Radioactivity in Trinitite

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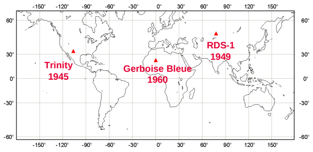
Introduction



ATOMSITE – a fused glass-like material formed during ground - level nuclear tests

TRINITITE – a more widely used name for atomsite from Trinity site

TRINITY – The World´s first nuclear explosion, conducted in the desert in White Sands Missile Range, New Mexico, USA, on July 16, 1945. Plutonium bomb, detonated on a 30 m tower, yield estimated to 20 kt TNT.

RDS-1 (JOE-1) - The USSR first nuclear test at the Semipalatinsk site in Kazakhstan on August 29, 1949. Plutonium bomb, design similar to that in Trinity, detonated on a 30 m tower, yield estimated to 20 kt TNT.

GERBOISE BLEUE - The French first nuclear test at the Saharan Military Test Centre near Reggane, Algeria, conducted on February 13, 1960. The fission device was detonated on a 100 m tower with an estimated yield of 40-80 kt TNT.

Methods

11 samples of Trinitite and 2 samples of soil from Trinity site were studied in the Radioactivity measurements laboratory at the University of Bremen (LMS) and at the authors' facilities in Anaheim, and Edgewater. Gamma spectroscopy was used to identify and quantify radionuclides in Trinitite and to perform a radiometric characterization of soil at the Trinity site. Additionally, atomsite formed during a soviet test at the Semipalatinsk test site was investigated.

Obtained data on Trinitite and soil from Trinity site were compared to previously published results and literature data on atomsite formed during atmospheric nuclear tests in Algeria and soil from the Semipalatinsk site.

Results and conclusions

Tab. 1: List of detected artificial gamma emitters in Trinitite and their origin

Isotope	Half-live (yr)	Origin
^{60}Co	5.3	Activation of ^{59}Co – from test tower steel and from soil
^{133}Ba	10.5	Activation of ^{132}Ba. Baratol - Ba $(NO_3)_2$ - was part of explosive lens system of the Trinity device
^{137}Cs	30.0	Fission product (beta decay of ^{137}Xe and ^{137}I and also independently)
^{152,154}Eu	13.3 / 8.8	Activation of stable isotopes ^{151,153}Eu in soil by slow neutrons
^{155}Eu	4.8	Fission product, found to be detectable in Trinitite after more than 13 half-lives
^{239}Pu	24110	Principle isotope of nuclear fuel
^{241}Am	433	Mostly present as daughter product of ^{241}Pu (beta emitter), produced mainly from ^{239}Pu during the explosion via double-neutron capture. Based on ^{241}Am ingrowth, activity of ^{241}Pu can be determined.

***Fig. 1:** A specimen of Trinitite. Left: top side. Middle: edge. Right: bottom side. Mass: 3.170 g.*

***Fig. 2:** A specimen of atomsite from Semipalatinsk test site. Left: top side. Middle: edge. Right: bottom side. Mass: 2.545 g.*

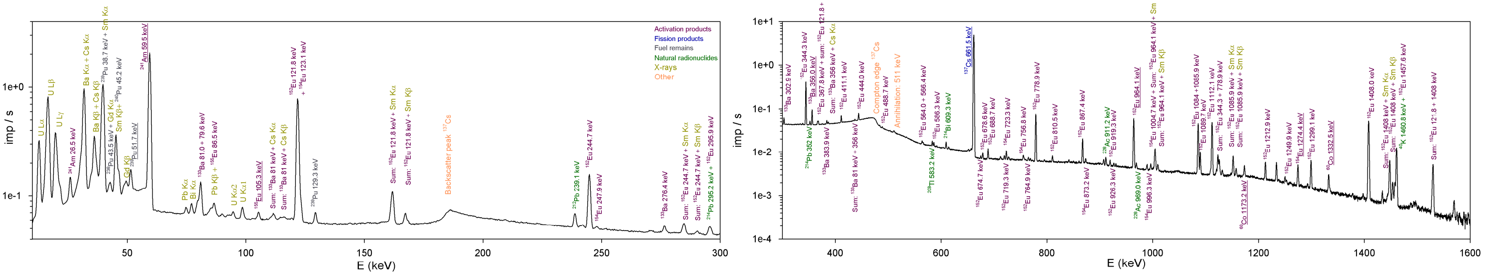


***Fig. 3:** A HP-Ge gamma spectrum of a sample of Trinitite measured in LMS (50.2 g, pieces of Trinitite in a plastic cylindrical container, height 20 mm, diameter 70 mm, live-time 423281 s).*

New measurements of Trinitite and soil form Trinity and literature values

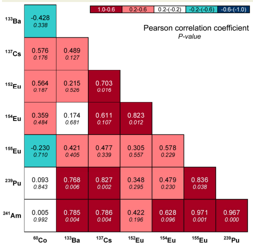
Comparison of Trinitite to atomsite from Algeria and soil from Trinity to soil from Semipalatinsk

***Tab. 2:** Table of comparison of activity concentrations (Bq/g, uncertainties 1σ) of radionuclides detected in Trinitite and soil from nuclear test sites recalculated to the date of respective nuclear explosions (^{241}Am, which is ingrowing from ^{241}Pu, is reported to the date of analysis - in brackets).*

Isotope	LMS, 2010	Atkatz & Bragg, 1995	Schlauf et al., 1997	Parekh et al., 2006	IAEA, 2005	LMS, 2010	Hansen & Rodgers, 1985	Yamamoto et al., 1996
	Median, Min - Max			Min, Max	Min - Max	Min, Max	Min - Max	
	TRINITITE				ATOMSITE ALGERIA	SOIL TRINITY		SOIL SEMIPALATINSK
Bq/g	11 samples of Trinitite (see text)	Small piece	8.2 g piece	3 samples: several small pieces and 2 bigger individual pieces	Black fragments of fused sand	2 samples of soil (see text)	Samples at GZ area	2-3 upper mm of soil
^{60}Co	47.7 ± 4.6 <51.8[1] - (72.5 ± 4.8)	-	44 ± 4	44.4 ± 4.6 62.0 ± 4.9	168.9	2.9 ± 0.8 20.8 ± 1.3	64 - 320	1946 ± 43
^{133}Ba	9.10 ± 0.77 (5.04 ± 0.51) - (17.8 ± 1.3)	-	9.9 ± 0.6	7.55 ± 0.45 9.80 ± 0.26	48.9	0.104 ± 0.009 0.36 ± 0.03	0.73 - 1.73	-
^{137}Cs	48.3 ± 1.4 (16.26 ± 0.88) - (80.9 ± 2.4)	83.2	90 ± 9	27.33 ± 0.08 121.8 ± 0.1	78.1	0.142 ± 0.004 0.879 ± 0.026	0.38 - 1.87	236 ± 2
^{152}Eu	26.0 ± 1.1 (14.2 ± 1.3) - (55.5 ± 1.3)	-	27 ± 1	22.61 ± 0.38 78.89 ± 0.61	54.0	7.92 ± 0.19 33.42 ± 0.79	3.2 - 347	998 ± 10
^{154}Eu	7.08 ± 0.24 <6.03[2] - (12.76 ± 0.36)	-	4.8 ± 0.6	2.45 ± 0.60 16.1 ± 1.3	27.2	1.07 ± 0.08 4.80 ± 0.28	-	100.8 ± 4.5
^{155}Eu	274 ± 25 <361[3] - (461 ± 54)	-	-	-	241.2	<28.4 10.8 ± 2.8	-	-
^{239}Pu	73.6 ± 3.5 (25.7 ± 3.6) - (133 ± 25)	-	-	86.3 ± 2.7	<230	< MDA < MDA	-	-
^{241}Am	1.870 ± 0.080 (0.741 ± 0.048) - (4.47 ± 0.19) (2009)	-	2.9 ± 0.5 (1997)	1.841 ± 0.053 4.137 ± 0.058 (2006)	2.3 (1999)	0.0082 ± 0.0004 0.0369 ± 0.0018 (2009)	-	0.52 ± 0.01 (1994)
^{241}Pu[4]	63.6 ± 2.7 (25.2 ± 1.6) - (152.0 ± 6.5)	-	100 ± 17	62.9 ± 1.8 141.3 ± 2.0	85	1.254 ± 0.061 0.279 ± 0.014	-	18.6 ± 0.4

Several values measured by LMS were below detection limit, mainly due to low sample mass and/or shorter measurement times.
[1] 3 values under MDA, minimal value above MDA is 34.5 ± 5.6. [2] 3 values under MDA, minimal value above MDA is 2.70 ± 0.07. [3] 5 values under MDA, minimal value above MDA is 115 ± 38. [4] Calculated from ^{241}Am ingrowth.

Correlations of radionuclides in Trinitite



	^{60}Co	^{133}Ba	^{137}Cs	^{152}Eu	^{154}Eu	^{155}Eu	^{239}Pu
^{133}Ba	-0.428 *0.338*						
^{137}Cs	0.576 *0.176*	0.489 *0.127*					
^{152}Eu	0.564 *0.187*	0.215 *0.526*	0.703 *0.016*				
^{154}Eu	0.359 *0.484*	0.174 *0.681*	0.611 *0.107*	0.823 *0.012*			
^{155}Eu	-0.230 *0.710*	0.421 *0.405*	0.477 *0.339*	0.305 *0.557*	0.578 *0.229*		
^{239}Pu	0.093 *0.843*	0.768 *0.006*	0.827 *0.002*	0.348 *0.295*	0.479 *0.230*	0.836 *0.038*	
^{241}Am	0.005 *0.992*	0.785 *0.004*	0.786 *0.004*	0.422 *0.196*	0.628 *0.096*	0.971 *0.001*	0.967 *0.000*

***Tab. 3:** Corrgram for gamma spectroscopic data set (11 Trinitite samples measured in LMS). For specifying relationships between radionuclides, Pearson correlation coefficients (normality was positively tested by Shapiro-Wilk test) were used.*
Several significantly positive correlated pairs were found with P-values < 0.05.

Inhomogeneous distribution of radioactivity in Trinitite

*The difference of activity at the top surface and the bottom surface of Trinitite is remarkable, mainly for beta activity. Measurements performed on 6 Trinitite specimens using a 2" pancake tube showed the **top/bottom surface ratios 2.6 - 22.9**.*
*Gamma measurements do not show such a pronounced difference due to higher penetrability of gamma radiation. **Top/bottom ratios were found significantly increased for ^{137}Cs** (1.24±0.05), ^{239}Pu (1.49±0.11) **and ^{241}Am** (1.25±0.08). **Top/bottom ratios for ^{133}Ba and ^{152}Eu, however, were close to 1** (1.0±0.1 and 0.96±0.09, respectively).*

Comparison of Trinitite to atomsite from Semipalatinsk

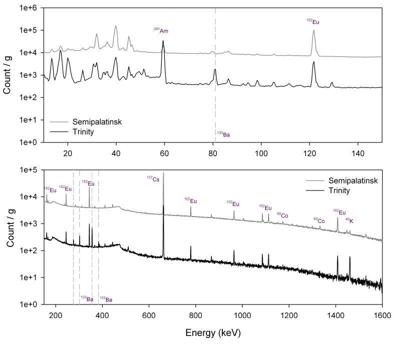
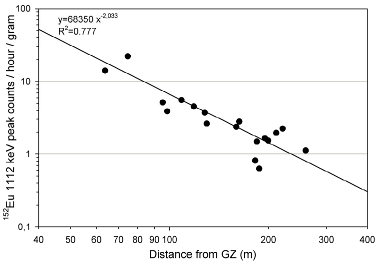


***Fig. 4 (left):** Gamma activity of a 2.545 g specimen of atomsite (Fig. 2) from Semipalatinsk in comparison to a typical 6.5 g specimen of Trinitite. The net peak areas of radionuclides measured in both spectra were corrected by respective masses and decay corrected to the date of explosions (1945 and 1949, respectively). **Atomsite from Semipalatinsk showed significantly higher activity than Trinitite.** The activity ratios of Semipalatinsk/Trinity atomsite were: ^{137}Cs: 16.1±0.1, ^{152}Eu: 23.0±1.5, ^{241}Am (^{241}Pu): 3.4±0.1 and ^{239}Pu: 3.4±0.6. ^{154}Eu and ^{60}Co were under detection limits in this specimen of Trinitite. **^{133}Ba was not detected in atomsite from Semipalatinsk.** This is surprising due to the fact, that Baratol was used in explosive lenses in the first Soviet nuclear test.*

***Fig. 5 (right):** Trinitite collected by the author (WMK) from 18 locations between 60 and 260 meters from GZ exhibited a **power-law dependence between ^{152}Eu and slant range to the nuclear explosion center (top of 30 m high tower) with an exponent close to -2**. The same specimens showed no significant relationship between ^{137}Cs activity and slant range.*

Dependence between ^{152}Eu and distance from GZ



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