



# The Distribution of Cs-137 at Three Locations in Puerto Rico

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Puerto Rico has been the site of several experiments in which anthropogenic radionuclides were introduced to what many might consider to be a fairly pristine environment. Two of these experiments, which began in the 1960's, involved the use of gamma sources in tropical ecosystem studies and the testing of a prototype nuclear power plant. The most recent experiment, involving the use of depleted uranium military munitions, was conducted during the 1990's. After the release of this anthropogenic material little research has been conducted to evaluate the environmental health of these experimental sites that served as living laboratories.

Radiogeochemistry results described during the presentation are part of an ongoing study to investigate radionuclide distribution and behavior near the decommissioned BONUS reactor, in the Caribbean National Forest and on the island of Vieques. Cs-137 activities in sediments collected from these three study sites range from below detection limits to 0.0084 Bq/g (determined at BONUS, Rincon). Results from particle size analysis indicate the presence of a wide range of grain sizes. Clay and silt size particles were found in greatest abundance at BONUS, Rincon and Mosquito Bay, Vieques, respectively. Porosity and lost on ignition (proxy for organic content) data are also discussed in this presentation.

### Introduction

The Commonwealth of Puerto Rico, located in the Caribbean's Major Antilles, is comprised of several islands: a larger island (referred to as the main island) and several smaller islands, of which only two (Vieques and Culebra) are inhabited. With a growing population of over four million people and major development projects (both residential and industrial), Puerto Rico's natural resources have been impacted by stress (e.g. viable drinking water limitations, increased erosion and sedimentation, decreased water quality, etc.), destruction (e.g. deforestation and habitat destruction); and anthropogenic contamination of the island's natural resources (Hunter and Arbona 1995).

Most rivers and reservoirs in Puerto Rico have been adversely impacted by man (Hunter & Arbona, 1995). Soil and groundwater near petrochemical facilities have been contaminated by accidental releases of petroleum, petroleum-related products and other chemicals, including benzene, toluene, ethyl benzene, and xylene (US EPA, 2001). Heavy metals, trace elements and carcinogens have also negatively impacted Puerto Rico's natural resources (Nazario, et al 2002, Massol-Deya, 2002).

In addition to the local introduction of these contaminants, Puerto Rico's natural resources have also been exposed to anthropogenic radionuclides as a result of various US Department of Energy (US DOE) and Department of Defense (US DOD) sponsored activities (US EPA, 2001, US Dept. Energy, 2003, PRNC 1970). Upon introduction into the environment, these radionuclides can be transported away from their original site via local transport processes, further impacting the island's natural resources.



Fig 1a. Map of Puerto Rico



Fig 1b. Map of the municipality of Vieques

### Boiling Nuclear Superheated Reactor

During the early 1960's the US Atomic Energy Commission (US AEC) and the Puerto Rico Water Resource Authority (PRWRA) constructed the Boiling Nuclear Superheated (BONUS) reactor facility in order to investigate the technical and economic feasibility of the integral boiling-superheated concept. The BONUS reactor experienced numerous problems, including 106 unintentional reactor shutdowns, one of which resulted in the released of 582.3MBq into the atmosphere (US Dept Energy, 2003). The BONUS reactor facility was operational for a total of six years (1962-1968) before being decommissioned; a process which was completed in 1970.

### Atlantic Fleet Weapons Training Facility

For more than 60 years the eastern portion of the island of Vieques served as a weapons testing site for the US Department of Defense. During the 1990's US Navy targeting exercises at the Atlantic Fleet Weapons Training Facility (AFWTF) involved the use of armor-piercing munitions containing depleted uranium (Lindsay-Poland, 2001, Yarrow, M. 2000). A major concern regarding the local introduction of radionuclides is the potential health risks and environmental impact (Bem and Bou-Rabeea 2003, Bleise, et al. 2003, Clark 2002, US Navy, 2002). The isotopic composition of depleted uranium typically used by the US Department of Defense is U-234 = 0.0006%, U-235= 0.2%, U-236 = 0.0003% and U-238 = 99.8%. Typical trace isotopes identified as being present in depleted uranium munitions and armor include Pu-238, Pu-239, Pu-240, Am-241, Np-237 and Tc-99 (WHO, 2001, CHPPM, 2000).

### Caribbean National Forest

In the late 1960's the US DOE-sponsored Puerto Rico Nuclear Center conducted experiments at the El Verde Experimental Station of the El Yunque Caribbean National Forest that involved inoculating and irradiating several trees with radionuclides (PRNC Report, 1970). In 1968 a series of radioactive Cs inoculation experiments were conducted on several trees located within the study site in order to investigate the defoliation rates of various tree species (PRNC Report 1970). Results indicated that approximately 50 % of total amount of Cs-137 (17.02 MBq) that was injected into the trees was eliminated. It was also determined that the Cs-137 retained by the trees resulted in increased radiation levels of 200 mR/hr, in an area where the average background level was 5 mR/hr (USNRC, 2001). During a set of experiments in tree trunks 777 MBq tritium was injected at a 45° angle, 25 cm above ground in order to examine transpiration rates (PRNC Report, 1970).



Fig. 2A. USS Iowa Bombarding the island of Vieques, 2B Aerial view of the Targeting Facility, 2C Military debris left at island of Vieques

### Study Area and Sample Collection

Sediment cores from the island of Puerto Rico area aquatic system were obtained using a core liner.

Sampling took place at:

- Caribbean National Forest, "El Verde" Experimental Station 18°19.351' N, 65°48.913' W
- Bonus Reactor, Rincon 18°21.969' N, 67°16.095' W
- Vieques 18°06.187' N, 65°27.074'W

Sediment cores were extruded, sectioned and transferred into "whirl pac" bags, weighed, frozen and freeze-dried.

Sediment samples were prepared for radionuclide analyses.



Fig. 3A. BONUS Facility, Rincon, PR; 3B Target Facility, Vieques, PR; 3C Inoculation Area, El Verde, Caribbean National Forest, Rio Grande, PR, 3D. Red Beach, Vieques, PR; 3E Cocoa Beach, Rio Grande, PR

### Gamma Analysis

Samples were assayed for gamma emitters using a Canberra Genie multichannel analyzer planar gamma detector.

Calibration was performed using US National Institute of Standards and Technology 4357 line and Ocean Sediment multi-line standards and the Canberra Multichannel MGS-5.

Activities of the gamma emitters were determined via radionuclide-specific energy peaks located at 661 keV (Cs-137)

### Grain Size Analysis

Analysis of sediment particle size was performed using the Saturn Digsizer 5200. To estimate the population size one gram of the freeze dried sample was sieved using a #230 mesh (62 µm) screen sieve. After sieving the sample, larger particles were retained. The grain size distribution of the smaller particles was determined using standard methods for the Saturn Digsizer and Saturn Software 5200. Particle size classes were defined as follows: clay size < 4 µm; 4 µm < silt < 63 µm; sand and larger > 63 µm.

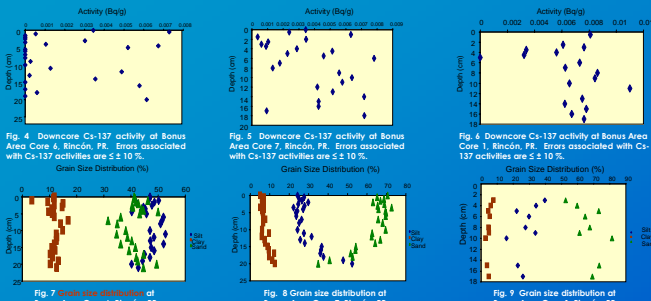


Fig. 4 Downcore Cs-137 activity of Bonus Area Core 8, Rincon, PR. Errors associated with Cs-137 activities are ± 10%. Fig. 5 Downcore Cs-137 activity of Bonus Area Core 7, Rincon, PR. Errors associated with Cs-137 activities are ± 10%. Fig. 6 Downcore Cs-137 activity of Bonus Area Core 1, Rincon, PR. Errors associated with Cs-137 activities are ± 10%. Fig. 7 Downcore Cs-137 activity of Bonus Area Core 4, Rincon, PR. Errors associated with Cs-137 activities are ± 10%. Fig. 8 Grain size distribution at Bonus Area Core 7, Rincon, PR. Fig. 9 Grain size distribution at Bonus Area Core 1, Rincon, PR.

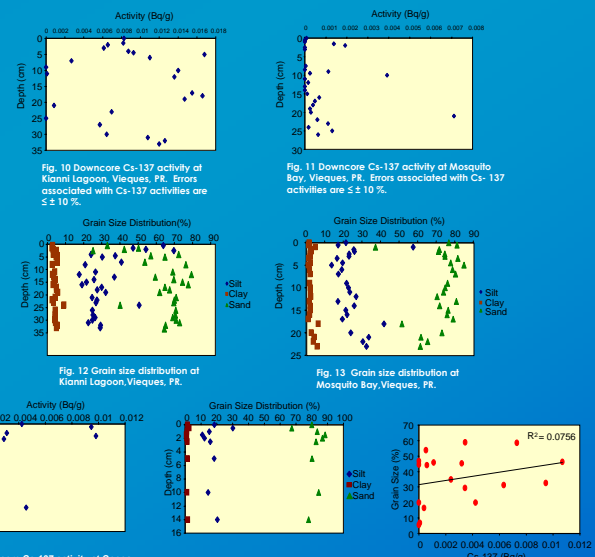


Fig. 10 Downcore Cs-137 activity of Kianil Lagoon, Vieques, PR. Errors associated with Cs-137 activities are ± 10%. Fig. 11 Downcore Cs-137 activity of Mosquito Bay, Vieques, PR. Errors associated with Cs-137 activities are ± 10%. Fig. 12 Grain size distribution of Kianil Lagoon, Vieques, PR. Fig. 13 Grain size distribution of Mosquito Bay, Vieques, PR. Fig. 14 Downcore Cs-137 activity at Cocoa Beach, Rio Grande, PR. Errors associated with Cs-137 activities are ± 10%. Fig. 15 Grain size distribution of Cocoa Beach, Rio Grande, PR. Fig. 16 Correlation between finer grain size and Cs-137 retention in the island of Puerto Rico. R<sup>2</sup> = 0.0756.

### Preliminary conclusions:

- Sediment and soil samples indicate the presence of Cs-137 at each study site, finding the highest concentration at the BONUS Facility in Rincon, PR.
- Grain size analysis indicates that clay size particle concentrations exceed 10 % at the Bonus Area, Rincon.
- There is no strong correlation between particle size and Cs-137 retention at each site.
- Further examination is needed to determine dominant factor(s) influencing the sediment retention capacity and stability at each location within Puerto Rico's ecosystem.

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