

Information Document

Prepared on behalf of the Department of Energy in response to article by Robert N. Celestial (Atomic Veteran, SGT, Retired US Army) entitled;

RADIATION FALLOUT – GUAM

Terry Hamilton
Lawrence Livermore National Laboratory

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This document attempts to address the environmental radiation issues raised in the Celestial report as well as give some background and a brief overview of atmospheric nuclear weapons testing with some specific references to the local impacts on the Federated States of Micronesia and the Mariana Islands (including Guam).

Table of Contents

Definitions.....	3
Executive Summary	6
Background Information	7
Basic Concepts in Radioecology.....	7
Atmospheric Nuclear Weapons Denotations	8
Radioactive Fallout On Guam.....	16
Discussion Points related to the Celestial Report	19
Under supplementary pages on 'Guam-exposure to Radiation- ⁹⁰ Sr.....	21
References	22
Appendix 1. Worldwide Deposition of ⁹⁰ Sr through 1982, R.L. Larson, 1984	23

Attachments:

Radiological survey of plants, animals, and soil in Micronesia, V. A. Nelson (1979),
University of Washington, NVO-269-35, 31 pp.

List of Tables

Table 1. Radionuclides produced in nuclear weapons tests.....	10
Table 2. Atmospheric nuclear weapons tests.....	11
Table 3. Annual and cumulative ⁹⁰ Sr deposit in worldwide fallout.	15

List of Figures

Figure 1. Sources of radiation exposure to the US population.	7
Figure 2. Atmospheric Nuclear Weapons Tests.	9
Figure 3. Hemispherical air circulation patterns and associated latitudal ⁹⁰ Sr deposition densities on earth	13
Figure 4. Integrated deposition density of ⁹⁰ Sr versus latitude band	16
Figure 5. Map of the Federated States of Micronesia and the Mariana Islands.....	18

DEFINITIONS

Unit	Explanation
Radiation	The emission and propagation of waves or particles all of which carry energy
Radionuclides	Isotopes of elements that give rise to spontaneous nuclear transformations
Activity, A	Used to characterize a source of radiation, and is defined by the average number of nuclear spontaneous transformations per unit time of an isotope. The standard SI unit is the reciprocal second (s^{-1}) and is given the name of Becquerel (Bq). One Bq corresponds to one disintegration per second. The conventional unit of activity used in the US is the Curie (Ci). One picoCi (1×10^{-12} Ci) corresponds to 2.2 decays per minute
Isotope	Forms of a specific element that have the same number of protons but different numbers of neutrons in their nuclei
Mass Number	Sum of the number of protons and neutrons in the nucleus of an atom
Fission Products	Isotopes with atomic masses between 70 and 170 formed by thermal fission of uranium-235 (^{235}U) and other heavy fissile nuclei such as plutonium-239 (^{239}Pu)
Half-life, $T_{1/2}$	Radioactive isotopes have a unique property called a half-life defined by the time needed for half of a statistically large number of radioactive atoms in a sample to decay. Radionuclides may have half-lives of milliseconds to millions of years
Explosive yield	Measure of the explosive energy of a nuclear denotation, and is usually expressed in kilotonnes (kT) or megatonnes (MT) of TNT equivalent

Alpha-particle decay

Alpha particles are heavy, slow moving, charged particles that consist of two protons and two neutrons (identical to the nucleus of an helium ion). Alpha particles travel only one or two inches in air, and can be stopped by a piece of paper or the dead outside layers of our skin. Possible health effects from alpha-ray exposure come from internal exposure (i.e., alpha emitting radionuclides that enter the body from ingestion, inhalation and/or through open wounds). An example of an important alpha-emitting radionuclide is plutonium

Beta-particle decay

Beta decay is a process leading to the emission of electrons or positrons with a change in the number of protons in the parent radioactive nucleus of an atom. Beta particles penetrate a few tens of centimeters in air. An example of a beta-emitting radionuclide is Strontium-90 (^{90}Sr)

Gamma radiation

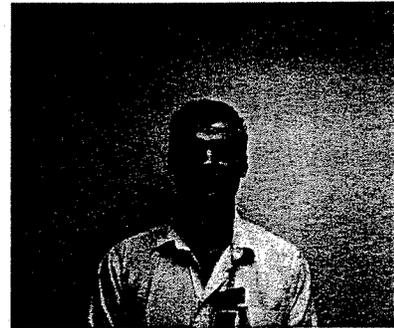
Gamma rays are electromagnetic waves similar to ordinary visible light but have a much higher energy (i.e., short wavelengths of 10^{-13} to 10^{-10} m). Gamma rays are produced following spontaneous decay of radioactive materials and are commonly associated with the emission of alpha or beta particles. Cesium-137 (^{137}Cs) is an important gamma-emitting radionuclide that occurs in world-wide fallout from nuclear weapons tests. Cobalt-60 (^{60}Co) is also a gamma-emitter and can penetrate deeply into the human body, so it has been widely used for cancer radiotherapy. The high-energy gamma rays of ^{137}Cs may also penetrate deeply into the body and affect cells. Gamma radiation is important in evaluating both external and internal sources of radiation exposure.

Adsorbed dose, D

The adsorbed dose in an organ or tissue is the radiation energy absorbed per unit mass of the organ or tissue. The standard SI unit is joule per kilogram and is termed the gray (Gy). The conventional unit used in the United States is the rad. $1 \text{ Gy} = 100 \text{ rad}$.

Dose equivalent	The absorbed dose multiplied by weighing factors that express the relative effectiveness of different types of radiation to cause biological damage, i.e., the concept is that equal dose-equivalents generate equivalent amounts of biological damage. The standard SI unit for dose equivalent is also joule per kilogram, and is termed the Sievert (Sv). The conventional unit used in the United States is the rem. 1 Sv = 100 rem.
Effective dose equivalent	The effective dose is the sum of the weighted dose equivalents of different tissues and organs of the body, i.e., measure of the total detriment to the whole body. The standard SI unit is the Sievert (Sv) but is often expressed in milliSievert (mSv). The traditional unit used in the United States is the millirem (mrem). 1 mSv = 100 mrem.
Stratosphere	The region corresponding to the maximum density of ozone in the atmosphere, located between altitudes of 10-60 km
Troposphere	The alter of atmosphere below the stratosphere, in which temperature degree with altitude

Terry Hamilton has a Ph.D. in environmental radioactivity from the University of Melbourne (Australia), and has a long standing interest in radiological assessments and innovative measurement techniques. He is currently the Leader of the Marshall Islands Dose Assessment and Radioecology Program at the Lawrence Livermore National Laboratory (LLNL). From 1987 through 1995, he served in the United Nations as a Group Leader within the Radiometrics Section of the International Atomic Energy Agency's (IAEA) Monaco Laboratory. During this time he was involved in a number of international research programs designed to study the fate, distribution and impacts of radionuclides on the environment. He has coordinated a number of IAEA technical cooperation projects in the Asia and Pacific region, and conducted expert services missions to Australia, Bangladesh, China, India, Indonesian, Malaysia, Singapore, Sri Lanka, Pakistan, and Vietnam. In 1992, he served as the UN observer and adviser to the first Norwegian-Russian scientific expedition to the Arctic to investigate the radiological consequences of dumping of nuclear waste in the Kara Sea. He has also served as an IAEA expert on a study of radiological conditions at former nuclear tests sites in the South Pacific Ocean. Present interests include the development of new measurement techniques to assess low-level human exposure (past or present) to plutonium using urinalysis.



Executive Summary—*This report attempts to provide some background information on the pattern and density of nuclear fallout from nuclear weapons testing—especially in relation to the Marshall Islands and the north equatorial Pacific Ocean. The Environmental Measurements Laboratory (EML) in New York has maintained a worldwide network of sampling stations since 1958 to collect and measure the range and extent of nuclear fallout around the globe. Based on this information, the pattern and worldwide fallout deposition densities for long-lived radionuclides are reasonably well known from the measured geographical deposition densities of ⁹⁰Sr. Guam received radioactive fallout during the atmospheric nuclear testing era but based on our expert knowledge and some limited environmental data, there appears to be no evidence to suggest that Guam was more heavily impacted by radioactive fallout than what would have been expected from world-wide fallout deposition. There are, however, some uncertainties concerning the transport dynamics and possible doses to the local population from short-lived radionuclides (e.g., ¹³¹I) at the time of the test program. Because of probable rainout events (rainfall that washes radionuclides out of the atmosphere), other variable localized climatic conditions and the vast distance between Guam and test sites in the Marshall Islands, it would be difficult to provide an accurate retrospective assessment of doses to the Guam population exposed to fresh fallout. However, it is expected that these local doses would be less than the normal annual background radiation levels, and pose little or no health consequence to those exposed.*

Performing a simple comparative analysis with dose assessments performed in the Marshall Islands, the transfer co-efficient for the population average effective dose is around 0.0025 mrem y⁻¹ per Bq m⁻² (or 2.4 x 10⁻⁵ mSv y⁻¹ per Bq m⁻²). The estimated decay corrected present day ¹³⁷Cs deposition density on Guam is estimated to be around 700 Bq m⁻²—this equates to an annual effective dose of only 1.7 mrem (or 0.017 mSv). The dietary habits of people living on Guam are probably such that they depend much more heavily on imported foods so this is a very conservative estimate. The average annual dose from natural sources of radiation in the Marshall Islands is around 140 mrem (1.4 mSv)—and as a first approximation is probably similar on Guam. Most people around the globe receive annual doses in the order of 100-2000 mrem (1-20 mSv) but it is not unusual to find population groups living in areas with background doses in excess of 10,000 mrem y⁻¹. The estimated annual effective dose on Guam from exposure to nuclear weapons fallout is only 1.7 mrem. This is only a very small fraction of the dose that Guam residents unavoidably receive from natural sources of radiation, and is much, much less than what some other isolated populations groups receive in other parts of the world. Moreover, the risk coefficient as determined by the International Commission on Radiological Protection (ICRP) for fatal cancers in members of the public is 5 x 10⁻⁴/rem. An annual dose of 1.7 mrem provides an annual risk factor of 8 x 10⁻⁷ or a lifetime risk of 6 x 10⁻⁵ (0.005%). This is very small compared with the underlying lifetime risk of death from cancer of around 20%.

There is a large degree of uncertainty in these dose estimates of current radiological conditions on Guam. Nonetheless, the intent was to demonstrate that the risks from exposure to residual fallout on Guam are likely to be extremely small, and below the threshold where health impacts could be medically diagnosable in any individual or epidemiologically discernible in any group.

BACKGROUND INFORMATION

Basic Concepts in Radioecology

Atoms consist of a positively charged nucleus surrounded by a cloud of negatively charged electrons. The cloud of electrons enables atoms to bind together to form molecules – the basic building block of all things. Radiation emitted by radioactive materials is derived from within the charged nucleus of atoms where unstable nuclei undergo changes involving strong nuclear forces. Ionizing radiation falls into two main groups (1) particle emissions such as high-energy electrons, neutrons, and protons, and (2) electromagnetic radiations or photons such as X-rays and gamma rays. When radiation transverse through cells, it leaves a trail of ions and uncharged molecular fragments, called free radicals, which can damage the molecular bonds between the atoms, and disrupt cellular mechanisms. At lower level exposures, such as those typically encountered by the general public exposed to background sources of radiation, the body is able to replace the dead cells without degradation of normal bodily functions.

An assessment on the average exposure of the US population to ionizing radiation was recently made by the National Council on Radiation Protection and Measurements (NCRP 1987) (Figure 1). The average annual effective dose equivalent for people in the United States is around 360 mrem. The effective dose equivalent relates the effects of exposure to risk. About 300 mrem y^{-1} of ionizing radiation (or 82% of the total) can be attributed to natural sources of radiation, and the other 18% to man-made sources including exposures to medical X-rays and nuclear medicines.

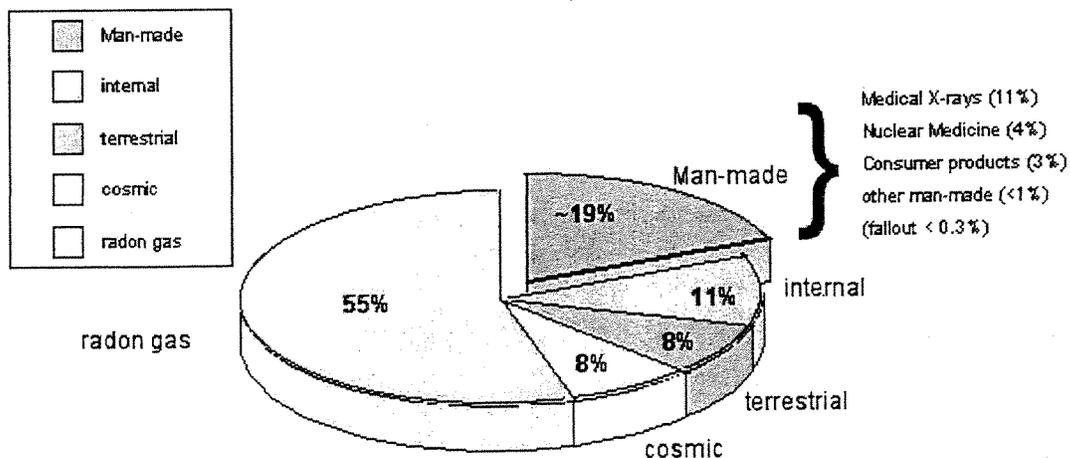


Figure 1. Sources of radiation exposure to the US population.

About half of the total exposure to ionizing radiation is derived from radon gas and its decay products in the air that that people breathe. The other contributions are approximately equally divided between cosmic radiation, terrestrial radiation (exposure to naturally occurring radionuclides in rocks and soil), and internally deposited radionuclides such as potassium-40 (^{40}K), carbon-14 (^{14}C), uranium-238 (^{238}U), thorium-232 (^{232}Th), and radium-226 (^{226}Ra). The abundance of ^{40}K in the environment makes it a major source of both the external (terrestrial) and internal dose from naturally occurring radiation. The term 'cosmic radiation' refers both to the primary high-energy particles of extraterrestrial origin that strike the earth's atmosphere, and to the secondary particles generated by their interaction with the atmosphere. Smokers are additionally exposed to the naturally occurring polonium-210 (^{210}Po) in tobacco that may cause an increased risk of lung cancer. *Uncertainties exist in these data but it is important to point out that people around the globe are constantly being exposed to different sources and types of radiation, and that natural radiation is potentially just as harmful as man-made radiation.*

The annual natural background dose for people living in the Marshall Islands is around 140 mSv. Cosmic radiation accounts for nearly 16% of the dose (or 22 mrem y^{-1}). Exposures to radon gas and terrestrial radiation are very low because of the unique nature and low mineral content of carbonate soils. A very significant proportion (about 70%) of the natural background dose (~ 100 mrem y^{-1}) can be attributed to the consumption of fresh fish which contain naturally occurring Polonium-210 (^{210}Po) and Lead-210 (^{210}Pb). *The estimated annual background dose of around 140 mrem (1.4 mSv) in the Marshall Islands can be used to put doses from other sources in perspective.*

Atmospheric Nuclear Weapons Denotations

A nuclear explosion is simply the very rapid release of energy due to nuclear fission or fusion in a small volume. The first nuclear explosion took place in the early hours of July 16, 1945 in the New Mexico desert near the town of Alamogordo. This first nuclear explosion (code named Trinity) utilized the fission of ^{239}Pu , and achieved an explosive yield of 19 kilotons of TNT. Similarly, the nuclear weapons dropped on the city of Hiroshima and Nagasaki along with first nuclear tests conducted at Bikini Atoll in the Marshall Islands were all based on the nuclear principles of an uncontrolled fission reaction. A fission reaction requires a supercritical mass of a fissionable nuclide (e.g., ^{239}Pu , ^{235}U) and an initial source of neutrons. The nucleus of the fissionable nuclide is bombarded with a neutron, and typically splits into two lighter nuclei (*what we commonly call fission products*) along with the release of energy, and 2-3 other neutrons that can fission other ^{235}U nuclei in a chain reaction that releases enormous amounts of energy.

The basic fission reaction for ^{235}U is shown below:



Nuclear fission is one of the main production modes for radionuclides distributed in worldwide fallout. Fission products have characteristic yields (i.e., produced in

characteristic quantities) based on the nucleus undergoing fission and the energy of the impinging neutrons. An average of around two fission products are produced per fission with each individual fission product varying according to its mass number. The highest yields from fission of ^{235}U occur with mass numbers in two distinct nodes with maxima between mass numbers of 85 to 104, and between mass numbers of 130 to 149 (shown in Figure 2). Other fissionable nuclei such as ^{239}Pu show similar bimodal curves. *The production yields for strontium-90 (^{90}Sr) and cesium-137 (^{137}Cs) are high. Consequently, these two fission products are often used to assess the range and extent of worldwide fallout deposition.* There are a total of more than 200 different fission products generated in a nuclear explosion with half-lives ranging from fractions of a second to 17 million years.

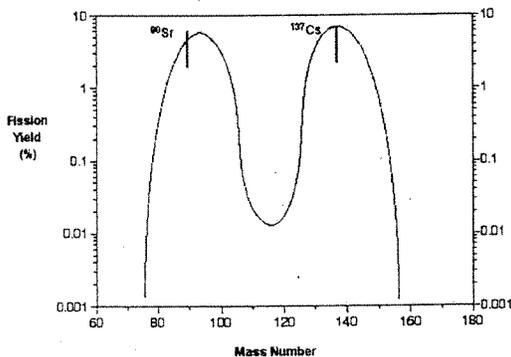


Figure 2. Fission Yield curve for ^{235}U .

The extremely high temperatures produced in nuclear explosions can also bring about fusion of certain light element nuclei with the concomitant release of additional energy. Nuclear fusion is the basis for so-called hydrogen bombs or thermonuclear explosions where the high temperatures of the fission explosion trigger are used to fuse various hydrogen isotopes with release of vast amounts of energy and neutrons, and production of tritium (^3H). In turn, the high-energy neutrons produced in thermonuclear explosions can be used to split the atoms of a second fission stage often composed of a uranium-238 (^{238}U) blanket. *In general, these types of nuclear weapons with multiple stages increase the explosive power or yield of the detonations.*

The yield of individual nuclear tests controls the altitude to which the nuclear cloud rises and, as a result, the residence time (time delay) before any debris impacts on man. A nuclear detonation implies that at least some residual radioactive material will always be released to the environment. Furthermore, nuclear detonations do not proceed to ultimate completion, so some residual nuclear fuel (e.g., ^{235}U , ^{238}U , ^{239}Pu , ^3H , other) remains after the detonation, and can be dispersed in either the local environment and/or contribute to world-wide fallout deposition.

Of the more than 200 fission products generated in nuclear explosions, only a few have environmental behaviors and are sufficiently long-lived to be of environmental or

ecological concern. A list of key radionuclides produced in atmospheric nuclear weapons tests along with basic data of radioactive half-life, mode of decay and mode of production are shown in Table 1.

Table 1. Radionuclides produced in nuclear weapons tests.

Radionuclide	Half-life	Mode of decay	Mode of production
³ H	12.3 a	Beta	Fuel residue & fuel product
¹⁴ C	5730 a	Beta	Activation product
⁵⁴ Mn	312.5 d	Electron capture (EC), gamma	Activation product
⁵⁵ Fe	2.74 a	Electron capture (EC)	Activation product
⁶⁰ Co	5.3 a	Beta	Activation product
⁸⁹ Sr	50.55 a	Beta	Fission
⁹⁰ Sr	28.6 a	Beta	Fission
⁹¹ Y	58.51 d	Beta	Fission
⁸⁵ Zr	10.8 a	Beta	Fission
⁹⁵ Zr	64.03 d	Beta, gamma	Fission
¹⁰³ Ru	39.25 d	Beta, gamma	Fission
¹⁰⁶ Ru	371.6 d	Beta, gamma	Fission
¹²⁵ Sb	2.73 a	Beta, gamma	Fission
¹³¹ I	8.02 d	Beta, gamma	Ingrowth from fission
¹³⁷ Cs	30.14 a	Beta, gamma	Fission
¹⁴⁰ Ba	12.75 d	Beta, gamma	Fission
¹⁴¹ Ce	32.5 d	Beta, gamma	Fission
¹⁴⁴ Ce	284.9 d	Beta, gamma	Fission
¹⁵² Eu	13.5 a	Electron capture	Activation product
¹⁵⁴ Eu	8.6 a	Beta	Fission, activation product
¹⁵⁵ Eu	4.8 a	Beta	Fission
²³⁹ Pu	24100 a	Alpha, gamma	Fuel residue and fuel product
²⁴⁰ Pu	6560 a	Alpha, gamma	Fuel residue and fuel product
²⁴¹ Pu	14.4 a	Beta	Fuel residue and fuel product

a = years, d = days

A total of 423 atmospheric nuclear weapons tests were conducted between 1945 and 1980 with an estimated fission yield of 217 megaton (Table 2). There were two main periods when most of the radioactive debris produced by nuclear explosions was injected into the atmosphere—namely 1952-58 and 1961-62. The total fission yields during these two periods were almost equally divided with about 42% of the total occurring in the former period and 47% in the latter. The United States (US), the Former Soviet Union (FSU) and the United Kingdom (UK) agreed to a partial test ban treaty in 1963. France (1966-74) and China (1964-80) continued to test nuclear weapons in the atmosphere but these <<late phase>> tests only account for 11% of the total fission yield. Over 90% of the fission yield was due to weapons explosions in the Northern Hemisphere – the main

test sites were the Marshall Islands (USA), Christmas Island, and Johnson Island (USA) in the Pacific Ocean, Amchitka (Alaska, USA), the Nevada Test Site (USA), Semipalatinsk (FSU) and the Novaya Zemlya archipelago (FSU).

Table 2. Atmospheric nuclear weapons tests.

Year	County	Number of tests	Fission yield (~MT)
1945	USA	3	0.05
1946	USA	2	0.04
1948	USA	3	0.1
1949	USSR	1	0.02
1951	USA/USSR	17	0.54
1952	UK/USA	11	6.62
1953	UK/USA	13	0.29
1954	USA/USSR	7	30.1
1955	USA/USSR	17	1.67
1956	UK/USA/USSR	27	12.3
1957	UK/USA/USSR	45	10.89
1958	UK/USA/USSR	83	28.94
1960	France	3	0.11
1961	France/USSR	51	25.42
1962	USA/USSR	77	76.55
1964	China	1	0.02
1965	China	1	0.04
1966	France/China	8	1.3
1967	France/China	5	1.92
1968	France/China	6	5.3
1869	China	1	2
1970	France/China	9	4.55
1971	France/China	6	1.97
1972	France/China	5	0.24
1973	France/China	6	1.65
1974	France/China	8	1.55
1976	China	3	2.37
1977	China	1	0.02
1978	China	2	0.04
1980	China	1	0.45
	TOTAL	423	217

Source: UNSCEAR (1982)

In a nuclear explosion bomb materials are vaporized to hot gases with pressures of several billion atmospheres and temperatures in excess of 100 million degrees (*similar to the temperature of the sun*). A large fireball develops as a function of the explosive yield of the device growing at an initial rate of about 300 miles per hour. The cloud from a 1 MT explosion would reach an altitude of about 14 miles after about 6 minutes – and as it reaches the top of the troposphere it expands out into a classical mushroom shape. In near surface denotations conducted in the Marshall Islands, the fireball carried large quantities of vaporized soil and water into the atmosphere. As the cloud rose, cool air and additional dust and debris—to which radioactive nuclei could attach—were drawn into the center of the fireball, and produced large sized particles and significant amount of local or close-in fallout contamination. *The division of high temperature vaporization and condensation products into different particle types and size ranges is known as fractionation – large particles (greater than ~0.4 micrometer) settle to earth quickly under gravity within the vicinity of the test sites and are loosely defined as local fallout.* Smaller particles containing most of the volatile fission products such as ^{137}Cs , ^{90}Sr , and ^{131}I were injected higher into the atmosphere where they remained suspended for longer periods. Up until 1952 nuclear weapons testing was confined to the Northern Hemisphere—the tests were sufficiently low yield that most of the radioactive debris injected into the atmosphere was confined to the troposphere. *Tropospheric fallout has a residence time of about 3 weeks and, depending on local climatic conditions, radioactive debris will fall over an area perhaps as large as several thousands miles.* During high yield tests radioactive particles were largely injected into the stratosphere, and produced a pattern of global or world-wide fallout deposition. In order to understand the global distribution of fallout you need to understand the global model for the atmospheric transport. An idealized view of the hemispherical air circulations patterns and associated latitudinal ^{90}Sr deposition densities on earth are shown in Figure 3. In general, the nature and partitioning of radioactive debris between the local environment, the troposphere and stratosphere are determined by the type, location and altitude of test, the total yield, and the quantity and type of environmental material interacting with the device. The contributions from local, tropospheric and stratospheric fallout to the total are estimated to be 12, 10, and 78%, respectively. There was a large local fallout contribution associated with tests conducted in the Marshall Islands because most of the tests were exploded in the near surface environment (e.g., on barges and towers). Stratospheric fallout was largely confined to the hemisphere where the denotation took place because there is little mixing of air between hemispheres. Injection of radioactive debris into the stratosphere and subsequent deposition on the earth's surface has varied in space and time. The nature and partitioning of injected radioactive debris within the stratosphere also depended upon on the total yield of the explosion, the denotation conditions, and test location. Air from the troposphere rises into the stratosphere near the equatorial tropopause—the interface between the troposphere and the stratosphere—and moves towards the poles, where it sinks back into the troposphere (Figure 3). The height of the tropopause varies but is roughly 60,000 ft in equatorial regions, and 26,000 in the polar regions. The exchange between the polar stratosphere and the troposphere at temperate latitudes is accelerated, and is maximal during late winter and early spring when the air at high latitude is cold and dense; this, in conjunction with rainfall and storm activity gives to a characteristic increase in fallout activity in mid-latitudes during spring (Figure 3).

High yield nuclear tests conducted in the Marshall Islands injected significant amount of radioactive debris into the upper equatorial stratosphere but came down more slowly than fallout from FSU tests conducted in the Arctic regions. Aerosols in the upper stratosphere descend gravitationally with a residence time of up to 24 months-this long residence time leads to a significant time delay before fallout of stratospheric origin reaches the upper troposphere and eventually deposits on the earth's surface.

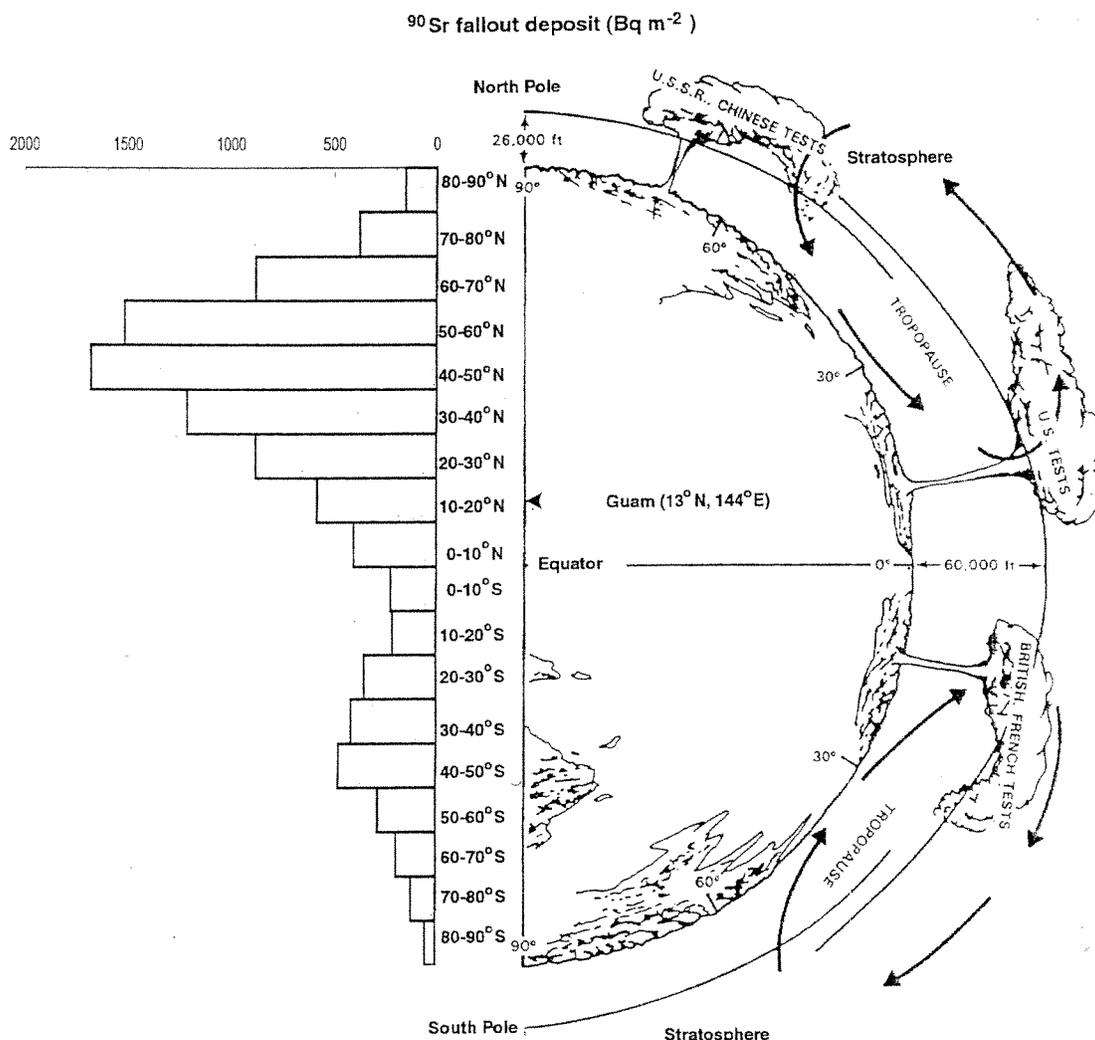


Figure 3. Hemispherical air circulation patterns and associated latitudinal ^{90}Sr deposition densities on earth

The deposition of ^{90}Sr has been monitored world-wide in a network of between 50 and 200 stations operated by or in conjunction with the Environment Measurements Laboratory (EML), formally the Health and Safety Laboratory (HASL), located in New York. ^{90}Sr was chosen as the primary fallout radionuclide of interest because of its long

half-life (28.5 years), relatively high fission yield ($\sim 3.7 \times 10^{15}$ Bq per MT of fission energy) and concerns about the potential incorporation of ^{90}Sr into the biosphere. Data on annual and cumulative depositions of ^{90}Sr are freely available in EML reports and publications. Similarly, individual data for specific monitoring stations are made available in regular reports and publications. An example of the type of information provided is shown in Appendix 1 for Anderson AFB on Guam. *It should be noted that this monitoring station was established to help complete a world-wide monitoring network not because of specific concerns about radioactive fallout over Guam.* Other stations were established on Yap, Truk, and Ponape during the same timeframe (late 1950's). *The information obtained from these monitoring stations has been used to calculate the total fallout on the surface of the earth (Figure 4).* The method used at EML assumes that monitoring samples are representative of fallout in each 10 degree latitude band within which the sampling sites are located. Summing the totals for the 10 degree latitude bands give the world-wide deposit. The U.K. Atomic Energy commission has also conducted a worldwide fallout-monitoring program since the early 1950's, and the integrated fallout records are in excellent agreement with EML estimates. *Consequently, ^{90}Sr deposition data are often used to estimate the dose commitments from other fallout radionuclides. Some uncertainties do exist because of the influence of local climatic conditions, e.g., precipitation biases and oceanic effects, localized and/or tropospheric fallout patterns, and lack of specific deposition data on short-lived radionuclides.* A short-lived radionuclide can be defined as nuclides with a physical half-life of less than 100 days. In this context, the uncertainty associated with fallout deposition estimates increases as the physical half-life of the radionuclide considered decreases. *Short-lived radionuclides show different fallout patterns depending on the decay chain and chemical properties of the elements involved.* For example, the first fission products of a decay chain may be very short-lived but determine the types of particles that radionuclides are incorporated into within the ensuring fireball of a nuclear explosion, only to decay within minutes, hours or days to a longer-lived member of the chain which may have very different geochemical transport properties.

The annual and cumulative deposition densities of ^{90}Sr on the earth's surface for the period between 1958 and 1990 are shown in Table 3. The units are expressed in PBq (1 PBq = 1×10^{15} Bq). *This is to say that a very large quantity of ^{90}Sr and associated fallout radionuclides have been distributed around the globe as a result of atmospheric nuclear weapons testing.* The number of nuclear weapons denotation peaked in 1962, and as shown in the Table 3, produced a peak in the annual ^{90}Sr deposition during 1963 in the Northern Hemisphere and a peak in 1964 in the Southern Hemisphere. The integrated annual global deposit of ^{90}Sr at the end of 1980 was about 603 PBq. The cumulative global ^{90}Sr deposit (total decay-corrected activity deposited around the globe) increased sharply though the early 1960's reaching a maximum of 451 PBq in 1966. *Since 1972 the cumulative ^{90}Sr deposit has decreased because the annual loss from radioactive decay has been greater than the annual deposit.* The cumulative global ^{90}Sr deposit at the end of 1990 was approximately 311 PBq.

Table 3. Annual and cumulative ⁹⁰Sr deposit in worldwide fallout.

Year	Northern Hemisphere		Southern Hemisphere		Global	
	Annual deposition (PBq)	Cumulative deposit (PBq)	Annual deposition (PBq)	Cumulative deposit (PBq)	Annual deposition (PBq)	Deposit (PBq)
1945-58	67#	63#	24#	22.2#	90.5#	85#
1958	23	85	9.6	29.6	32.6	115
1959	39	122	6.7	37	45.9	159
1960	9.6	126	6.3	40.7	15.9	170
1961	13	137	6.3	48.1	19.2	185
1962	53	185	9.6	55.5	63.3	244
1963	97	278	12	66.6	108.4	344
1964	61	333	16	81.4	77.0	411
1965	29	352	13	92.5	41.8	444
1966	12	355	7.8	96.2	20.0	451
1967	6.3	352	4.1	96.2	10.4	451
1968	7.4	352	3.7	99.9	11.1	451
1869	5.6	348	5.2	103.6	10.7	451
1970	7.8	348	4.8	103.6	12.6	451
1971	7	344	5.6	107.3	12.6	451
1972	3.2	340	3.6	107.3	6.7	448
1973	1.2	333	1.2	107.3	2.3	440
1974	4.5	329	1.4	103.6	5.9	433
1975	2.2	322	1.3	103.6	3.4	426
1976	1	315	0.8	103.6	1.8	418
1977	3	311	0.8	99.9	3.8	411
1978	3.7	307	0.7	99.9	4.4	407
1979	1.1	303	0.4	96.2	1.5	400
1980	0.6	296	0.3	96.2	0.9	392
1981	1.6	289	0.3	92.5	1.9	381
1982	0.5	283	0.2	91	0.7	374
1983	0.3	277	0.2	89	0.5	366
1984	0.3	270	0.1	87	0.4	357
1985	0.1	264	0.1	85	0.2	349
1986	1.5	259	0.2	83.2	1.7	343
1987	0.1	253	0.2	81.3	0.3	334
1988	0.1	247	0.1	79.7	0.2	326
1989	0.1	241	0.2	77.8	0.2	319
1990	0	235	0.1	76.2	0.1	311
1995	(0)	213#	(0)	68.9#	(0)	282#

Source: Updated from UNSCEAR (1982) using Monetti (1996). # estimates only.

As discussed, the exchange between the polar stratosphere and the troposphere at temperate latitudes is accelerated in late winter and the early spring. *As a consequence, fallout deposition has a strong latitudinal dependency as shown in Figure 4.* The majority of fallout occurs in the 30-60° latitude band with much less towards the polar and equatorial regions. About 24% of the ⁹⁰Sr deposit occurs in the Southern Hemisphere where less than 10% of the total number of nuclear weapons tests were conducted.

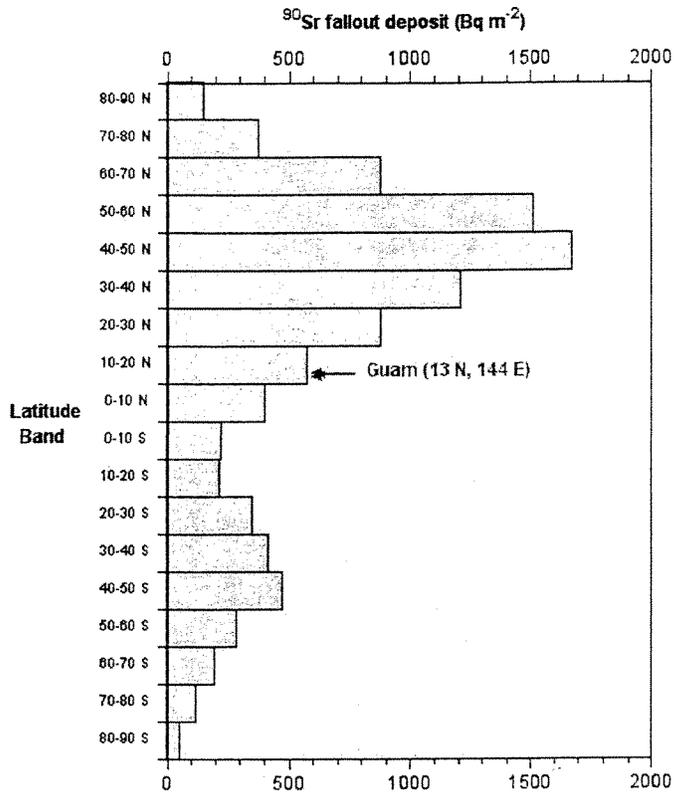


Figure 4. Integrated deposition density of ⁹⁰Sr versus latitude band (taken from Hamilton *et al.*, 1996).

RADIOACTIVE FALLOUT OVER GUAM

The pattern and worldwide fallout deposition densities for long-lived radionuclides are reasonably well known from the measured geographical deposition densities of ⁹⁰Sr (Figure 4). There is also no doubt that Guam received radioactive fallout during the atmospheric nuclear testing era but based on our expert knowledge and some limited environmental data, there appears to be no evidence to suggest that Guam was more heavily impacted by radioactive fallout than what would have been expected from worldwide fallout deposition. There are, however, some uncertainties concerning the transport dynamics and possible doses to the local population from short-lived radionuclides (e.g., ¹³¹I) at the time of the testing program. It should also be noted that the main period of potential localized exposure to long-range tropospheric transport of radioactive debris from nuclear tests in the Marshall Islands would have occurred between 1954 and 1958. This was before the time that the air monitoring station was established on the Anderson AFB.

Guam is located some 1200 miles from tests sites in the Marshall Islands (Figure 5). ¹³¹I has a half-life of only 8.05 days but following deposition on land is rapidly transferred through pasture to cow's milk, and then to man. Iodine accumulates in the thyroid gland,

and infants can be particularly susceptible to receiving high doses because they have small thyroids and typically consume large quantities of milk. The nuclide can also be taken up directly by inhalation, ingested through water and leafy vegetables, and possibly adsorbed through the skin. *Because of the probability of rainout events (rainfall that washes radionuclides out of the atmosphere), other variable localized climatic conditions and the vast distance between Guam and test sites in the Marshall Islands, it would be difficult to provide an accurate retrospective assessment of doses to the Guam population exposed to fresh fallout. However, it is expected that these local doses would be less than the normal annual background radiation levels, and pose little or no health consequence to those exposed.*

During November 1975, the University of Washington carried out a limited environmental monitoring survey of radionuclides in foods and soil collected from Majuro Atoll in the Marshall Islands, Truk and Ponape in the Caroline Islands, Guam in the Marianas Islands, and Koror and Babelthau in the Palau Islands. The sampling program consisted of collection of native soils and foodcrop products that were consumed by the local population (e.g., coconut, *Pandanus*, breadfruit, coconut crab, and fish). The samples were analyzed by gamma-spectrometry (to measure ^{137}Cs and naturally occurring gamma-emitting radionuclides), beta spectrometry (to measure ^{90}Sr) and alpha-spectrometry (to measure plutonium isotopes).

A copy of the document is enclosed with this report.

^{137}Cs was the only fallout radionuclide detected in most of the biological samples. The activity concentration of ^{137}Cs in four species of plants, coconut, *Pandanus*, and papaya were mostly below 1 pCi g^{-1} (dry weight). By comparison, the present day concentration of ^{137}Cs in coconut meat from Bikini Atoll in the Marshall Atolls can exceed 600 pCi g^{-1} (dry weight). One edible portion of *Pandanus* fruit from Guam did contain up to 18 pCi g^{-1} (dry weight) of ^{137}Cs . If this value is excluded from the data, then ^{137}Cs values in plants from Guam are very similar to those observed in Truk and Palau. *Guam is located at slightly higher northern latitude than Truk and Palau, so would actually have higher levels of world-wide fallout on Guam compared to those countries located nearer the equator.* Also, in our studies in the Marshall Islands we do observe a very high degree of variability in soil-to-plant uptake of ^{137}Cs . It is highly probable that similar levels of variability would occur on other Pacific Islands, and may explain the high value reported.

No analyses were made of ^{90}Sr in soils collected from Guam. As discussed previously, the production ratios of ^{90}Sr to other fission products such as ^{137}Cs are defined by characteristic curves for the fissioning nuclide (Figure 2). Hence, we can estimate the amount ^{90}Sr from environmental measurements of ^{137}Cs , and compare this with the theoretical ^{90}Sr deposit for the latitude band from where the sample was taken (Figure 3 & 4). The $^{137}\text{Cs}/^{90}\text{Sr}$ activity ratio in worldwide fallout is around 1.44 which is very close to the theoretical mix of total energy yields due to fission.

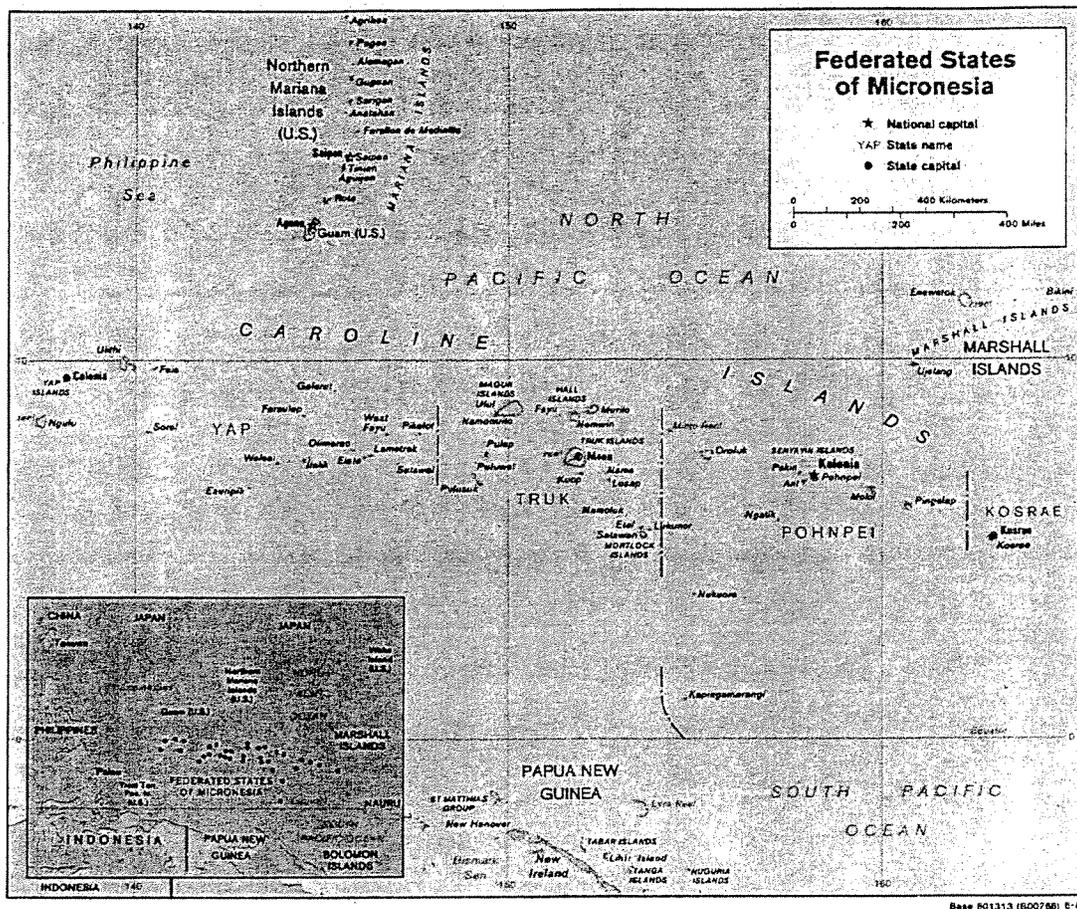


Figure 5. Map of the Federated States of Micronesia and the Mariana Islands.

Based on the very limited data from Nelson (1979), the average ^{137}Cs concentration in soil samples collected over the top 10 cm of the soil column on Guam was $0.5 \pm 0.4 \text{ pCi g}^{-1}$ (or $0.019 \pm 0.015 \text{ Bq g}^{-1}$). Assuming an *in-situ* soil density of 1 g cm^{-3} , the total inventory of ^{137}Cs to a soil depth of 10 cm is about 1900 Bq m^{-2} (i.e., $10 \text{ cm} \times 0.019 \text{ Bq g}^{-1} \times 100 \text{ cm} \times 100 \text{ cm} \times \text{g cm}^{-3}$). Dividing by the $^{137}\text{Cs}/^{90}\text{Sr}$ of 1.44 gives an estimate for the total ^{90}Sr deposit of 1300 Bq m^{-2} . The cumulative global deposit for the 10-20 degree latitude band in 1995 was 600 Bq m^{-2} (Figure 3) which converts to 1000 Bq m^{-2} in 1974 when the soil samples were collected. This value is very close to the inventory calculated from the soil sample analyses, and provides a first approximation that ^{137}Cs concentrations in the local soils on Guam can largely be attributed to world-wide fallout deposition. It should be noted that no other data on fallout radionuclides in the local environment of Guam was found during the time this report was in preparation. *A more extensive environmental survey would be required to provide a defensible dose assessment for the resident population exposed to residual fallout contamination.*

Performing a simple comparative analysis with dose assessments performed in the Marshall Islands-based on data from Utirik Atoll in the northern Marshall Islands-the transfer co-efficient for the population average effective dose is around 0.0025 mrem y⁻¹ per Bq m⁻² (or 2.4 x 10⁻⁵ mSv y⁻¹ per Bq m⁻²). The decay corrected present day ¹³⁷Cs deposition density on Guam is around 700 Bq m⁻² – this equates to an annual effective dose of only 1.7 mrem (or 0.017 mSv). The dietary habits of people living on Guam are probably such that they depend much more heavily on imported foods so this is a very conservative estimate. As stated, the average annual dose from natural sources of radiation in the Marshall Islands is around 140 mrem (1.4 mSv). Most people around the globe receive doses in the order of 100-2000 mrem (1-20 mSv) but it is not unusual to find population groups living in areas with background doses in excess of 10,000 mrem. *The estimated annual effective dose on Guam from exposure to nuclear weapons fallout is only 1.7 mrem. This is only a very small fraction of the dose that Guam residents unavoidably receive from natural sources of radiation, and is much, much less than what some other isolated populations groups receive around the globe.*

DISCUSSION POINTS RELATED TO THE CELESTIAL REPORT

Page 1. In comments related to the radiation exposure and subsequent compensation of Japanese fisherman.

Comments. The Japanese fishing boat was no where near Guam at the time of the Bravo shot on Bikini Atoll– the boat was sitting off Rongelap Atoll about 90 mile to the east of Bikini directly in the path of the ‘BRAVO’ fallout cloud.

Page 2. Guam has been monitored for Strontium-90 since the 1950’s to present.

Comments. True! But, there were over 200 radiation monitoring stations established around the globe at one time, Guam just happened to be one of the selected sites in the monitoring network. The monitoring network was established in the late 1950’s to monitor the nuclear fallout patterns around the globe and not as a human research radiation experiment. *Reports are made freely available in the open literature.*

Page 2. Strontium-90 and Cesium-137 are radionuclides with half-lives of 24,000 years

Comments. Strontium-90 and Cesium-137 are considered to be long-lived radionuclides but they have half-lives of 28.5 years and 30.1 years, respectively. ¹³⁷Cs can be a significant source of internal and external exposure. Cesium is soluble in bodily fluids and upon digestion is rapidly taken adsorbed and distributed uniformly around the body, and finally eliminated by the kidneys with a biological half-life in adults of 70-110 days. Its biological half-life in children ranges from 12 days in infants to about 57 days in older children; it is also somewhat shorter in females than in man. ⁹⁰Sr is absorbed into extra cellular fluids and a significant fraction of that ingested and/or inhaled deposited in bone. Beta particles emitted by ⁹⁰Sr and its daughter products irradiate both calcified bone and adjacent bone marrow. ⁹⁰Sr has an effective half-life in the body of 15 years.

The main radiation exposure pathway in the Marshall Islands is from ingestion of locally grown foods that contain high elevated levels of ^{137}Cs . ^{90}Sr is a minor contributor to the dose. As similar foods are grown on Guam we can reasonably assume that the people on Guam are similarly exposed to some level of residual worldwide fallout contamination in their diet (as are peoples all around the globe). *The average concentration of ^{137}Cs in foods collected from Guam in 1974 (Nelson, 1979) were already very low, i.e., less than 1 pCi g⁻¹ (dry weight), and would have been further depleted by radioactive decay and natural environmental processes that would either wash out the ^{137}Cs from the soil or make it less bioavailable to the plants. And it is important to realize that what is unique about coral ecosystems is that coralline soils such as those in the Marshall Islands contain very low concentrations of natural potassium (K). Potassium is an essential element while cesium (Cs) is not. However, K and Cs have very similar chemical behaviors and plants will take up natural occurring Cesium (Cs) (and any available ^{137}Cs) where there isn't sufficient K in the soil. Consequently, the issue concerning the dose to people consuming locally grown foods is derived as much from the unique behavior of fallout ^{137}Cs in the plant-vegetation-man pathway as to the actual deposition density of ^{137}Cs . Guam contains soils which contain higher concentrations of natural occurring potassium and aluminosilicates minerals that help bind up available ^{137}Cs —both processes will depress the uptake of ^{137}Cs into plants and reduce the relative dose to the local population.*

The estimated population average annual effective dose to people living on Guam from fallout radionuclides is estimated to be in the order of 1.7 mrem or about 1 % of the radiation background dose that people will unavoidably receive from natural radiation sources. Another perspective on the significance of radiation doses can be obtained from considering the system of radiological protection. The annual dose limit for members of the public recommended by the ICRP (International Commission on Radiological Protection), and adopted in the Basic Safety Standards, is 100 mrem (1 mSv). This limit applies to the sum of the exposures from beneficial activities by humans – termed 'practices' by the ICRP. Furthermore, practices giving to annual radiation doses of less than 1 mrem (*close to the value we estimate for Guam*) are commonly exempted from regulatory requirements on the grounds that such doses are considered trivial. *The risk coefficient as determined by the ICRP for fatal cancers in members of the public is $5 \times 10^{-4}/\text{rem}$. An annual dose of 1.7 mrem provides an annual risk factor of 8×10^{-7} or a lifetime risk of 6×10^{-5} (0.005%). This is very small compared with the underlying lifetime risk of death from cancer of around 20%.*

There is a large degree of uncertainty in the dose estimate provided in this brief report of current radiological conditions on Guam. Nonetheless, the intent was to demonstrate that the risks from exposure to residual fallout on Guam are likely to extremely small, and below the threshold where health impacts could be medically diagnosable in any individual or epidemiologically discernible in any group.

UNDER SUPPLEMENTARY PAGES ON 'GUAM'—EXPOSURE TO RADIATION-⁹⁰Sr.

The ⁹⁰Sr air monitoring data from Guam does indicate elevated levels of ⁹⁰Sr were detected in 1963. Nuclear testing in the Marshall Islands began with Operation crossroads and the ABLE test on 30 June (GCT) 1946 and terminated with Operation Hardtrack with the FIG test conducted on 18 August 1958. A moratorium on nuclear testing began shortly after but when the FSU resumed testing in September 1961, the US also resumed testing in the area of Christmas Island, Johnson Atoll and other Pacific locations. All US tests conducted near Christmas Island and Johnson Atoll were air bursts. No further tests were ever conducted in the Marshall Islands. A total of 36 nuclear tests were carried by the US during 1962 in the Pacific region outside the Marshall Islands. Two of these tests were underwater explosions and one was launched from a Polaris submarine. The total explosive yield was about 37.1 MT. During the same period, the FSU conducted a total of 39 tests but with a much higher total explosive yield of 180.3 MT. Consequently, the peak in ⁹⁰Sr deposition on Guam in 1963—and as seen at many other monitoring stations around the globe—can largely be attributed to worldwide fallout from nuclear tests conducted by the FSU. The US tests account for only 17% of the total explosive yield, and were carried out at high altitude many thousands of miles from Guam where the impacts of tropospheric fallout within the regions would have been minimized. The last atmospheric nuclear test was carried by China in 1980.

The reports issued by EML on worldwide fallout are freely available, and should not be interpreted as new or secret information.

Long range atmospheric and oceanic circulation patterns off Guam are dominated by north-easterly trade winds, and the westward flowing North Pacific Equatorial Current. Tropospheric fallout derived from tests conducted in the Marshall Islands could conceivably reach Guam in the days, weeks or months following a nuclear detonation. However, measurements of ¹³⁷Cs in soils collected from Guam show no measurable levels of fallout above what would be expected from global fallout deposition.

The potential impacts of the marine pathway are more difficult to evaluate. The Japanese tuna fishing industry was devastated immediately after the 'Bravo' blast because of concerns over high levels of radiation contamination in fish caught in Micronesian waters. I have no knowledge of local fishing habits and/or dietary information for Guam on which to make a sound assessment. However, tropospheric fallout from high yield nuclear tests in the Marshall Islands are known to have produced elevated levels of ¹³⁷Cs and other short-lived fissions in surface waters within the region. These radionuclides are also known to be transferred through the marine food chain. There is a possibility high intake consumers of fish and other marine products caught within the region received a higher dose, albeit very small, from the marine pathway during the testing era between 1954 and 1958. However, it is expected that these doses would have been small compared with natural sources of radiation exposure. Such small doses pose no health effects that could be medically diagnosable in any individual or epidemiologically discernible in any group.

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- R. J. Larsen, *Worldwide Deposition of ⁹⁰Sr through 1982*, Environmental Measurements Laboratory, New York, NY, EML-430 (1984).
- R. L. Kathren, *Radioactivity in the Environment: Sources, Distributions, and Surveillance*, Hard Academic Publishers, (1984).

Appendix I

Environmental Measurements Laboratory Worldwide Deposition of ^{90}Sr through 1982

R. J. Larsen

The individual site figures consist of three separate graphs labeled A, B and C. Graph A is a linear graph of deposition versus time. The units of deposition are in Bq m^{-2} . The scale on the ordinate is fixed between 0.0 and 200.0 Bq m^{-2} . The spaces between minor tick marks on the abscissa represent 1 year. Graph B is a semi-logarithmic graph of deposition versus time. The scale on the ordinate is fixed between 1 and 10,000 Bq m^{-2} . All other graph attributes are identical to those of graph A. Graph C is a linear graph of precipitation versus time. The units of precipitation are cm. The scale on the ordinate varies, dependent upon the range of the data. The abscissa is identical to that in graphs A and B. Gaps in any of these graphs reflect periods of missing data.

EML-430

Environmental Measurements Laboratory

WORLDWIDE DEPOSITION OF ^{90}Sr THROUGH 1982

Richard J. Larsen

June 1984



DEPARTMENT OF ENERGY

NEW YORK, N. Y. 10014

Quarterly Fallout Deposition Collections

Site: Guam, Anderson AFB

Lat. N 13 35 Long. E 144 55 Alt. 185 m. (Column)

Source: U.S. Air Weather Service

	1 st	2 nd	3 rd	4 th	Cum. Total
	----	----	----	----	-----
1976 Precip. (cm.)	91.2	113.4	114.4	73.3	392.3
Sr-90 (Bq/sq.m.)	1.1	*	0.4	0.4	1.9
Sr-90 Conc. (mBq/l)	1.2	--	0.3	0.5	
1977 Precip. (cm.)	31.6	34.0	77.6	60.0A	203.2
Sr-90 (Bq/sq.m.)	0.4	0.4	1.1	1.9C	3.7
Sr-90 Conc. (mBq/l)	1.2	1.1	1.4	3.1	
1978 Precip. (cm.)	13.1	41.0	87.0	73.9	215.1
Sr-90 (Bq/sq.m.)	3.7	3.0	0.7	0.7	8.1
Sr-90 Conc. (mBq/l)	28.3	7.2	0.9	1.0	
1979 Precip. (cm.)	29.3	12.4	50.0A	114.0	205.7
Sr-90 (Bq/sq.m.)	1.1	0.4	*	0.4	1.9
Sr-90 Conc. (mBq/l)	3.8	3.0	--	0.3	
1980 Precip. (cm.)	50.5	69.1	113.5	67.7	300.8
Sr-90 (Bq/sq.m.)	0.4	0.7	0.4	0.4	1.9
Sr-90 Conc. (mBq/l)	0.7	1.1	0.3	0.5	
1981 Precip. (cm.)	27.2	41.3	75.7	92.4	236.6
Sr-90 (Bq/sq.m.)	1.1	1.5	*	0.4	3.0
Sr-90 Conc. (mBq/l)	4.1	3.6	--	0.4	
1982 Precip. (cm.)	34.9	50.6	79.0	60.7	225.2
Sr-90 (Bq/sq.m.)	0.7	0.4	*	0.7	1.9
Sr-90 Conc. (mBq/l)	2.1	0.7	--	1.2	
1983 Precip. (cm.)	15.4	8.4	--	--	23.8
Sr-90 (Bq/sq.m.)	0.4	*	--	--	0.4
Sr-90 Conc. (mBq/l)	2.4	--	--	--	

Notes

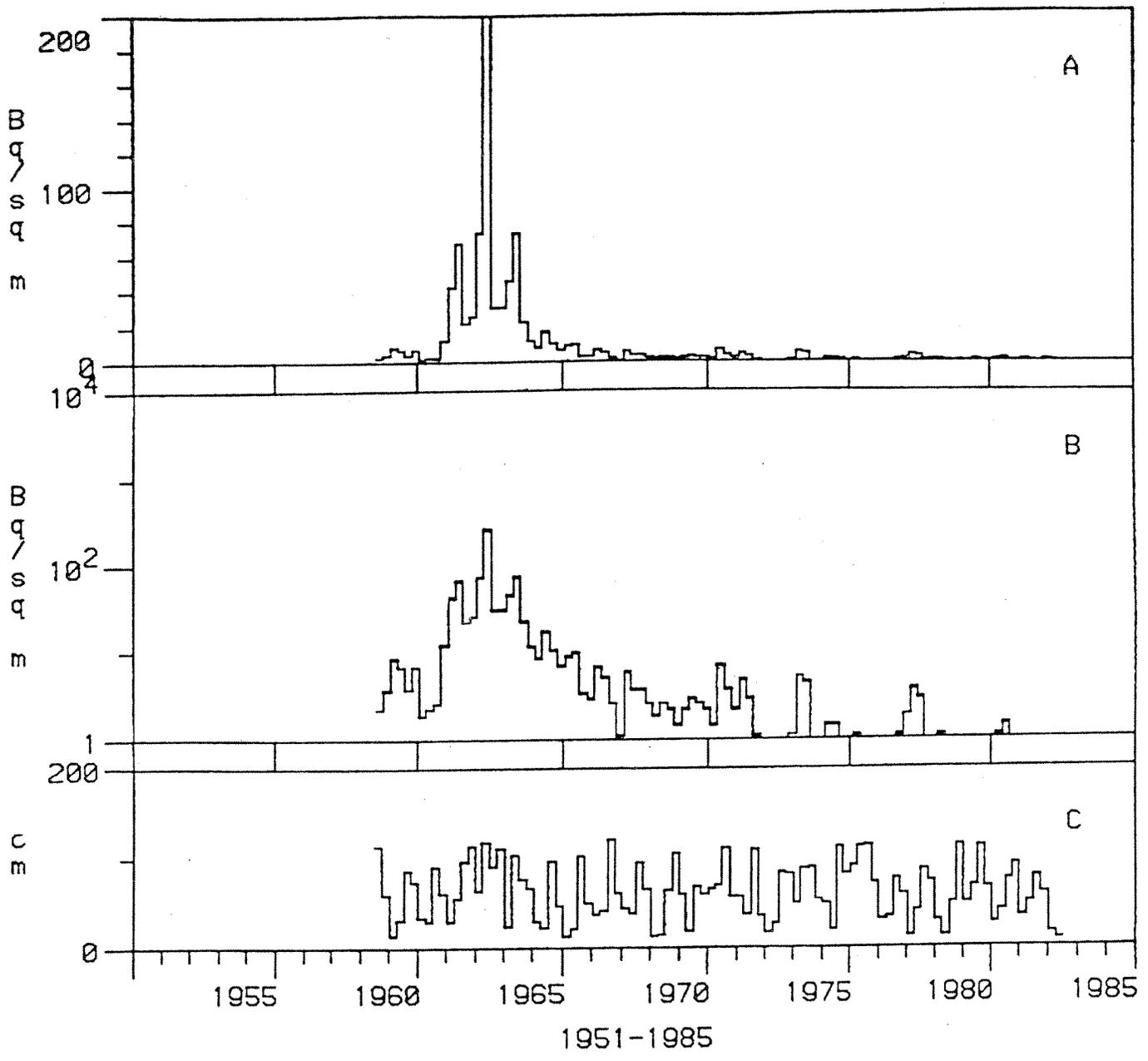
--: Data not available

*: Zero or trace

A: Approximate

B: Lower limit of reported data

C: Extrapolated from incomplete data set



Site: Guam, Anderson AFB
 Latitude: N 13 35 Longitude: E 144 55
 Altitude: 185 M Collector: Column



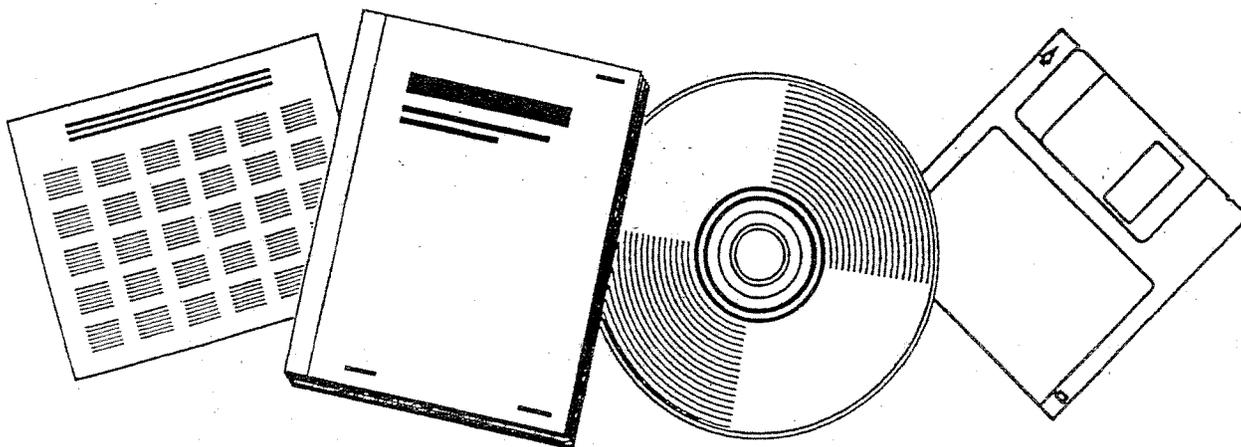
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RADIOLOGICAL SURVEY OF PLANTS, ANIMALS, AND SOIL IN MICRONESIA

WASHINGTON UNIV., SEATTLE

NOV 1975



U.S. DEPARTMENT OF COMMERCE
National Technical Information Service

NV0026935



**HEALTH AND
SAFETY**

**RADIOLOGICAL SURVEY OF PLANTS,
ANIMALS, AND SOIL IN MICRONESIA**

NOVEMBER 1975

By
Victor A. Nelson

JANUARY 1979

**UNIVERSITY OF WASHINGTON
COLLEGE OF FISHERIES
LABORATORY OF RADIATION ECOLOGY
SEATTLE, WASHINGTON 98105**

**PREPARED FOR THE U.S. DEPARTMENT OF ENERGY
NEVADA OPERATIONS OFFICE
UNDER CONTRACT NO. EY-76-S-08-0269**

ABSTRACT

In 1974 the Laboratory of Radiation Ecology began a program to determine the radionuclides found in foods, plants, animals, and soils of the Central Pacific. As part of this program the present study was undertaken to determine radionuclides found in the common foods and soils in areas of Micronesia other than those areas receiving local fallout from the test sites at Bikini or Enewetak atolls. Areas sampled in 1975 were Majuro Atoll in the Marshall Islands, Truk and Ponape in the Caroline Islands, Guam in the Marianas Islands and Koror and Babelthaup in the Palau Islands.

All samples were analyzed for gamma-emitting radionuclides while some were also analyzed for ^{90}Sr or $^{239,240}\text{Pu}$. Results of the analyses indicate that naturally occurring ^{40}K is the predominant radionuclide in the biological samples. Cesium-137 in amounts less than 1 pCi/g (dry) was the only fallout radionuclide detected in most of the biological samples. Soil samples usually contained ^{90}Sr , ^{137}Cs , ^{238}U and $^{239,240}\text{Pu}$, while soil from Truk, Palau, and Ponape also contained isotopes of radium and thorium. Soil from Guam also contained ^{210}Pb and ^{235}U in addition to the above radionuclides. Considering only the fallout radionuclides, the values for ^{90}Sr , ^{137}Cs , and $^{239,240}\text{Pu}$ in samples from Guam, Palau, Truk, Ponape, and Majuro are less than the values for these radionuclides in similar samples from atolls such as Utirik, Rongerik, and Ailinginae in the northern Marshall Islands, and are much less than values of these radionuclides in samples from Bikini and Rongelap atolls.

TABLE OF CONTENTS

	<u>PAGE NO.</u>
ABSTRACT	i
INTRODUCTION	1
SAMPLING PROGRAM	1
ANALYTICAL METHODS	5
GAMMA-RAY SPECTROMETRY.	5
STRONTIUM-90 AND PLUTONIUM ANALYSES	7
ERROR LIMITS.	7
LIMITS OF DETECTION	7
RESULTS AND DISCUSSION	8
FISH.	8
COCONUT CRABS . . . . .	.11
PLANTS. . . . .	.12
SOIL. . . . .	.12
SUMMARY AND CONCLUSIONS. . . . .	.14
REFERENCES . . . . .	.16
APPENDIX TABLES. . . . .	.17
DISTRIBUTION LISTS . . . . .	.29

FIGURES

FIGURE

1.	SAMPLING LOCATIONS IN MICRONESIA, NOVEMBER 1975 . . . . .	.2
2.	LOCATIONS SAMPLED AT PONAPE, TRUK, GUAM, AND PALAU IN DECEMBER, 1975. . . . .	.3
3.	LOCATIONS SAMPLED AT MAJURO ATOLL IN NOVEMBER, 1975 . . . . .	.4

TABLE OF CONTENTS (CONTINUED)

TABLES

<u>TABLE</u>	<u>PAGE NO.</u>
1. DISPOSITION OF SAMPLES COLLECTED ON THE NOVEMBER, 1975 TRIP TO MICRONESIA	6
2. COMMON NAMES AND WET WEIGHT TO DRY WEIGHT RATIOS OF SOME MICRONESIAN ORGANISMS	9

APPENDIX TABLES

1. PREDOMINANT RADIONUCLIDES IN FISH COLLECTED IN MICRONESIA IN NOVEMBER, 1975	17
2. SOME RADIONUCLIDES IN PLANTS COLLECTED ON MAJURO ATOLL IN NOVEMBER, 1975.	19
3. SOME RADIONUCLIDES IN PLANTS COLLECTED IN PONAPE DISTRICT IN NOVEMBER, 1975	20
4. SOME RADIONUCLIDES IN PLANTS COLLECTED IN TRUK DISTRICT IN NOVEMBER, 1975	21
5. SOME RADIONUCLIDES IN PLANTS COLLECTED IN THE PALAU ISLANDS IN NOVEMBER, 1975	22
6. SOME RADIONUCLIDES IN PLANTS COLLECTED IN GUAM IN NOVEMBER, 1975.	23
7. SOME RADIONUCLIDES IN SOIL COLLECTED ON MAJURO ATOLL IN NOVEMBER, 1975	24
8. SOME RADIONUCLIDES IN SOIL COLLECTED IN THE PONAPE DISTRICT IN NOVEMBER, 1975	25
9. SOME RADIONUCLIDES IN SOIL COLLECTED AT TRUK IN NOVEMBER, 1975.	26
10. SOME RADIONUCLIDES IN SOIL COLLECTED IN THE PALAU ISLANDS IN NOVEMBER, 1975	27
11. SOME RADIONUCLIDES IN SOIL COLLECTED ON GUAM IN NOVEMBER, 1975.	28

INTRODUCTION

From 1946 to 1962 atomic devices were detonated by the United States under water, over water, on land or in the atmosphere over the water of the central Pacific. France and Great Britain also conducted atmospheric nuclear tests in the Central and South Pacific which have released radioactivity to the environment of this area. Most of these tests took place at Bikini and Enewetak atolls in the Marshall Islands and some at Johnston Island and Christmas Island further east. The distribution of radionuclides produced by the U. S. tests has been studied extensively, especially at Bikini and Enewetak atolls. The present study is part of a Laboratory of Radiation Ecology program begun in 1974 and described in a previous report (Nelson, 1977). The purpose of this study was to determine qualitatively and quantitatively, radionuclides presently found in common foods and soils in areas of Micronesia other than those areas receiving local fallout during the test periods. Areas sampled were Majuro Atoll in the Marshall Islands, Truk and Ponape in the Caroline Islands, Guam in the Marianas Islands and Koror and Babelthaup in the Palau Islands. Data from samples collected in these areas will provide a comparison with the amounts and kinds of radionuclides found in similar samples from Bikini and Enewetak atolls.

SAMPLING PROGRAM

The areas mentioned above were visited in November 1975. In Figure 1 these areas are shown in relationship to the test sites at Bikini and Enewetak atolls, while in Figures 2 and 3 the collection sites within these areas are shown. The trip was a joint survey with personnel from Brookhaven National Laboratory (BNL) who took radiation survey readings with sodium iodide (NaI) scintillation detectors and a pressurized ion chamber. The results of the survey readings will be given in a separate BNL report. Personnel from our

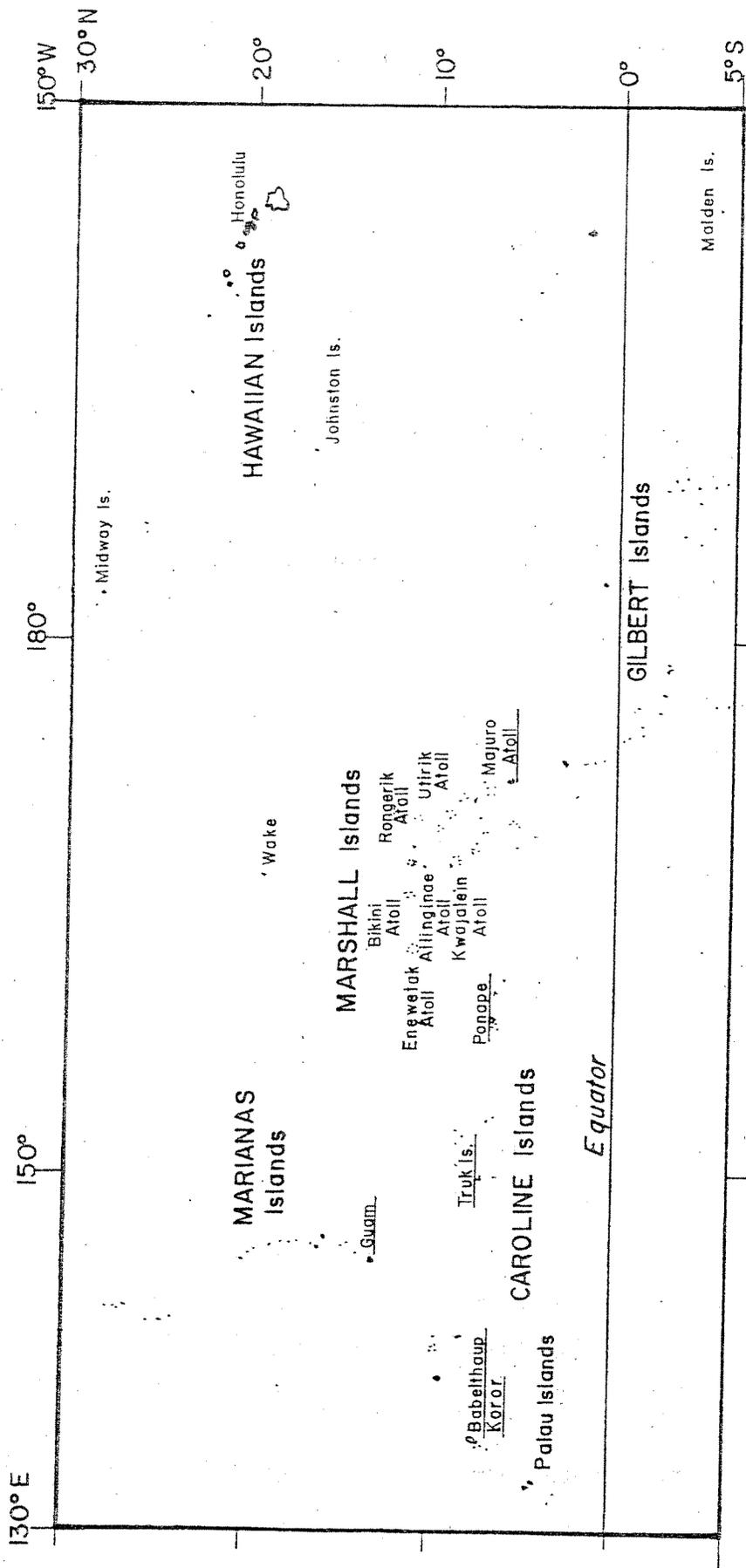
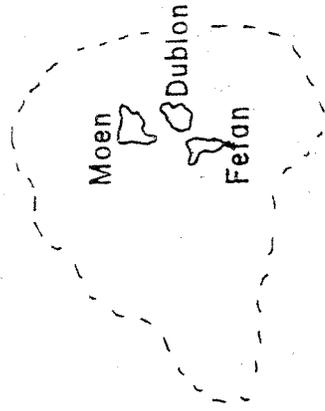


Figure 1. Sampling locations (underlined) in Micronesia, November 1975.

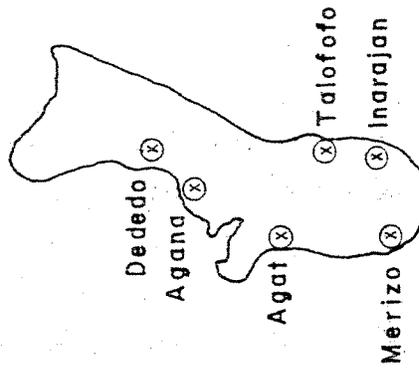
Ponape District



Truk Atoll



Guam Island



Palau Islands

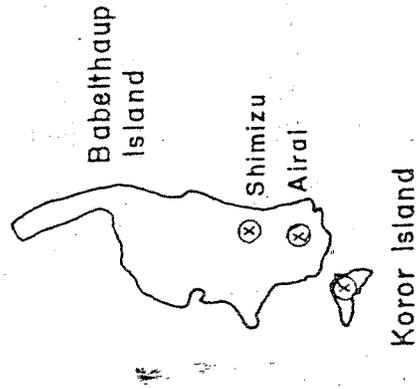
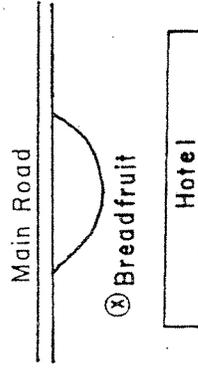
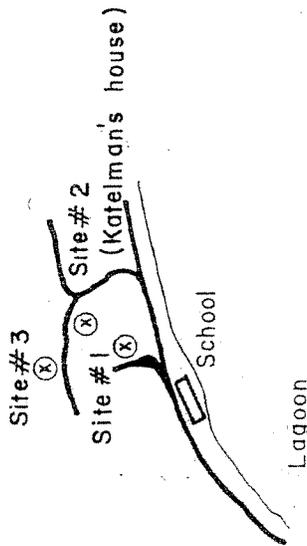
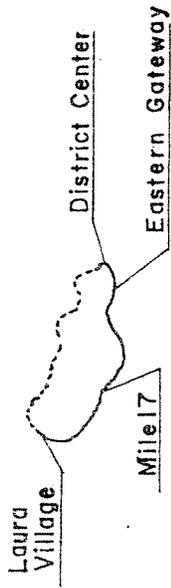


Figure 2. Locations sampled at Ponape, Truk, Guam and Palau in November 1975.

Majuro Atoll



Laura Site

Eastern Gateway Site

Figure 3. Locations sampled at Majuro Atoll in November 1975.

Laboratory collected representative biological and soil samples with emphasis on food items common to the diet of the Marshallese people (i.e., fish, coconut, pandanus, breadfruit, coconut crabs, etc.) although nonedible portions of these items were also collected and analyzed. Soils were collected to provide data for estimation of future distribution and quantities of radionuclides in the environment and biota.

The number of samples, after division into tissues or soil fractions, is shown in Table 1. Seventy percent of the samples were biological - plants, fish, and coconut crabs - and thirty percent were soils - surface (0-2.5cm) and profile (0-50cm). Approximately equal numbers of samples came from each of five major collection areas.

ANALYTICAL METHODS

Gamma-Ray Spectrometry

All of the samples were analyzed by gamma-ray spectrometry, either with a 3" X 3" sodium iodide (thallium-drifted) crystal and 200-channel, pulse-height analyzers or with a germanium (lithium-drifted) diode detector and 4096-channel, pulse-height analyzer. Soil samples were analyzed on the Ge(Li) system, and the biological samples were analyzed on both systems.

All samples were oven-dried, ground and a portion compressed into sample holders of polyvinyl chloride (PVC) pipe 2 inches in diameter and either 1/2 or 1 deep for radionuclide measurement. Fifty grams of tissue or 68 grams of soil could be compressed into the 2" X 1" holder. The densities of the biological and soil samples were 1.0 and 1.35, respectively. These samples were then analyzed for gamma-emitting radionuclides.

The gamma-emitting radionuclides in the samples counted on the NaI crystal were determined by a method of least squares. The radionuclide values for samples counted on the Ge(Li) detector were calculated either manually or with

Table 1. Disposition of Samples Collected on the November 1975 Trip to Micronesia.

Sampling Location	Samples Processed ^a			Samples Analyzed ^b		
	Plants	Soil	Fish	⁹⁰ Sr	^{239,240} Pu	
Majuro	29	12	8	47	26	18
Ponape	23	13	14	50	30	17
Truk	31	14	1	46	14	12
Guam	31	13	5	49	16	7
Palau ^b	25	15	3	43	23	13
Total	139	67	31	235	109	67

a. The number given is the total after the samples have been divided into tissues or increments of soil depth.

b. Three coconut crabs were also collected on an island south of Koror. The muscle, exoskeleton, and hepatopancreas from these crabs were ⁹⁰Sr and ^{239,240}Pu. pooled and analyzed for γ -emitting radionuclides plus ⁹⁰Sr and ^{239,240}Pu.

Many factors influence the limit of detection, including the type of detector and analyzer, the presence of other radionuclides, the duration of the counting period, the size and density of the sample, and the geometry relationship of the sample and detector. Hence, the limits of detection varied considerably for various radionuclides and types of samples, but can be summarized by stating that detection limits were approximately as follows:

Limits of Detection

For a single sample, the errors given for all radionuclides listed are two-sigma, propagated, counting errors. The error term for the mean of more than one sample is one standard deviation and disregards counting error.

Error Limits

To measure ^{90}Sr content, ^{90}Y was chemically separated from ^{90}Sr , collected on a filter paper and counted with a [low-level] beta counting system. Plutonium was extracted by ion exchange, electroplated on platinum discs, and analyzed by alpha spectrometry with systems using surface barrier alpha detectors and pulse-height analyzers. Chemical yield was determined by use of ^{242}Pu as a tracer.

Strontium-90 and Plutonium Analyses

All values were corrected for decay to the date of collection. A set of previously reported reference spectra for the type of sample holder and radio-nuclide was used. Applying correction factors to convert counts to picocuries (pci). A set of peaks in the spectrum, subtracting the appropriate background counts, and a computer by adding the counts in an energy range of five channels under

Seven species of fish were collected from one or more of the five districts. Goatfish, mullet and parrotfish were the most common fish available and they were collected at three sites each. As shown in Appendix Table 1, naturally occurring ⁴⁰K was the only radionuclide measured in fish tissues at a concentration greater than 0.6 pCi/g, dry and the average value was 4.6 pCi/g, of dry tissue. Cesium-137 was detected in only 6 of 31 samples. The maximum concentration of ¹³⁷Cs measured was 0.59 pCi/g, dry in the viscera of goatfish from Ponape. Strontium-90 was detected in 1 of 15 tissue samples analyzed.

Fish

Data are presented in Appendix Tables 1 through 11 for the results of the analyses of the samples collected by LRE in Micronesia in 1975. All data are given as picocuries per gram of dry weight (pCi/g, dry), except where expressly noted. Table 2 gives the mean wet weight to dry weight ratios for the biological samples. Thus the pCi/g, dry values may be converted to pCi/g, wet for purposes of computing dietary uptake of the measured radionuclides. Since there are greater differences in the radioactivity values between sample types than area of collection, other than soil, the results will be discussed by sample type.

RESULTS AND DISCUSSION

By gamma detection	⁴⁰ K	2.1 pCi/g or less
	²³⁸ U	0.41 " "
	^{102m} Rh, ¹²⁵ Sb, ¹³⁷ Cs, ²¹⁰ Pb, ²²⁶ Ra, ²²⁸ Th, ²³² Th	0.12 pCi/g or less
By beta detection	⁹⁰ Sr	0.2 pCi/g or less
By alpha detection	²³⁹⁺²⁴⁰ Pu	0.02 pCi/g or less

Table 2. Common Names and Wet Weight to Dry Weight Ratios of Some Micronesian Organisms.

Species	Number of Samples	Tissue	Mean Wet/Dry Ratio	Deviation
Mullet	(4)	Eviscerated whole	3.31	+ .30
"	(4)	Viscera	4.66	+ .99
"	(1)	Entire	3.55	
Parrotfish	(2)	Muscle	4.30	+ .11
"	(2)	Viscera	4.96	+ .97
"	(2)	Remainder	3.45	+ .15
Goatfish	(6)	Eviscerated whole	3.57	+ .15
"	(5)	Viscera	4.31	+ .82
Snapper	(1)	Viscera	4.25	
"	(1)	Eviscerated whole	3.76	
Flagtail	(1)	Viscera	3.72	
"	(1)	Eviscerated whole	3.09	
Convict Surgeon	(1)	Viscera	5.94	
"	(1)	Eviscerated whole	3.53	
Jack	(1)	Entire	3.92	
Breadfruit	(12)	Edible	6.12	+ 2.27
"	(12)	Inedible	6.24	+ 1.48
"	(13)	Leaves	4.28	+ .64
Pandanus	(12)	Edible	7.28	+ 1.43
"	(13)	Inedible	4.22	+ .81
"	(16)	Leaves	3.56	+ .97
Coconut	(11)	Meat	2.60	+ .97
"	(13)	Leaves	2.21	+ .20
"	(2)	Copra	1.12	+ .02
Taro	(5)	Edible	2.71	+ .53
"	(2)	Leaves	7.90	+ .20
"	(2)	Stems	14.70	+ 1.56
Papaya	(7)	Edible	12.19	+ 3.82
"	(7)	Inedible	10.49	+ 2.44
"	(7)	Seeds	6.32	+ 1.38
Cassava	(1)	Root	2.58	
Banana	(1)	Edible	5.17	
<u>FISH</u>				
<u>PLANTS</u>				

Table 2. (continued)

Species	Number of Samples	Tissue	Mean Wet/Dry Ratio	Deviation
Coconut crab	(1)	Exoskeleton	1.53	
"	(1)	Hepatopancreas	2.86	
"	(1)	Muscle	4.90	
<u>INVERTEBRATES</u>				

The values for ^{90}Sr and ^{137}Cs in these crabs are less by a factor of ten than amounts in coconut crabs from Rongerik and Ailinginae atolls and are similar to amounts found in crabs from Kwajalein Atoll, which did not receive any appreciable local fallout from the testing at the Pacific Test Sites.

a. ns = not significant.

Tissue	^{40}K	^{60}Co	^{137}Cs	^{90}Sr	$^{239,240}\text{Pu}$
Exoskeleton	17.0 ± 11	2.2 ± 0.83	1.5 ± 0.09	1.7 ± 0.2	<0.002
Hepatopancreas	ns ^a	ns	0.17 ± 0.09	<0.25	<0.004
Muscle	5.1 ± 1.1	ns	0.30 ± 0.09	<0.23	<0.004

Results of these analyses are shown below in pci/g, dry. Three coconut crabs from Palau were dissected and the tissues pooled for analysis.

Coconut Crabs

fish samples analyzed for this report. of detection in fish samples from the three atolls noted above and in the The concentrations of ^{90}Sr and $^{239,240}\text{Pu}$ was near or below the limits and 1975 (NIRS, 1975). Seymour, 1977), and in fish collected from Japanese coastal waters in 1974 concentrations in fish from Amchitka Island in the Aleutians (Nelson and in quantities greater than our limits of detection was similar to ^{137}Cs The amount of ^{137}Cs in the few (6 of 31) fish samples which contained receive some local fallout during the testing at Bikini and Eniwetok atolls. northern Marshall Islands which have low radiation levels, but which did (Nelson, 1977) in fish from Utirik, Rongerik, and Ailinginae atolls in the The amount of ^{137}Cs in these fish was less than the amount measured samples analyzed. white $^{239,240}\text{Pu}$ was not above the limits of detection in any of the eight

Plants

Four species of plants, pandanus, coconut, breadfruit and papaya, were collected from one to three sites within each of the five major collection locations. In addition bananas, taro and cassava were collected at a few sites. Results of the analysis of these samples are given in Appendix Tables 2 through 6.

Naturally occurring ^{40}K was the most abundant radionuclide measured in the plant samples. Of the fallout radionuclides only ^{137}Cs was detected in more than 50 percent of the samples. Most values of ^{137}Cs were less than 1 pCi/g, but a value of 18 pCi/g was measured in the edible portion of a pandanus fruit from Guam. The inedible portion of this fruit also had a high ^{137}Cs value, 16 pCi/g. If these high unexplained values of ^{137}Cs are excluded, the ^{137}Cs values in plants from Guam are similar to values in plants from Palau and Truk where the lowest values were measured. Ponape had slightly higher amounts of ^{137}Cs in the plants, while plants from Majuro had the highest average amount of ^{137}Cs . About 50 percent of the ^{137}Cs values in the plants from Majuro were above 1 pCi/g. Strontium-90 values in plants followed a similar pattern, while $^{239,240}\text{Pu}$ values were above the limits of detection in one sample of copra from Majuro and in two samples of breadfruit from Ponape.

The values for ^{137}Cs and ^{90}Sr in plants from Guam, Palau, Ponape, and Truk were less than values for the same plants from the Marshall Islands, (Nelson, 1977) but were similar to values found in food plants from Japan (NIRS, 1976) and Washington State (Nelson and Seymour, 1975).

Soil

Surface (0-2.5 cm) soil samples and shallow soil profiles were collected from several sites in each district. Results of the analysis of these samples

are presented in Appendix Tables 7 through 11. Soil from the coralline atoll, Majuro, generally contained small (< 1 pCi/g) amounts of ^{90}Sr , ^{137}Cs , ^{238}U , and $^{239,240}\text{Pu}$, while soils from the volcanic islands of Ponape, Truk, Guam, and Palau, in addition to these radionuclides, also contained naturally occurring isotopes of radium and thorium. The soil from Guam also contained ^{210}Pb and ^{235}U in addition to ^{137}Cs , ^{226}Ra , ^{232}Th , and $^{239,240}\text{Pu}$ (no analyses for ^{90}Sr were made on the soils from Guam). No major differences in the amount of ^{137}Cs , ^{90}Sr or $^{239,240}\text{Pu}$ found in the soil samples were noted between the five districts.

Soil from the northern stations on Guam had much higher values of ^{210}Pb , ^{226}Ra , ^{232}Th and ^{235}U than did the soil samples from the other station on Guam or from the other districts. For instance, the ^{226}Ra values from these northern sites were two orders of magnitude higher than ^{226}Ra from other districts, while the ^{232}Th values were one order of magnitude higher. Lead-210 and ^{235}U were not detected in soils from any district other than Guam. The range of values for the radionuclides in the soils from Guam were as follows: ^{137}Cs (ns to 1), ^{210}Pb (ns to 22), ^{210}Ra (ns to 78), ^{232}Th (ns to 5) and ^{235}U (ns to 5.6). Results of the analyses of the soil profiles indicated that the concentration of the fallout radionuclides ^{137}Cs and ^{90}Sr decreased with depth, while the concentration of the naturally occurring radionuclides remained relatively constant up to the depth of our deepest samples. Most of the ^{137}Cs and ^{90}Sr was present in the top 5 cm of the soil profiles. Considering only the fallout radionuclides, the values for ^{90}Sr , ^{137}Cs and $^{239,240}\text{Pu}$ in soils from Palau, Guam, Truk, Ponape and Majuro are less than values for these radionuclides in soil from atolls in the northern Marshall Islands such as Utrik, Rongerik, and Ailinginae, and are much less than values for soils from Bikini and Rongelap atolls (Nelson, 1977).

SUMMARY AND CONCLUSIONS

This study of radionuclides in plants, fish, and soil from five districts

in Micronesia was one part of LRE's Pacific Radioecology Program. The general purpose of this part of the program is to determine the kinds and amounts of

radionuclides in biological and environmental samples from the Central Pacific. The specific purpose of this study was to measure the radionuclides presently

found in common foods and soil from areas of Micronesia which did not receive appreciable local fallout from the tests at Bikini and Eniwetok atolls.

Approximately 240 samples for this study were collected during November 1975, and 235 γ -spectrum, 109 strontium-90, and 67 plutonium-239,240 analyses were performed.

Results of the analyses indicate that naturally occurring ^{40}K is the

predominant radionuclide in the biological samples. Cesium-137 was the only fallout radionuclide detected in most of the biological samples. Amounts of

^{137}Cs present in the biota were usually less than 1 pci/g of dry tissue, although plants from Majuro had slightly greater amounts of ^{137}Cs than the

plants from the other districts.

Soil samples from all districts usually contained less than 1 pci/g of ^{90}Sr , ^{137}Cs , ^{238}Pu , and $^{239,240}\text{Pu}$, while soil from Truk, Palau, and Ponape,

also contained less than 2 pci/g naturally occurring isotopes of radium and thorium. Soil from Guam contained the above fallout and naturally occurring

radionuclides and in addition contained ^{210}Pb and ^{235}U . Amounts of the

naturally occurring radionuclides in the Guam soils were much higher than

amounts of fallout or naturally occurring radionuclides from the other districts.

Considering only the fallout radionuclides, the values for ^{90}Sr , ^{137}Cs ,

and $^{239,240}\text{Pu}$ in fish, plants and soils from Palau, Guam, Truk, Ponape, and Majuro are less than values for these radionuclides in similar samples from

atolls such as Ulirik, Rongerik and Ailinginae in the northern Marshall Islands,

and are much less than values of these radionuclides in samples from Bikini and Rongelap atolls.

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Appendix Table 1. Predominant Radionuclides in Fish Collected in Micronesia in November, 1975.

Collection Site	Species	Tissue	Radionuclide concentration in pci/g, dry ^a			
			40K	137Cs	90Sr	239,240Pu
Majuro Atoll/Majuro I.	Mullet	Viscera	2.9 ± 1.6	ns ^c	na ^c	na
"	"	Evisc. whole ^b	4.3 ± 1.2	ns	< 0.07	na
"	Goatfish	Viscera	8.3 ± 4.7	ns	< 0.9	na
"	"	Evisc. whole	2.8 ± 0.9	ns	< 0.19	< 0.004
"	Snapper	Viscera	ns	ns	na	na
"	"	Evisc. whole	6.0 ± 1.2	ns	na	na
"	Flagtail	Viscera	6.6 ± 2.0	ns	na	na
"	"	Evisc. whole	2.8 ± 0.4	ns	na	na
Truk/Moen I.	Parrotfish	Evisc. whole	6.6 ± 0.8	ns	na	na
Ponape/Kitti	Goatfish	Viscera	5.7 ± 2.4	ns	< 0.2	na
"	"	Evisc. whole	2.4 ± 0.4	ns	< 0.1	na
"	"	Viscera	16 ± 4.7	0.59 ± 0.30	na	na
"	"	Evisc. whole	4.7 ± 0.7	0.09 ± 0.04	< 0.1	na
"	"	Viscera	ns	ns	na	na
"	"	Evisc. whole	2.5 ± 1.0	ns	< 0.25	< 0.002
"	Mullet	Entire	4.6 ± 2.8	ns	< 0.35	< 0.007
"	"	Viscera	5.8 ± 3.2	ns	< 0.43	na
"	"	Evisc. whole	2.8 ± 3.2	ns	< 0.25	< 0.002
"	Convict Surgeon	Viscera	9.5 ± 2.6	ns	< 0.43	na
"	"	Evisc. whole	ns	ns	0.05 ± .02	< .04
"	Parrotfish	Muscle	4.0 ± 1.2	0.07 ± 0.05	na	< 0.03
"	"	Viscera	3.4 ± 2.3	ns	< 0.9	na
"	"	Remainder	3.2 ± 1.7	ns	na	na

Table 1. (Continued)

Collection Site	Species	Tissue	Radionuclide concentration in pCi/g, dry ^a			
			⁴⁰ K	¹³⁷ Cs	⁹⁰ Sr	^{239,240} Pu
Palau/Majakal I.	Jack	Entire	8.3 ± 1.4	0.20 ± 0.9	< 0.3	< 0.004
"	Goatfish	Evisc. whole	5.5 ± 0.1	0.06 ± 0.04	< 0.23	< 0.003
"	"	Evisc. whole	3.3 ± 1.1	0.04 ± 0.03	na	na
Guam	Parrotfish	Muscle	4.5 ± 3.2	ns	na	na
"	"	Viscera	14 ± 3.4	ns	na	na
"	"	Remainder	2.4 ± 1.1	ns	na	na
"	Mullet	Viscera	7.5 ± 5.3	ns	na	na
"	"	Evisc. whole	2.8 ± 2.1	ns	na	na

a. The error values are two-sigma, propagated, counting errors for a single sample.

b. Evisc. whole = eviscerated whole fish, e.g. the entire fish less the viscera.

c. ns = not significant; the net sample count is less than the two-sigma propagated counting error. na = not analyzed.

Appendix Table 2. Some Radionuclides in Plants Collected on Majuro Atoll in November 1975.

Collection Site	Sample Type	Radionuclide concentration in pCi/g, dry ^a		
		40K	137Cs	90Sr
Eastern Gateway	Pandanus, edible fruit	4.0 ± 1.6	1.9 ± 0.1	<0.02
"	" inedible fruit	5.1 ± 1.6	2.0 ± 0.2	na
"	" leaves	2.7 ± 2.3	0.51 ± 0.15	na
Laura Village	" edible fruit	2.3 ± 1.0	4.6 ± 0.19	na
"	" inedible fruit	ns ^b	3.2 ± 0.17	<.24
"	" leaves	1.3 ± 0.5	0.82 ± 0.03	<.09
Mile 17.3	" edible fruit	na	na	<.09
"	" inedible fruit	6.5 ± 1.3	1.5 ± 0.11	0.66 ± 0.32
"	" leaves	8.9 ± 1.5	0.72 ± 0.06	na
Eastern Gateway	Coconut, meat	6.6 ± 1.7	0.74 ± 0.07	<.08
"	" milk	39.0 ± 9.8	5.9 ± 5.9	<.76
"	" leaves	12.0 ± 1.9	0.41 ± 0.06	na
"	" meat	na	na	na
"	" milk	32.0 ± 11	na	na
"	" leaves	5.9 ± 2.1	0.20 ± 0.06	na
Mile 17.3	" meat	13.0 ± 1.9	0.97 ± 0.08	<.14
"	" milk	72.0 ± 9.9	4.0 ± 0.51	<.07
"	" leaves	4.3 ± 0.3	0.60 ± 0.02	<.62
"	" copra	7.4 ± 0.7	0.27 ± 0.04	na
Laura Village	" Breadfruit, edible portion	9.8 ± 1.8	1.5 ± 0.1	<.02
Eastern Gateway	" inedible portion	10.0 ± 0.1	1.4 ± 0.1	0.07 ± 0.06
"	" leaves	6.4 ± 2.1	1.0 ± 0.2	na
Laura Village	" edible portion	18.0 ± 2.0	0.73 ± 0.07	na
"	" inedible portion	17.0 ± 1.9	0.53 ± 0.07	<.19
"	" leaves	8.1 ± 1.4	2.0 ± 0.13	0.28 ± 0.22
"	" edible fruit	19.0 ± 1.9	1.8 ± 0.12	0.15 ± 0.10
"	" inedible fruit	21.0 ± 2.6	2.3 ± 0.17	0.79 ± 0.05
"	" seeds	22.0 ± 7.5	4.0 ± 0.40	na
"	" edible fruit	17.0 ± 2.0	0.05 ± 0.04	<.05

a. The error values are two-sigma, propagated, counting errors for a single sample.

b. ns= not significant; the net sample count is less than the two-sigma counting error. na= not analyzed.

Appendix Table 3. Some Radionuclides in Plants Collected in Ponape District in November 1975.

Collection site	Sample type	Radionuclide concentration in pci/g, dry ^a			
		40K	137Cs	90Sr	239,240Pu
Kolonja	Pandanus, edible fruit	9.6 ± 1.6	1.9 ± 0.13	0.27 ± 0.02	na ^b
"	" inedible fruit	10.0 ± 0.6	1.2 ± 0.6	0.11 ± 0.02	na
"	" leaves	5.1 ± 1.7	0.73 ± 0.10	0.61 ± 0.07	na
Napali I.	" edible fruit	7.8 ± 2.3	0.23 ± 0.06	<.10	na
"	" inedible fruit	8.6 ± 2.1	0.18 ± 0.13	na	na
"	" leaves	2.9 ± 0.4	ns ^b	na	na
Kolonja	Breadfruit, edible fruit	15.0 ± 1.9	0.73 ± 0.13	<.07	na
"	" inedible fruit	8.7 ± 0.5	0.47 ± 0.04	na	.027 ± .006
"	" leaves	13.0 ± 2.0	0.77 ± 0.10	na	na
"	" edible fruit	11.0 ± 1.8	2.3 ± 0.12	na	na
"	" inedible fruit	11.0 ± 2.1	2.5 ± 0.18	<.17	.003 ± .002
"	" leaves	3.5 ± 1.2	0.73 ± 0.09	<.35	na
Nan Modal	" leaves	9.2 ± 0.7	0.53 ± 0.04	1.4 ± 0.1	na
Kolonja	Coconut, meat	5.8 ± 1.3	0.38 ± 0.06	0.10 ± 0.6	na
"	" milk	54.0 ± 31	2.6 ± 1.2	<.09	<.002
"	" leaves	3.9 ± 0.3	0.25 ± 0.02	<.85	<1.1
Nand	" leaves	ns	0.25 ± 0.06	na	na
Kolonja	" copra	5.4 ± 1.6	0.30 ± 0.05	0.23 ± 0.08	na
"	" edible fruit	19.0 ± 2.1	0.25 ± 0.05	<.06	<.001
"	" inedible fruit	22.0 ± 2.9	0.25 ± 0.08	0.20 ± 0.04	<.001
"	" seeds	18.0 ± 2.6	0.23 ± 0.08	na	na
"	" edible fruit	19.0 ± 2.2	0.05 ± 0.04	<.09	na
"	Banana, root	2.4 ± 1.1	0.31 ± 0.07	1.3 ± 0.1	<.001
"	Taro,				

a. The error values are two-sigma, propagated, counting errors for a single sample.

b. ns= not significant; the net sample count is less than the two-sigma counting error. na= not analyzed.

Appendix Table 4. Some Radionuclides in Plants Collected in Truk District in November 1975.

Collection Site	Sample Type	Radionuclide concentration in pCi/g, dry ^a			
		40K	137Cs	90Sr	239,240Pu
Fefan I.	Pandanus, edible fruit	16.0 ± 1.0	0.15 ± 0.05	0.06 ± 0.03	na ^b
"	" inedible fruit	10.0 ± 0.8	0.14 ± 0.05	na	na
"	" leaves	2.2 ± 0.6	0.06 ± 0.03	na	na
Moen I.	" edible fruit	7.3 ± 0.1	0.25 ± 0.03	<.11	na
"	" inedible fruit	9.5 ± 0.6	ns ^b	na	na
"	" leaves	8.1 ± 0.7	ns	na	na
Dublon I.	" edible fruit	17.0 ± 0.4	0.23 ± 0.03	<.12	<.001
"	" inedible fruit	12.0 ± 0.5	0.06 ± 0.03	na	na
"	" leaves	13.0 ± 0.5	0.08 ± 0.03	na	na
Fefan I.	Breadfruit, edible fruit	12.0 ± 0.5	ns	na	na
"	" inedible fruit	19.0 ± 0.9	0.06 ± 0.05	na	na
"	" leaves	9.5 ± 1.3	0.11 ± 0.08	<.14	na
Moen I.	" edible fruit	5.4 ± 0.7	1.2 ± 0.1	<.12	<.002
"	" inedible fruit	9.5 ± 0.6	1.5 ± 0.1	na	na
"	" leaves	5.3 ± 1.3	1.2 ± 0.1	1.1 ± 0.4	na
Dublon I.	" edible fruit	13.0 ± 0.4	ns	<.07	na
"	" inedible fruit	21.0 ± 0.7	ns	na	na
"	" leaves	12.0 ± 0.7	ns	na	na
Fefan I	Coconut, meat	1.4 ± 0.5	0.18 ± 0.03	<.07	na
"	" milk	2.2 ± 0.1	0.09 ± 0.01	na	na
"	" leaves	8.8 ± 0.5	0.26 ± 0.03	na	na
Moen I.	" meat	3.8 ± 0.3	0.36 ± 0.02	<.09	<.001
"	" leaves	4.4 ± 0.4	0.03 ± 0.02	na	na
Dublon I.	" meat	3.6 ± .	0.04 ± 0.04	<.07	na
"	" leaves	4.2 ± 3.3	ns	<.07	na
Fefan I.	Papaya, edible fruit	21.0 ± 2.4	0.71 ± 0.08	na	<.001
"	" inedible fruit	23.0 ± 1.0	0.61 ± 0.07	<.18	<.001
"	" seeds	19.0 ± 1.0	0.78 ± 0.07	na	na
Dublon	" edible fruit	11.0 ± 0.4	1.9 ± 0.03	<.07	na
"	" inedible fruit	12.0 ± 1.2	2.1 ± 0.1	na	<.001
"	" seeds	15.0 ± 0.6	3.0 ± 0.1	na	na
"	Coconut copra	1.8 ± 0.7	ns	<.07	na

a. The error values are two-sigma, propagated, counting errors for a single sample.

b. ns= not significant; the sample count is less than the two-sigma counting error. na= not analyzed.

Appendix Table 5. Some Radionuclides in Plants Collected in the Palau Islands in November 1975.

Collection Site	Sample Type	Radionuclide concentration in pCi/g, dry ^a			
		⁴⁰ K	¹³⁷ Cs	⁹⁰ Sr	^{239,240} Pu
Babelthaupt I.	Pandanus, edible fruit	8.5 ± 1.7	0.67 ± 0.07	<0.34	<0.001
"	" inedible fruit	4.0 ± 0.5	0.23 ± 0.03	<0.07	na
"	leaves	4.5 ± 0.7	0.06 ± 0.05	<0.10	na
Koror I.	edible fruit	13.0 ± 0.6	0.53 ± 0.04	0.36 ± 0.18	<0.001
"	inedible fruit	10.0 ± 0.7	0.23 ± 0.05	na	na
"	leaves	8.6 ± 2.5	0.24 ± 0.07	0.16 ± 0.10	na
Babelthaupt I.	Breadfruit, edible fruit	14.0 ± 0.5	0.06 ± 0.03	<0.07	na
"	inedible fruit	15.0 ± 0.8	0.07 ± 0.04	<0.09	<0.002
"	leaves	5.4 ± 0.8	ns ^b	na	na
Koror I.	edible fruit	18.0 ± 0.5	0.13 ± 0.03	<0.07	na
"	inedible fruit	14.0 ± 0.6	0.04 ± 0.03	na	<0.001
"	leaves	16.0 ± 0.5	ns	na	na
Babelthaupt I.	Coconut, meat	13.0 ± 1.7	0.17 ± 0.05	<0.07	na
"	leaves	8.7 ± 0.5	0.10 ± 0.03	na	na
"	meat	18.0 ± 0.8	ns	na	na
"	leaves	5.7 ± 0.4	ns	na	na
Koror I.	"	7.4 ± 0.5	0.05 ± 0.03	<0.07	<0.001
"	meat	4.7 ± 0.5	ns	<0.07	na
Babelthaupt I.	Papaya, edible fruit	14.0 ± 0.5	0.12 ± 0.03	<0.22	<0.001
"	inedible fruit	18.0 ± 0.6	0.13 ± 0.04	na	na
"	seeds	20.0 ± 4.2	ns	na	na
"	Taro, root	8.4 ± 0.7	ns	<0.07	<0.002
"	" stem	28.0 ± 0.9	0.24 ± 0.05	<0.14	na
"	" leaves	26.0 ± 3.3	0.26 ± 0.23	<0.26	na
"	Cassava, root	4.9 ± 0.7	ns	<0.12	na

a. The error values are two-sigma, propagated, counting errors for a single sample.

b. ns= not significant; the sample count is less than the two-sigma counting error. na= not analyzed.

Appendix Table 6. Some Radionuclides in Plants Collected on Guam in November 1975.

Collection Site	Sample Type	Radionuclide concentration in pCi/g, dry ^a			
		40K	137Cs	90Sr	239,240Pu
Agana	Pandanus, edible fruit	17.0 ± 0.6	1.1 ± 0.04	<0.23	<0.001
"	" inedible fruit	11.0 ± 1.8	0.84 ± 0.10	na	na
"	" leaves	13.0 ± 2.5	1.0 ± 0.10	na	na
Agat	" edible fruit	22.0 ± 0.7	ns ^b	<0.55	<0.001
"	" inedible fruit	15.0 ± 2.0	ns	na	na
"	" leaves	12.0 ± 0.4	0.04 ± 0.02	na	na
Dededo	" edible fruit	6.1 ± 1.7	18.00 ± 0.26	<0.85	<0.001
"	" inedible fruit	6.6 ± 1.0	16.00 ± 0.17	0.16 ± 0.06	na
"	" leaves	4.0 ± 1.0	1.6 ± 0.08	0.58 ± 0.12	na
Merrizo	Breadfruit, edible fruit	16.0 ± 0.4	ns	<0.11	na
"	" inedible fruit	22.0 ± 0.4	ns	na	na
"	" leaves	9.7 ± 0.5	ns	na	na
Dededo	" edible fruit	18.0 ± 0.6	0.35 ± 0.03	<0.12	<0.001
"	" inedible fruit	24.0 ± 0.7	0.51 ± 0.05	<0.07	na
"	" leaves	17.0 ± 2.1	0.74 ± 0.08	0.49 ± 0.09	na
Inarajan	" edible fruit	12.0 ± 0.4	ns	<0.07	na
"	" inedible fruit	20.0 ± 2.0	ns	na	na
Agana	Coconut, meat	9.3 ± 1.6	ns	na	na
"	" leaves	3.0 ± 1.1	0.20 ± 0.05	<0.07	<0.002
Dededo	" meat	4.7 ± 0.5	0.13 ± 0.04	<0.08	na
"	" milk	3.7 ± 1.6	0.28 ± 0.05	<0.06	na
"	" leaves	0.8 ± 0.2	ns	na	na
Agana	Papaya, edible fruit	44.0 ± 3.4	0.19 ± 0.05	na	na
"	" inedible fruit	40.0 ± 4.2	0.41 ± 0.21	<0.71	na
Inarajan	" edible fruit	40.0 ± 1.5	ns	na	na
"	" inedible fruit	40.0 ± 1.6	0.12 ± 0.10	<0.42	<0.001
"	" seeds	26.0 ± 0.7	ns	na	na
Dededo	Taro, root	5.6 ± 0.3	0.05 ± 0.02	<0.18	<0.001
"	" stem	38.0 ± 1.4	ns	na	na
"	" leaves	29.0 ± 1.4	0.24 ± 0.08	na	na

a. The error values are two-sigma, propagated, counting errors for a single sample.

b. ns= not significant; the sample count is less than the two-sigma counting error. na= not analyzed.

Appendix Table 7. Some Radionuclides in Soil Collected on Majuro Atoll in November 1975.

Collection Site	Sample Depth in cm	Radionuclide concentration in pCi/g, dry ^a			
		⁹⁰ Sr	¹³⁷ Cs	²³⁸ U	^{239,240} Pu
Eastern Gateway	Surface composite	1.3 ± 0.38	0.11 ± 0.03	ns ^b	0.022 ± 0.020
"	0 - 2.5	0.20 ± 0.10	0.07 ± 0.04	ns	0.14 ± 0.09
"	2.5 - 5	<0.25	0.06 ± 0.04	ns	na ^b
"	5 - 10	0.19 ± 0.08	ns	0.78 ± 0.24	0.009 ± 0.006
"	10 - 15	na	ns	0.33 ± 0.25	na
"	15 - 25	na	ns	0.56 ± 0.23	na
"	25 - 50	na	ns	ns	na
Laura Village	0 - 2.5	0.19 ± 0.12	0.09 ± 0.04	0.47 ± 0.21	na
"	2.5 - 5	na	ns	0.75 ± 0.41	0.014 ± 0.006
"	5 - 10	na	ns	0.77 ± 0.41	na
"	Surface composite	0.49 ± 0.07	0.08 ± 0.04	1.3 ± 0.55	0.004 ± 0.002
Mile 17	"	<0.19	0.19 ± 0.04	0.88 ± 0.25	0.018 ± 0.006

a. The error values are two-sigma, propagated, counting errors for a single sample.

b. ns= not significant; the net sample count is less than the two-sigma counting error. na= not analyzed.

Appendix Table 8. Some Radionuclides in Soil Collected in the Ponape District in November 1975.

Collection Site	Sample Depth in cm	Radionuclide concentration in pCi/g, dry ^a							
		⁹⁰ Sr	¹³⁷ Cs	²²⁶ Ra	²²⁸ Th	²³² Th	²³⁸ U	^{239,240} Pu	
Nand Napa'i I.	Surface composite	<0.19	0.49 ± 0.08	0.56 ± 0.06	1.5 ± 0.12	0.94 ± 0.26	0.54 ± 0.39	na ^b	
"	0 - 2.5	1.2 + 0.3	0.09 ± 0.03	ns ^d	ns	ns	ns	0.03 + 0.02	
"	2.5 - 5	<0.19	0.19 ± 0.04	0.13 ± 0.06	ns	0.30 ± 0.19	1.2 ± 0.5	0.008 ± 0.004	
Kolonia	5 - 10	na	0.16 ± 0.05	0.09 ± 0.06	ns	0.92 ± 0.23	0.62 ± 0.19	na	
"	0 - 2.5	na	0.28 ± 0.05	0.60 ± 0.05	+ 0.12	0.98 ± 0.17	1.3 ± 0.45	<0.004	
Kolonia	2.5 - 5	na	0.14 ± 0.04	0.49 ± 0.04	0.89 ± 0.08	0.66 ± 0.13	0.78 ± 0.29	<0.018	
"	5 - 10	na	0.09 ± 0.04	0.53 ± 0.05	0.97 ± 0.09	0.66 ± 0.13	0.80 ± 0.47	na	
Kolonia	0 - 2.5	na	0.78 ± 0.09	0.68 ± 0.06	1.5 ± 0.11	1.3 ± 0.23	1.1 ± 0.36	0.014 ± 0.004	
"	5 - 10	<0.07	0.74 ± 0.08	0.68 ± 0.07	1.5 ± 0.11	1.3 ± 0.23	1.4 ± 0.63	na	
"	10 - 15	na	0.24 ± 0.06	0.52 ± 0.06	0.60 ± 0.29	1.2 ± 0.25	0.60 ± 0.29	na	
"	15 - 25	na	0.14 ± 0.05	0.45 ± 0.06	0.98 ± 0.11	0.81 ± 0.24	0.77 ± 0.58	na	
"	25 - 50	na	0.12 ± 0.04	0.51 ± 0.05	1.1 ± 0.09	1.2 ± 0.20	1.3 ± 0.48	na	
"	25 - 50	na	0.04 ± 0.03	0.69 ± 0.05	1.2 ± 0.09	0.88 ± 0.17	0.80 ± 0.32	na	

a. The error values are two-sigma, propagated, counting errors for a single sample.

b. ns= not significant; the net sample count is less than the two-sigma counting error. na= not analyzed.

Appendix Table 9. Some Radionuclides in Soil Collected at Truk in November 1975.

Collection Site	Sample Depth in cm	Radionuclide concentration in $\mu\text{Ci/g}$, dry ^a							
		⁹⁰ Sr	¹³⁷ Cs	²²⁶ Ra	²²⁸ Th	²³² Th	²³⁸ U	^{239,240} Pu	
Fefan I.	0 - 2.5	0.16 ± 0.16	0.41 ± 0.06	0.41 ± 0.06	0.49 ± 0.11	0.32 ± 0.13	ns ^b	0.092 ± 0.008	
"	2.5 - 5	0.52 ± 0.32	0.34 ± 0.06	0.51 ± 0.06	0.62 ± 0.09	0.76 ± 0.23	0.71 ± 0.29	0.007 ± 0.002	
"	5 - 10	na	0.28 ± 0.05	0.45 ± 0.06	0.82 ± 0.10	0.78 ± 0.28	0.83 ± 0.59	na	
Moen I.	0 - 2.5	na	0.10 ± 0.04	0.28 ± 0.05	0.28 ± 0.07	0.36 ± 0.20	0.97 ± 0.27	< 0.02	
"	2.5 - 5	na	0.07 ± 0.04	0.14 ± 0.05	0.21 ± 0.08	0.45 ± 0.26	1.3 ± 0.05	0.005 ± 0.002	
"	5 - 10	na	0.16 ± 0.05	0.28 ± 0.06	0.42 ± 0.08	0.51 ± 0.25	0.99 ± 0.27	na	
"	10 - 15	na	0.13 ± 0.05	0.42 ± 0.06	0.53 ± 0.10	0.74 ± 0.27	1.8 ± 0.59	na	
"	15 - 25	na	0.11 ± 0.05	0.89 ± 0.07	0.34 ± 0.10	0.49 ± 0.22	1.4 ± 0.33	na	
"	25 - 35	na	0.07 ± 0.04	0.30 ± 0.06	0.20 ± 0.09	0.59 ± 0.22	1.2 ± 0.57	na	
"	Surface composite	na	0.24 ± 0.05	0.22 ± 0.06	0.13 ± 0.09	0.41 ± 0.21	1.5 ± 0.53	na	
Dublon I.	0 - 2.5	na	0.35 ± 0.06	0.38 ± 0.05	0.55 ± 0.07	0.53 ± 0.21	0.76 ± 0.29	0.022 ± 0.005	
"	2.5 - 5	na	0.15 ± 0.05	0.27 ± 0.06	0.34 ± 0.09	0.97 ± 0.29	1.3 ± 0.58	0.004 ± 0.001	
"	5 - 10	na	0.16 ± 0.04	0.27 ± 0.05	0.28 ± 0.10	0.39 ± 0.29	1.3 ± 0.58	na	
"	5 - 10	na	0.19 ± 0.04	0.24 ± 0.05	0.42 ± 0.08	0.60 ± 0.19	1.2 ± 0.45	< 0.002	

a. The error values are two-sigma, propagated, counting errors for a single sample.

b. ns= not significant; the net sample count is less than the two-sigma counting error. na= not analyzed.

Appendix Table 10. Some Radionuclides in Soil Collected in the Palau Islands in November 1975.

Collection Site	Sample Depth in cm	Radionuclide concentration in pCi/g, dry ^a				
		⁹⁰ Sr	¹³⁷ Cs	²²⁶ Ra	²³² Th	^{239,240} Pu
Koror I.	Surface composite	<0.12	0.19 ± 0.04	0.24 ± 0.05	0.60 ± 0.19	na ^b
"	0 - 2.5	na	0.19 ± 0.04	ns	ns	na
"	2.5 - 5	na	0.22 ± 0.03	ns	ns	na
"	5 - 10	na	0.22 ± 0.05	0.12 ± 0.04	ns	na
Babelthaup I.	Surface composite	0.14 ± 0.08	0.60 ± 0.07	0.11 ± 0.05	0.27 ± 0.24	0.012 ± 0.003 ^c
"	0 - 2.5	<0.12	0.69 ± 0.08	0.39 ± 0.05	ns	0.006 ± 0.003 ^c
"	2.5 - 5	<0.10	0.42 ± 0.06	0.40 ± 0.06	ns	0.010 ± 0.002
"	5 - 10	na	0.17 ± 0.05	0.18 ± 0.05	0.40 ± 0.23	na
Babelthaup I.	0 - 2.5	<0.18	0.33 ± 0.06	0.15 ± 0.04	ns	0.006 ± 0.003 ^c
"	2.5 - 5	na	0.30 ± 0.06	0.15 ± 0.05	ns	na
"	5 - 10	na	0.21 ± 0.04	0.16 ± 0.07	0.33 ± 0.23	na
"	10 - 15	na	0.07 ± 0.04	0.13 ± 0.07	ns	na
"	15 - 25	na	0.04 ± 0.03	0.11 ± 0.07	0.56 ± 0.26	na
"	25 - 35	na	ns	ns	ns	na
"	35 - 50	na	ns	ns	ns	na

a. The error values are two-sigma, propagated, counting errors for a single sample.

b. ns= not significant; the net sample count is less than the two-sigma counting error. na= not analyzed.

c. These two samples were pooled for the ^{239,240}Pu analysis.

Appendix Table 11. Some Radionuclides in Soil Collected on Guam in November 1975.

Collection Site	Sample Depth in cm	Radionuclide concentration in pCi/g, dry ^a						
		137Cs	210pb	210Ra	232Th	235U	239,240Pu	
Agana	0 - 2.5	0.24 ± 0.06	20.0 ± 7.2	78.0 ± 0.4	4.4 ± 0.8	5.6 ± 0.1	0.010 ± .004	
"	2.5 - 5	1.0 ± 0.2	22.0 ± 5.7	ns	1.2 ± 0.3	ns	0.003 ± .002	
"	5 - 10	ns ^b	11.0 ± 6.6	69.0 ± 0.4	4.8 ± 0.6	5.1 ± 0.3	0.003 ± .002	
Dededo	0 - 2.5	ns	10.0 ± 3.5	42.0 ± 0.3	4.2 ± 0.6	4.8 ± 0.6	na	
"	2.5 - 5	ns	9.4 ± 5.7	44.0 ± 0.3	4.2 ± 0.6	4.0 ± 0.1	na	
"	5 - 10	ns	16.0 ± 5.8	44.0 ± 0.3	4.2 ± 0.6	4.0 ± 0.1	na	
"	10 - 15	ns	8.4 ± 3.5	43.0 ± 0.3	4.5 ± 0.6	3.8 ± 0.1	na	
"	15 - 25	ns	6.2 ± 5.8	46.0 ± 0.3	4.9 ± 0.6	3.6 ± 0.1	na	
"	25 - 35	ns	16.0 ± 3.5	43.0 ± 0.4	5.0 ± 0.6	3.5 ± 0.1	na	
"	35 - 50	ns	14.0 ± 3.6	43.0 ± 0.3	4.6 ± 0.6	3.4 ± 0.1	na	
Tajofoto	0 - 2.5	0.35 ± 0.05	ns	0.6 ± 0.1	0.4 ± 0.2	0.1 ± 0.3	na	
"	2.5 - 5	0.38 ± 0.05	ns	0.6 ± 0.5	0.5 ± 0.2	0.1 ± 0.3	na	
"	5 - 10	0.46 ± 0.05	ns	0.7 ± 0.1	0.6 ± 0.2	0.1 ± 0.04	0.012 ± .004	

a. The error values are two-sigma, propagated, counting errors for a single sample.

b. ns = not significant; the net sample count is less than the two-sigma counting error. na = not analyzed.



University of Hawaii at Manoa

John A. Burns School of Medicine
Department of Family Practice and Community Health
Wahawa General Hospital
95-390 Kuahelani Ave. • Milliam, HI 96759
Phone: (808) 627-3230 • Fax: (808) 627-3265

August 20, 2001

Honorable Robert A. Underwood

US Congress
2418 Rayburn House Office Building
Washington, DC 20515

Regarding: 1. Report: Radiation Fallout, Guam by Robert Celestial (Atomic Veteran)
2. Letter: Enewetak Cleanup; US Atomic Veterans, by Robert Celestial

Dear Congressman Underwood,

Thank you for meeting with Assistant Secretary of Health, Jeffrey Judge, Frank Hawkins DOE International Medical Programs Chief Operations Officer, Terry Hamillton PhD from Lawrence Livermore Laboratories, and I at your office on July 16, 2001. We met regarding health conditions of the people of Guam that may be attributed to the US Thermo-Nuclear Weapons testing Program in the Marshall Islands (1946-1958). Our discussions centered on the concerns which were raised by Mr. Robert Celestial in the above referenced documents. I have been asked to comment on the medical issues which Mr. Celestial reports.

Whereas this issue is sensitive, I wish to again introduce myself so that you may put my comments into the context of who I am, who I work for, my medical expertise, and my perspective on nuclear weapons testing. I was born and raised in Hawaii, attended medical school at the John Burns School of Medicine (JABSOM) at the University of Hawaii, completed residency training in Family Medicine at UCLA Hospital Center for the Health Sciences in Los Angeles, and completed a Master of Public Health (MPH) degree from Johns Hopkins University School of Public Health and Hygiene. After residency I lived and worked in the Republic Marshall Islands (RMI) for over nine years as a Commander (0-5) in the US Public Health Service. During my tenure (1983-1992) in the RMI I co-developed and was co-medical director of the Four Atoll Health Care (federally funded health care program for the peoples of the four radiation affected

atolls), and subsequently became the Medical Director for the Bureau of Preventive Health Care and Public Health for the Republic of the Marshall Islands.

Presently I am the interim Chairperson and residency director for the Department of Family Medicine and Community Health at JABSOM. I am also the Principal Investigator for a Cooperative Agreement with the Department of Energy. The Congressional funding for the Cooperative Agreement funds a health program for the peoples of Utrik and Rongelap atolls who were directly exposed to the fallout from the 1954 Hydrogen bomb detonation. Funds for this program provides 30% of my University salary. I spend 30% of my time directly working with this program. Our residents and faculty also work intimately to provide health care to this population affected by the nuclear testing program. Additionally I have conducted cancer prevalence studies in most of Micronesia and have developed many other health related research programs in the RMI.

I work integrally with Frank Hawkins in the Department of Energy, with the Ministry of Health and Ministry of Foreign Affairs in the RMI, JABSOM, the Pacific Basin Medical Association (PBMA) and the Pacific Islands Health Officers Association (PIHOA). The RMI has recently invited me to work with them on the health aspects of their changed circumstance document, and work with the health aspects of their Compact negotiations with the United States.

Regarding my personal perspective on the nuclear weapons testing program in the RMI: I feel that the nuclear testing program resulted in unfortunate and tragic health, cultural, social and environmental damages. Additionally the manner in which the testing was conducted and the compensation mechanisms which were instituted were not wholly appropriate and were culturally insensitive. I believe that the present direction of the Department of Energy to assess and deal with the health related issues associated with the weapons testing program has evolved, is bold, culturally sensitive, caring, and seeking the best solutions for the affected population.

Robert Celestial Report and Letter:

I applaud the effort of Mr. Robert Celestial to bring his concerns about health and environmental issues to the forefront. There are some inaccuracies in the factual elements of Mr. Celestial's report and letter. The inaccuracies may be placed into three categories, medical, environmental, and historical. I will be commenting on some of the medical issues, Dr. Terry Hamilton will be commenting on the environmental issues. It may be best to ask the RMI Office in Washington DC (Ambassador DeBrum and Political Officer Holly Barker) to comment on the historical accuracy of the documents.

Medical Comment:

Mr. Robert Celestial attributes several medical conditions to the US nuclear weapons testing program in the RMI. There are several medical conditions which Mr. Celestial

links to effects of ionizing radiation (strontium 90, iodine 131, cesium 137) and pyridostigmine bromide (PB).

Pyridostigmine bromide (PB): The references which Mr Celestial uses regarding PB are about chemicals found during the Gulf War. PB, to my knowledge, was not a product by product or contained in the nuclear weapons that were tested in the RML. Hence it is unclear what context the reference to PB is used by Mr. Celestial.

Ionizing Radiation: Although not all the effects of ionizing radiation and health are known at this time, there is a large body of medical and scientific literature which describes which medical conditions may be related to the effects of ionizing radiation. Several medical conditions which Mr. Celestial mentions are not, at the present time, known to be linked to ionizing radiation. Some of the conditions which **are not presently associated with** ionizing radiation, which were a concern of Mr. Celestial, include: Psoriatic Arthritis, Gout, Degenerative Disease of the bone, Hepatitis C, Gultate. Psoriasis, diabetes, Parkinson's Disease, Alzheimer's disease, Lou Gherig's Disease. Notably the rates of Alzheimer's disease, Parkinson's Disease, and Psoriasis do not appear to be excessive in the RML. Lou Gherig's disease is relatively unknown in the Marshalllese population. Those conditions which **have been** associated with ionizing radiation as mentioned by Mr Celestial are: leukemia, bone cancer, thyroid disease (nodules, cancer, hypothyroidism), miscarriages and birth defects.

Background. As a means to be helpful with this discussion without oversimplification, a brief overview of health and radiation will be provided. Hopefully this discussion will assist the reader understanding reports by Mr. Celestial report in the appropriate medical context.

Radiation may be defined as energy which is propagated as electromagnetic waves, photons, or subatomic particles. Common forms of radiation include ultraviolet rays and light. The type of radiation which is of concern, as it relates to nuclear weapons testing, is ionizing radiation. Ionizing radiation is emitted from radioactive particles and can displace electrons from surrounding atoms. Ionizing radiation therefore has a potential of significant health effects because it can affect the integrity of surrounding atoms and molecules. Many of the particles emitted by nuclear testing including I-131, strontium-90, cesium 131 as mentioned by Mr. Celestial are examples of particles which emit ionizing radiation.

The health effects of the ionizing radiation are directly related to the type of ionizing radiation to which one is exposed, the duration of exposure, the proximity of the exposure to vital tissues, and the dose (amount) of exposure. The longevity, or how long a radioactive particle will be around is a function of its half life. The half life is the period of time during which half the atoms of a radioactive element will undergo disintegration. I-131 has a half life of 3 days, Cesium 131 and strontium 90 about 30 years, and plutonium several thousand years. This means that if there are 100 pound of I-131 created by an atomic blast today, after three days there will be only 50 pounds of I-

I-131 remaining, in six days there will be 25 pounds and so on. Hence different radioactive elements naturally deplete themselves from the environment at various rates and thereby become less of a health hazard over time.

An important consideration to exposure and health effects is the proximity of exposure to critical organs and tissue. Cesium 131 can be concentrated in plants and subsequently ingested by humans. Plutonium can be inhaled when dirt (containing plutonium) is blown into dust particles and inhaled. There are numerous particles which emit ionizing radiation which result from a nuclear explosion. The particles mentioned above have the greatest health relevance for the purposes of this discussion.

The effects of nuclear testing and ionizing radiation for the purposes of this discussion can be broken down into acute effects (immediate, high dose, post explosion) and long term effects (years later, low dose for a long duration). Acute effects describes the health effects that occur after an individual is exposed to high doses of ionizing radiation. The peoples of Chernobyl, peoples of Hiroshima and the people of Utah and Rongelap who were acutely exposed to high levels of ionizing radiation suffered acute effects. The acute health effects include severe burns, loss of hair, bone marrow failure resulting in the loss of production of some or all blood cells, gastrointestinal effects (severe nausea and vomiting), thyroid shutdown, and death. The unborn children of pregnant women who are exposed to high doses of radiation have a greater chance of malformation, miscarriage, and mental retardation. Many of these acute health problems would probably not occur in the peoples of Guam because the dose, and proximity of the ionizing radiation would not be sufficient to cause these types of illness.

Long term effects are caused by ionizing radiation particles which have long half lives and therefore exist in the environment for long periods of time. A long half life coupled with ingestion or inhalation will increase the amount of ionizing radiation to which one may be exposed. Most of the effects of long term exposure are cancers. Cancers are caused by cells which grow in an uncontrolled, disorganized fashion and thereby invade and destroy normal tissues. Ionizing radiation is one of the factors which has been linked to destruction of the normal growth regulating genes in cells, thus, cancers may become prevalent. Long term, low dose radiation theoretically can cause an increase in genetic mutations, malformations and miscarriages. However, studies to date to not support this theoretical construct.

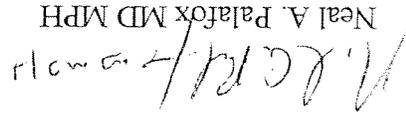
I-131 has a predilection for the thyroid gland. It is unlikely that I-131 would have caused much thyroid illness in Guam because I-131 has a short half life (3 days) and the distance from the RMI to Guam is great. Strontium 90 and cesium 131 both have half lives of about 30 years. If a significant amount of cesium 131 and strontium 90 reached Guam during the Pacific testing period, the amounts left in the Guam environment would now be smaller. Long term exposure to Cesium 131 and Strontium 90 may cause increased rates of certain cancers. Plutonium 90, though present in the RMI, is not thought to be as large a concern as cesium in the RMI. Plutonium, if present in significant doses, may cause higher rates of particular cancers. As mentioned earlier, the above particles which

emit ionizing radiation are **not associated** with an increased risk factor for diabetes, Lou Gherig's disease, Parkinson's disease, gout, or Hepatitis C.

Having stated the above, the only way to understand the true health risk Guam has/had from ionizing radiation and nuclear weapons testing is through formal scientific inquiry. The doses of ionizing radiation that reached Guam during the testing era, the amount of relevant ionizing radiation particles in the environment, and rates of illnesses associated with ionizing radiation can be compared.

Please let me know if I may be of further assistance. I sincerely hope Mr Robert Celestial's concerns will be addressed in a supportive meaningful fashion.

Sincerely,



Neal A. Palafox MD MPH

Interim Chair and Residency Director

Department of Family Practice and Community Health, JABSOM

Principal Investigator

DOE/PHRI Special Medical Care Program for the RMI

cc. Frank Hawkins, DOE
Terry Hamilton PhD, Lawrence Livermore Laboratories
Esther Kiaaina, Chief Political Officer, Office of Congressman Underwood