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Article: "Contamination Produced by Explosives and Explosive-Residues in Vieques, Puerto Rico"

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About the Author:

Engineer Rafael Cruz-Perez is a native of Vieques. He is an environmental consultant with vast experience in the field. Furthermore, he was an artillery officer in the U.S. Army. Because of his qualifications, he worked in Vieques studying environmental effects caused by artillery practices conducted there. This article presents interesting aspects from his experiences in Vieques.

I. Introduction:

During the early 1940's, the U.S. Armed Forces, and some United States and Puerto Rico National Guard (PRNG) allies, have used different areas in the island of Vieques for military exercises. These exercises have concentrated on the Western sector of the island, where explosives are not used, and in the Eastern area, where shooting ranges are principally located. These activities resulted in three sources of contamination. The first one consists of chemical compounds directly coming from the projectile-charge and other reactive compounds in the projectile itself. The second consists of dust particles that could be blown off to the air as the projectile impacts the ground or explodes right above it. The third one consists of metallic residues left after the fragmentation of the projectile, as well as from the metal scrap used as targets at the shooting range.

In order to evaluate these impacts, the author has made use of various studies conducted at those areas, as well as projections based on other studies conducted in similar areas. For the purpose of this evaluations, the term "contaminant" is untilized as "the presence of one or more materials, of such quantity or nature, that would cause a violation to an already established environmental-contamination criteria."

II. Types of explosives:

Given the variety of the artillery and explosives most commonly utilized in the Vieques area, being familiar with reports by the United States Navy (ref. 1) and also for understanding the complexity in the variety of materials and chemical compounds that exists in the field of artillery nowadays,... it was decided to evaluate only those compounds that were clearly identified as either military explosives or military-projectile residue. The fact that other specific agents or compounds are not discussed here does not mean nor should it be interpreted as the non-existance of such in the

III. Description of the study area:

The island of Vieques is located southeast of Puerto Rico. (See figure 1). It is divided into three sectors: one west, where maintenance/support operations and tactical military operations are held; one east, where active terrestrial (amphibious), naval and aerial exercises take place. The Central part of the island consists of the civilian sector in a north-south strait-like corridor.

This evaluation concentrated on the eastern sector; specifically, the area known as Cerro Matias and its contiguous drainage areas. It also considered the effect that activities in this sector have over the area where the civilian population reside.

The area east of Cerro Matias is utilized as the principal site for shooting and bombardment practices, both naval and aerial. From the military-needs point of view, the site represents ideal topographic and location characteristics for this type of activity.

The area presents a perspective/vision similar to a World War I battlefield where the ground and a large part of the flora have been reduced to dust. Intense erosion can be clearly observed, even in the coastal areas. On the surface, projectiles fragments and parts are noticeable, as well as unexploded ordnance. Scrap metal used as targets can also be observed. At the time of those evaluations, the area did not have the necessary control systems for this type of activity. (ref.2).

III.A. Soil:

The soil at Cerro Matias is consists primarily of decomposed limestone and Descalabrado Clay Loams.

III.B. Climatology:

The climate of Vieques is relatively dry, with annual precipitation between 20 and 40 inches, with a tendency to increase from east to west.(ref. 3,4 & 5). At Cerro Matias the annual precipitation estimate is aprox. 23 inches, placing it among the dryest areas in Puerto Rico. The island's precipitation is chatacterized by intense but short showers, which cause local flooding and catastrophic erosion of exposed soils.

The island's wind data are not acurate. However, it suggest a tendency towards normal winds controlled by trade-wind patterns, from east to west, blowing principally from east-north-east (ENE), with small local variations due to the island's situation, and to the shore-sea microclimate. Given this situation, based on isolated studies/readings and available data of the Roosevelt Roads area, in Ceiba, a wind pattern/rose was developed for this sector (See Fig. 1).(ref. 3, 4 & 5).

IV. Soil and air quality:

Either the natural condition or quality of the atmosphere or quality of the terrain can be altered by different factors. Some of these created by man, others, as a result of natural phenomenons that have been present since world's creation. The mechanisms through which nature or man alter the environment are the same, although of different magnitude. Three out of the most common mechanisms are: erosion by the irrigation of stubble-ground or hydraulic transport of sediment; waste disposal over ground; and the aero-transportation of particles.

IV.A. Erosion by the irrigation of stubble-ground, or sediment hydraulic-transport:

The most significant factor in the transportation of sediments is the presence or absence of vegetation over the ground. (The vegetation) (intercepts part of the solar radiation, decreasing the ground-surface temperature, decreases wind velocity over the surface, reduces the rate of soil-moisture evaporation), protects the soil from rain-drops' erosive energy, retards the speed of water as it flows over the ground, and it improves the soil's water-absorption capacity. These conditions minimize erosion and extreme sedimentation of rivers' basins and other bodies of water.

With this as a preamble, contaminants present in the soil, whether by natural causes or as a result of human activities, can easily and rapidly be transported from one place to another. These contaminants can be transported in water by solution or by suspension, or adhered to soil particles, or simply as part of bed-load's solid mass movement. Of these, the later two are the ones that cause the most damage, due to their tendencies to concentrate in the environment's most sensitive areas.

Cerro Matias shooting range is a clear example of these phenomena. At the time of the evaluation of this area, the vegetation present in the area was less than 40 percent (ref. 6), with a 60 percent of the vegetation of 2-3 meters totally removed. The area presents all the characteristics associated with the accelerated "meteorization" of soils facing this type of phenomenom. The problem is increased by the trituration or pulverization produced by explosives, and by the high temperatures generated by incendiary bombs.

IV.B. Waste disposal over the ground:

Waste disposal over the ground, eventually generates contaminants that when degraded produce solid, liquid and gaseous agents. Metals are oxidated, microorganisms either decompose organic compounds or form highly toxic metallic complexes. As a result of this aerobic or anaerobic degradation organic acids are produced that accelerate soil decomposition, that finally are "meteorized" by the same elements that effect soils.

Under these effects and the presence of water, solutions that contain decomposition products and other wastes are formed. These (lexivation) waters percolate through the terrain contamining the water table or dispersing contaminants over the terrain surface as the water drains downhill.

Due to the presence of vehicles, tanks, trucks, cranes, airplanes, other machines and scrap metal used as targets, Cerro Matias along with its fundamental characteristics, could be considered as a gigantic solid waste dump.

According to information provided by the U.S. Navy, this material is never removed, but instead it's detonated or simply covered with soil, once its use is no longer needed, or needs to be replaced because of its state of deterioration. Under the effects of subsequent explosions, sea breezes, and natural "meteorization," such metals are quickly oxidated, thus, becoming (lexivation) products that continue on to contamine the environment.

IV.C. Particle aero-transportation:

The removal and transportation of particles from the soil and rocks by the wind and water are known as erosion. Erosion can have different intensities from the normal and natural erosion of soil, to catastrophic erosion (i.e., landslides). The quantity of material that can be carried away will depend on various factors, among which are: wind, water, and the initial energy applied.

Aero-transportation of particles is the most common form of atmospheric contamination. The most common form of aero-transportation is known as "fugitive dust." It consists of material suspended in the atmosphere. A person or nature can apply energy over the particles or agitate the atmosphere. Nature produces this material mainly from areas that lack vegetation, or desserts. This type of particles have been observed moving across thousands of miles throughout continents and oceans.

These particles are placed in the atmosphere and then transported through a basic mechanism, with some variations that depends on particular situations. A particle that is over the surface needs an initial application of energy that can start its movement. Once in motion, this force or energy, must continue to accelerate the particle until the friction force of the particle with the soil's surface, and the air resistance, are equal or less to the originally applied force. At this point, the particle reaches a constant speed, known as terminal speed, that enables it to remain suspended in the atmosphere. This movement continues until the particle is affected by either a reduction or elimination of energy, or because it encounters a fixed obstacle or another force that opposes its original movement. The size and weight of the particles that gain access to the atmosphere will depend on the initial energy that is applied when it initiates access into the atmosphere.

Distribution of particles when they loose movement or energy, and its subsequent return to the ground, will follow a pattern directly related to the distribution of weight within the particle and the shape of individual particles, thus, depositing the heavier and larger ones first, and the lighter and smaller ones later and probably farther away.

V. Studies performed on this subject in Vieques:

The following includes an evaluation of some studies performed inside and above the shooting area (impact zone) in Vieques. The author will discuss his opinions on such studies and their particular limitations.

V.A. United States Navy:

The following studies have been performed by the United States Navy, utilizing some of its research components, as well as private consultants.

V. A.1. Environmental Dispersion of the Products of Explosions of Conventional Ordnance at Vieques Island; George A. Young (ref. 7)

It is pointed out that the objective in this study is to provide general guidelines for the evaluation of contaminant's potential produced by multiple-explosions such as: missiles, bombs, rockets, and other types of ordnance. (see page 1 of ref. 7).

When analizing the study, it is found that it does not cover its principal objective, by only analizing the explosion of an individual missile, without taking into consideration multiple explosions which would actually be more representative of military operations. With this as a preamble, it is estimated that the data obtained from this study are conservative and favorable towards gunfire operations, since this study tends to present lower values than the actual ones.

The are two versions on this study. One is the 3 AUG 78, and the other one the 28 AUG 78. Both versions present different and conflicting parameters. Still, the same data and procedures utilized, predict hydrocarbon values at the explosion site exceeding those regular values recorded a mile away from the explosion site. The estimated value of 4.68 ppm, exceeds the three-hour federal criteria (0.24 ppm).

V. A.2. Vieques Litigation Support: Explosives Analyses of Water and Soil Samples Taken on Vieques Island, Puerto Rico. May 11 through May 16, 1978(ref. 8)

This study is directed towards the measurement of explosives' residue in the island of Vieques. The study used TNT, NO3, NO2, RDX and Tetryl as (guiding) parameters. These materials are components from the ordnance explosive-charges utilized in Vieques, and with the exception of NO3 and NO2, they are all synthetic, and impossible to be found in nature.

The U.S. Navy finds in this study that the concentration of these contaminants in tab water sources at both Isabel Segunda and Esperanza are equal of similar to the ones found at ponds and lagoons located at Cerro Matias' shooting-range area. (ref. 6, page 5a, there is no essential difference between water and soil samples taken outside and inside the impact area in explosive content(TNT, RDX and Tetryl)." The study does not explain how these substances reached these water sources located more than 14 kilometers from the shooting area (impact zone).

V. A.3. Explosion Products Content of Water and Soil Samples taken on Vieques Island, Puerto Rico, May 11 through May 16, 1978 (ref. 9)

The objective in this investigation was to study products resulting and remaining from an explosion. For this purpose, amonium, cyanide, nitrate and nitrite were studied. This study mainly suffered from using analytic procedures with less precision than established criteria set as regulatory levels. For instance, in the case of cyanide, where the regulatory level set is 0.01 ppm, the detection (or accuracy) level used during the study was 0.02 ppm.

Based on this, the study's conclusion that "quantities of explosion products found in the samples collected in Vieques Island are well below the maximum permissible concentrations" (page 5), does not support its results presented. Moreover, when the study indicates that the presence of these compounds could be due to the presence of chemical products used in agriculture and not due to the explosions, it is not explained how agricultural chemical products had access in to the shooting range, in such concentrations.

V. A.4. Water Quality Survey, Navy, Puerto Rico,(ref. 10)

This study could not be evaluated in its entirety due to the fact that the only pages available were USN-P1, USPN2, a water quality table, and a map depicting the locations from where the samples were obtained.

According to the results of this study, all, except one of the sampling stations, exceeded the limits for sulfate, two exceeded the limits set for iron, and three exceeded the limits for phenols.

Nitrate, nitrite and amonium results could not be evaluated, because the methodology used to evaluate such results was unknown. However, these results contrast with the ones obtained in the study "Explosion Products Content of Water and Soil Samples taken on Vieques Island, Puerto Rico, May 11 through 16, 1978(ref. 7)," which got results that are two orders in magnitude higher than the ones found in this study.

V.B. Puerto Rico Department of Natural Resources:

The following was a study done by the Puerto Rico Department of Natural Resources using some research components of its own, as well as private consultants.

V. B.1. Geochemical Reconnaisance of Vieques by R.E. Learned, G.R. Grove and R. Boissen, 1972-73(ref. 3)

This compendium tabulates geochemical characteristics of soils in Vieques, in particular, resources of metallic minerals in the soil. Even though the study is limited to samples from horizon C, which is the most highly enriched sector due to the (lexivation) of surface metals, such study serves as the basis that notes differences in the soils within a sector.(ref. 2).

V.C. Environmental Quality Board of Puerto Rico

The following studies were done by the Environmental Quality Board, with the cooperation of the Puerto Rico Department of Natural Resources, utilizing some research components, as well as private laboratory facilities and consultants.

V. C.1. Water Quality, 1972(ref. 3)

This inventory is limited to a tabulation of those civilian activities in Vieques that could cause contamination to bodies of water, and the kind of contamination that could be associated with these activities.

V. C.2. Air Quality, 1972(ref. 3)

This inventory is limited to those civilian activites in Vieques that could cause atmospheric contamination, and the kind of contamination that could be associated with these activities.

As part of this inventory, some background samples were taken at Isabel Segunda and Esperanza, which although limited, could be utilized as part of the evaluation. The results of these samples were as follows: Nitrogen Oxide, 0-35.8 micrograms per cubic meter; photochemical oxidants (ozone), 0-29 micrograms per cubic meter; hydrocarbons (aldehydes), 2.74-40.0 micrograms per cubic meter; particulates, 13.9-98.98 micrograms per cubic meter. Sulfur dioxide was not detected in the area.

V. C.3 Soil Samples, 1978

Soil samples were taken at nine stations for a total of twelve samples. The sampling started on 16 May 78 at the stations identified in figure 4. Surface samples were taken and were analyzed for metals at the Department of Natural Resources laboratories, and at the OMNI laboratories in San German (P.R.).

Samples were analyzed for total metals and for (lexivation) products. From the results obtained, there are clearly demonstrated anomalous values for iron, at the shooting areas.

V. C.4. Water samples, 1978

Water samples were taken at 13 locations, including lagoons and coastal waters. The sampling started 16 May 78. Samples were analyzed for metals and other typical contaminants at the Department of Natural Resources and Environmental Quality Board laboratories.

V. C.5. Air Samples, 1978(ref. 11)

Air samples were taken at two locations. The sampling started 16 May 78 and continued through July 1978. It was performed using a high-volume collector system, for 24-hour periods per sample, taking a total of eleven valid samples. Samples were analyzed for particulate matter, including a gravimetric analysis (used to learn specific weights), at the Environmental Quality Board laboratories.

Results obtained in this sampling corroborate values that were obtained in the 1972 study, (ref. 3), showing values between 89 and 90 micrograms per cubic meter of particulate.

VI. Conclusions:

It is clear from the above information, that components resulting from the explosions in the shooting range east of Vieques, are transported to the civilian area in the center of the island by diverse mechanisms.

However, prediction-studies performed did not indicate that this was the case; in the contrary, they indicated that such components could not have been present in these areas. But contrary to this theory, they are indeed found in these areas.

As author, it is my view that the error is not present in the methods utilized, but in the criteria and concepts utilized as a basis the calculations.

In order to evaluate the effect that explosions have in the shooting range, it is necessary to establish basic concepts so when utilized, they can establish a model criteria. Utilizing any model without recognizing or applying a realistic foundation/base will only throw false results. "Garbage in, garbage out."

V.I. A. Dispersion of aero-transported contaminants

The facility with which contaminants are transported in the atmosphere, will depend on diverse factors relative to wind, soil, energy of movement, and the particles themselves.

In the case of explosions of artillery parts, rockets, or bombs, there are existing factors that directly or indirectly increase the facility of movement of these contaminants. These factors are, among others, (1) contaminants directly resulting from the chemical agents in the projectiles, (2) the elimination of vegetation at the impact site, (3) the pulverization of soil and rocks, and (4), particles forced into the air as a result of the energy generated by the explosions.

V.I. B. Artillery-fire characteristics:

An explosion near, or at ground level, raises dust and particles in the form of a cloud. In the case of a projectile that explodes at ground level, it forms a crater, and disperses particles and ordnance parts throughout the area. Large soil fragments fall back to the ground immediately, but the fine particles become components of the atmosphere, and are aero-transported through long distances.

A 105-HE artillery piece can displace up to 400 kilograms of soil in the atmosphere, 80 percent of which, falls back into the immediate explosion area. The remaining 20 percent will follow the normal distribution of aero-transported particles. The behavior of this cloud will be similar to that of a chimney exhaust, of 80 kilograms of particulate per event. Ninety-four percent out of these 80 kilograms will be deposited within 100 meters from the center of the explosion. The rest of the explosion's particulate will have a concentration of 1,500,000 miligrams of particulate per cubic meter, with an approximate volume of 3,375 cubic meters.

A 105-mm Howitzer can fire at a rate of six shells per minute, and a typical round fired by combat units consists of 18 shells. This is equivalent to a chimney emission of 7.7 kilograms of particulate material per minute.

VI. C. Calculations of particle aerotransportation

Based on this data and using the dispersion equation presented in V. A., particle iso-concentration curves can be developed, as well as their exposure time.

Distance from the explosion center (meters)	Concentration (micrograms/cubic meter)	Exposure Time (minutes)
15	1,500,000	
1,565	1,407	6.2
3,155	743	7.3
4,722	268	9.4
6,322	173	10.5
9,450	94	12.3
18,900	33	15.9

As indicated earlier, these values only reflect the impact of an explosion, which will produce a concentration of 33 micrograms per cubic meter in 15.9 minutes, at a distance of 18.9 kilometers from the center of the explosion. If this value is seen in the light of a typical shot (using the concept that the resulting particle concentration is directly proportional to to the concentration produced by each projectile, time of exposure and the number of projectiles fired, and inversely proportional to the regulated concentration period), we will find that a concentration of 98.38 micrograms of particulate material per cubic meter would be found in the civilian area of Vieques. If we add to this the background values of 99 micrograms per cubic meter, we will find that the effective concentration of particulate over the Vieques civilian area, would exceed 197 micrograms per cubic meter, thus, exceeding Clean Air Act federal criteria.

VII. References:

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6. Vegetation on Vieques' Impact Area, Internal memorandum-book, B. Cintron & K. R. Dugger, 1978, Environmental Quality Board.

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