removed along with the top layer of soil during surface remediation or leached out of the surface soil by environmental process. The $^{137}Cs$ / $^{152}Eu$ activity ratio measured in the soil is a factor of 20 smaller than typically observed in samples of Trinitite, suggesting that most of the $^{137}Cs$ has been removed as well.

## LABORATORY MEASUREMENTS

Measurements were made in a laboratory environment of Trinitite and analogous glass samples from other detonations (see Figure 3). This allowed us to quantify the radioisotope activity and compare to previously published results and to the *in situ* soil measurements. We did not collect soil samples for laboratory measurements.

We measured two samples of green Trinitite. Sample "A" was gathered from the Test Site by a museum curator and consists of 125.6 grams of typical green glass pieces. Sample "B" is a 248.6 gram portion of a bulk quantity of unknown origin. It is similar in appearance to Sample A. We also measured 21.2 grams of rare red Trinitite.

We measured a sample from a low-yield 1962 Nevada Test Site detonation. This is not precisely "Trinitite" so we use the generic mineral term "atomsite". It is a 4.4-gram piece, shiny black and porous on one side, dull grey on the other, about 2 cm in diameter.

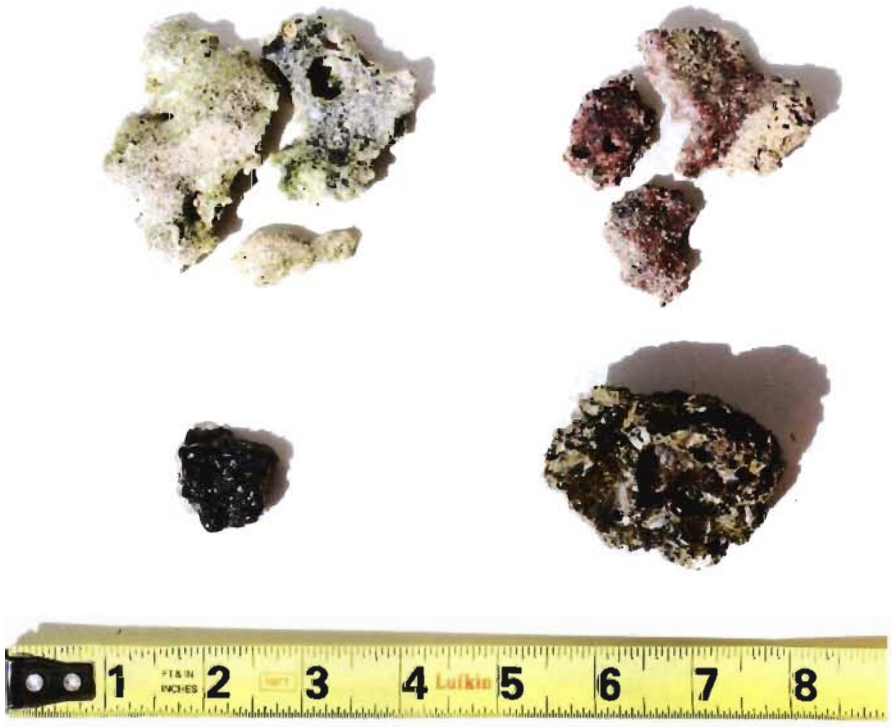


Figure 3. Clockwise from upper left: Green Trinitite from Sample A, Red Trinitite, Kharitonchik (Soviet analog of Trinitite), and Atomsite from the Nevada Test Site.

Kharitonchik is the Soviet analog to Trinitite, from the Semipalatinsk Test Site in Kazakhstan. We measured a 42.3-gram sample consisting of a single piece about 5 cm in diameter. It was reported to have been collected from the location of the first Soviet nuclear test RDS-1 (American nickname "Joe-1"), similar to the Trinity Gadget, detonated 29 August 1949. The same location was also used for the test RDS-6 (American nickname "Joe 4") on 12 August 1953, which was the first Soviet *thermonuclear* test, with a yield of about 400 kilotons.

A spectrum from a bulk sample of green Trinitite appears in Figure 4 with a long count time. Additional artificial radionuclides $^{241}$Am and $^{133}$Ba are now visible, as compared to the *in situ* spectrum. The ratio of radioisotopes is clearly different: the $^{137}$Cs peak is much stronger relative to $^{152}$Eu.

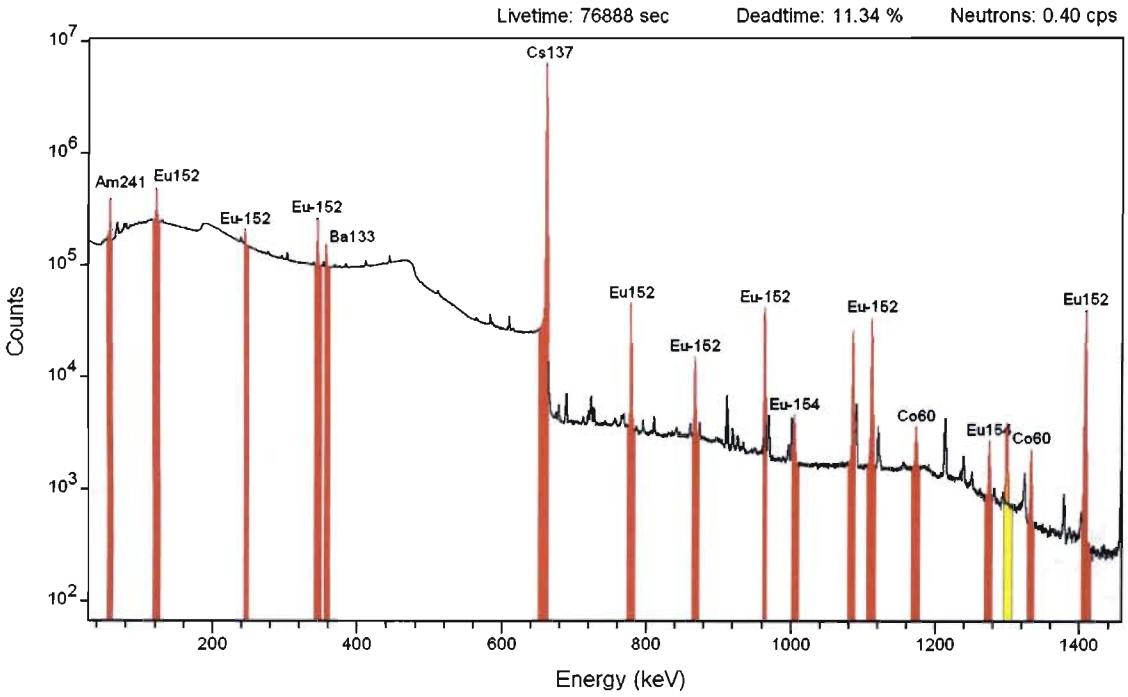


Figure 4. Spectrum of Trinitite. Signature peaks of artificial radionuclides are labeled. The trace signature of $^{239}$Pu is not visible on this scale.

Quantification measurements used an Ortec Detective-EX-100. Samples were counted in a close configuration in a low background region without additional shielding or collimation. Absolute calibration is based on a secondary measurement of each sample at 25 cm (to reduce geometry calibration errors). Results are shown in Table 1 and Figure 5. In addition to the radionuclides observed in the *in situ* measurements, we report observations of $^{241}$Am ($T_{1/2}$=433 years), $^{133}$Ba (activation of barium in the explosives, $T_{1/2}$=10.7 years), $^{237}$Np/ $^{233}$Pa (irradiation of uranium, see below), $^{239}$Pu (fuel, $T_{1/2}$=24000 years), and $^{155}$Eu (fission product, $T_{1/2}$=5 years).

Table 1: Activity concentration of the artificial radionuclides observed in the glass samples. Units are Bq/g and uncertainties are 1σ. All activities are recalculated to the date of the respective explosions, with Kharitonchik based on the RDS-6 detonation date.

| Radionuclide | Trinitite Green A | Trinitite Green B | Trinitite Red | Atomsite Nevada | Kharitonchik |
|---|---|---|---|---|---|
| $^{60}$Co | 79.1 ± 16.5 | 62.7 ± 14.4 | 143.9 ± 23.5 | 231.3 ± 46.8 | 2074.9 ± 67.3 |
| $^{133}$Ba | 13.5 ± 1.4 | 10.5 ± 0.5 | 8.9 ± 0.7 | 13.1 ± 2.6 | 4.5 ± 0.4 |
| $^{137}$Cs | 41.3 ± 4.2 | 81.0 ± 3.1 | 65.5 ± 4.4 | 37.0 ± 7.4 | 620.6 ± 19.7 |
| $^{152}$Eu | 80.7 ± 8.1 | 44.7 ± 1.8 | 47.4 ± 3.3 | 74.3 ± 14.9 | 1302.3 ± 41.3 |
| $^{154}$Eu | 13.7 ± 2.8 | 8.7 ± 1.8 | 9.1 ± 5.1 | 27.8 ± 6.6 | 261.6 ± 8.7 |
| $^{155}$Eu | – | – | – | – | 2206 ± 1105 |
| $^{241}$Am | 1.6 ± 0.2 | 2.7 ± 0.2 | 2.5 ± 0.2 | – | 2.7 ± 0.2 |
| $^{237}$Np/$^{233}$Pa | – | – | – | – | 0.7 ± 0.1 |
| $^{239}$Pu | – | 142 ± 36 | – | – | – |

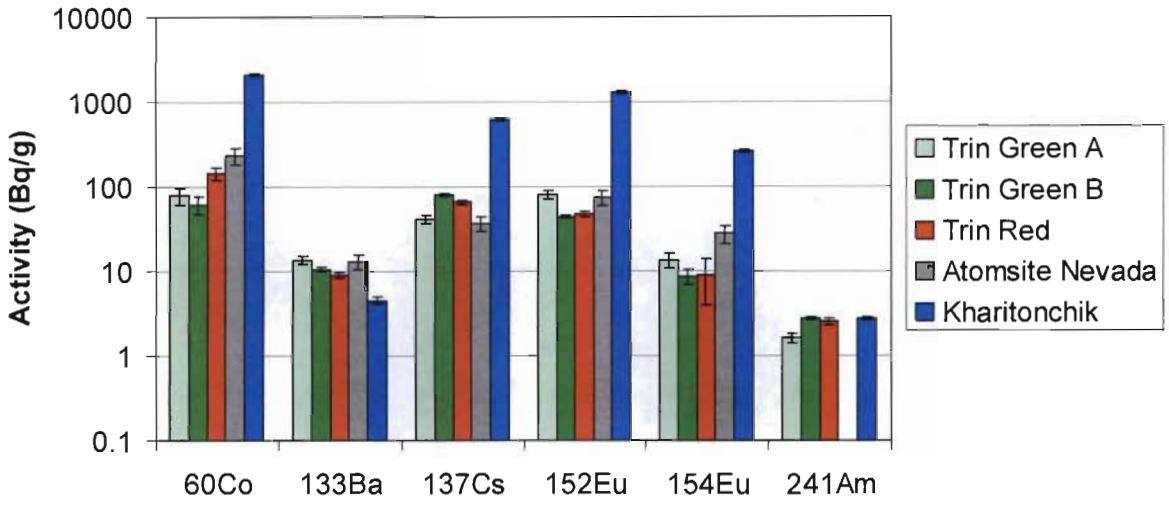


Figure 5: Graphical comparison of select results. The Nevada sample contained no detectable $^{241}$Am. The Kharitonchik sample had an order of magnitude higher activity for several radionuclides.

The three Trinitite samples show some variation in activities, which may be due to location, uneven mixing, and spatial distribution of the neutron fluence. The most notable difference among the Trinitite samples is the higher (2×) activity of $^{60}$Co visible in the red Trinitite. Presumably this sample contains more steel residue than the others. $^{60}$Co is a product of the $^{59}$Co($n,\gamma$) reaction, and cobalt was a component of the steel. The green Trinitite results are consistent with References [1-4] except that we are not able to

conclusively observe or quantify $^{155}$Eu in our samples, in contrast to Reference [3]. We do not know of any reference for previous measurements of red Trinitite activity.

$^{239}$Pu (residual fuel from the Gadget) was observed in one Trinitite sample but is difficult to quantify due to the weak signature and interference from other gamma rays. Our single result is consistent with the upper limit of Reference [3] and 1.7× higher than reference [1]. Plutonium observation in other samples is inconclusive.

The Atomsite sample from Nevada showed radionuclide activities generally similar to the Trinitite samples. The main exceptions are a higher activity of $^{60}$Co, and absence of any detectable $^{241}$Am (which was plainly visible in all other samples). From the latter observation we conclude that the fuel for this detonation likely did not contain plutonium.

$^{233}$Pa was tentatively observed in the Kharitonchik sample only. This may be generated by (*n,2n*) interactions with $^{238}$U or multiple neutron capture on $^{235}$U, producing $^{237}$U ($T_{1/2}$=6.75 days) which decays to $^{237}$Np ($T_{1/2} = 2.14 \times 10^6$ years). The observed $^{233}$Pa ($T_{1/2}$ = 27.4 days) is continuously regenerated by $^{237}$Np decay.

The Kharitonchik sample displays much higher levels of $^{60}$Co, $^{137}$Cs, $^{152}$Eu, and $^{154}$Eu than any Trinitite sample, and it is the only sample for which any $^{237}$Np/$^{233}$Pa is observed. Furthermore, it is the only sample in which we can positively identify $^{155}$Eu (although accurate quantification is difficult). The differences suggest that the character of the detonation is very different from that which produced Trinitite. It would appear to be dominated by the larger RDS-6 detonation. Our $^{60}$Co results are comparable to Semitalatinsk soil sample results of Reference [5], our $^{137}$Cs, $^{152}$Eu, and $^{154}$Eu results are 2-3× higher, and our $^{241}$Am results are 5× higher than reported in this reference. This reference does not report $^{133}$Ba, $^{155}$Eu, or $^{237}$Np/$^{233}$Pa; however, neptunium is reported in Reference [6].

## CONCLUSION

It is clear that the Trintity Test Site still shows evidence of a nuclear detonation observable 65 years after the event. Radioisotopes $^{152}$Eu, $^{154}$Eu, $^{137}$Cs, and $^{60}$Co are plainly visible in the soil.

Comparing the *in situ* soil measurements to Trinitite samples we see clear differences. Trinitite contains much more $^{241}$Am and $^{137}$Cs relative to $^{152}$Eu. This may be a result of attempts at surface remediation of the site, which removed most of the Trinitite but left irradiated subsoil.

We examined atomsite and Kharitonchik specimens from Nevada and Semipalatinsk test sites, and found significant differences from Trinitite, suggesting differences in the detonations that created the samples.

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