UCRL-TR-204361

Radiation Fallout—Guam

Terry Hamilton

August 2001

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Information Document

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

RADIATION FALLOUT – GUAM

Terry Hamilton
Lawrence Livermore National Laboratory

6 August 2001

This document attempts to address the environmental radiation issues raised in the Celestial report. The document also provides some background information on atmospheric nuclear weapons testing with specific references to the local impacts n the Federal States of Micronesia and the Mariana Islands (including Guam).

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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 U.S. 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, $T_{½}$	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 kilotons (kT) or megatons (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 the 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 adsorbed 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 Gy = 100 rad.
Dose equivalent	The adsorbed 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 Seivert (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 doses weighed by the relative sensitivities 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 Seivert, but is often expressed in milliSeivert (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 layer of atmosphere below the stratosphere, in which temperature decreases with increasing altitude.

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, alpha-particles, neutrons, and protons, and (2) electromagnetic radiations or photons such as X-ray and gamma rays. When radiation transverses 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. High radiation exposures in man can destroy the immune system, and lead to illness or death. 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 of the average exposure to the U.S. population to ionizing radiation has been made by the National Council on Radiation Protection and Measurements (NCRP 1978) (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.

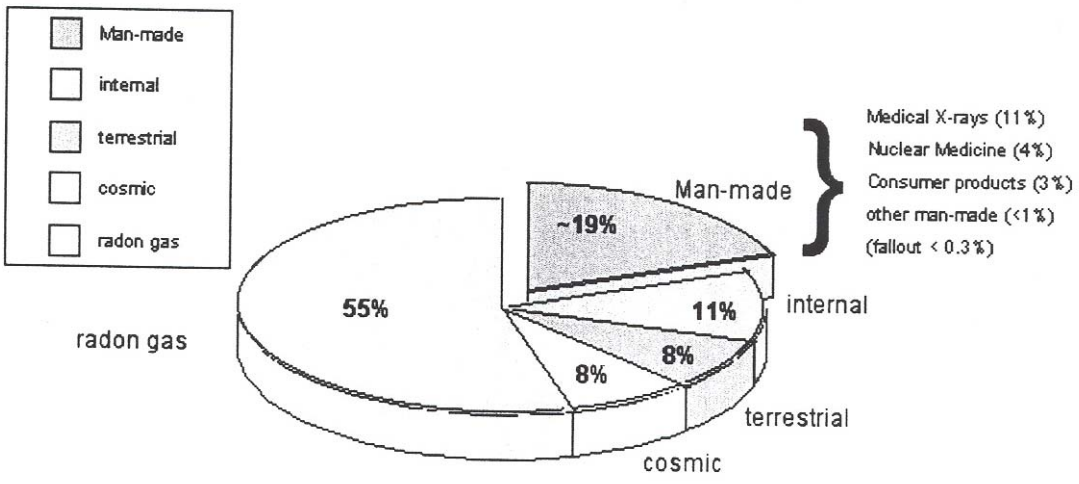

Figure 1. Sources of radiation exposure to the US population.

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 mrem (1.4 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 containing 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 detonation (code named Trinity) utilized the fission of ^{239}Pu, and achieved an explosive yield of 19 kT 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 and ^{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:

$$^{235}\text{U} + \text{Neutron} \rightarrow \text{Fission Fragments} + 2\text{-}3\ \text{Neutrons} + \text{Energy}$$

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 it 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 ^{90}Sr and ^{137}Cs are high. Consequently, these two fission products are often used to assess the range and extent of world-wide 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.

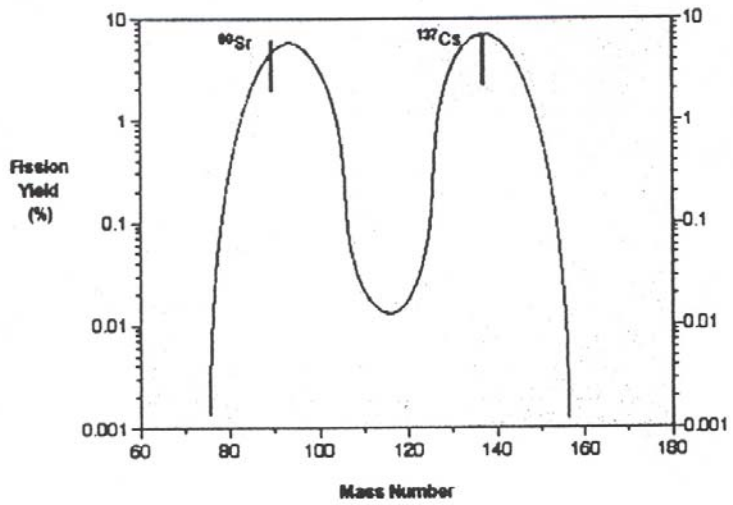

Figure 2. Fission Yield curve for ^{235}U.

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 (^{3}H).

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 denotation implies that at least some residual radioactive material will always be released to the environment. Furthermore, nuclear denotations do not proceed to ultimate completion, so some residual nuclear fuel (e. g., ^{235}U, ^{238}U, ^{239}Pu, ^{3}H, other) remains after the denotation, 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
$^{55}F_{e}$	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.

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	
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)

The United States, 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).

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.

Large-scale atmospheric transport processes are very important in describing the ultimate fate and distribution of radioactive fallout from nuclear weapons tests. An idealized view of the hemispherical air circulations patterns and associated latitudal ^{90}Sr deposition densities on earth are shown in Figure 3. 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 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 between 60,000 ft in equatorial regions down to approximately 26,000 ft. near the poles. 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 rise to the 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.

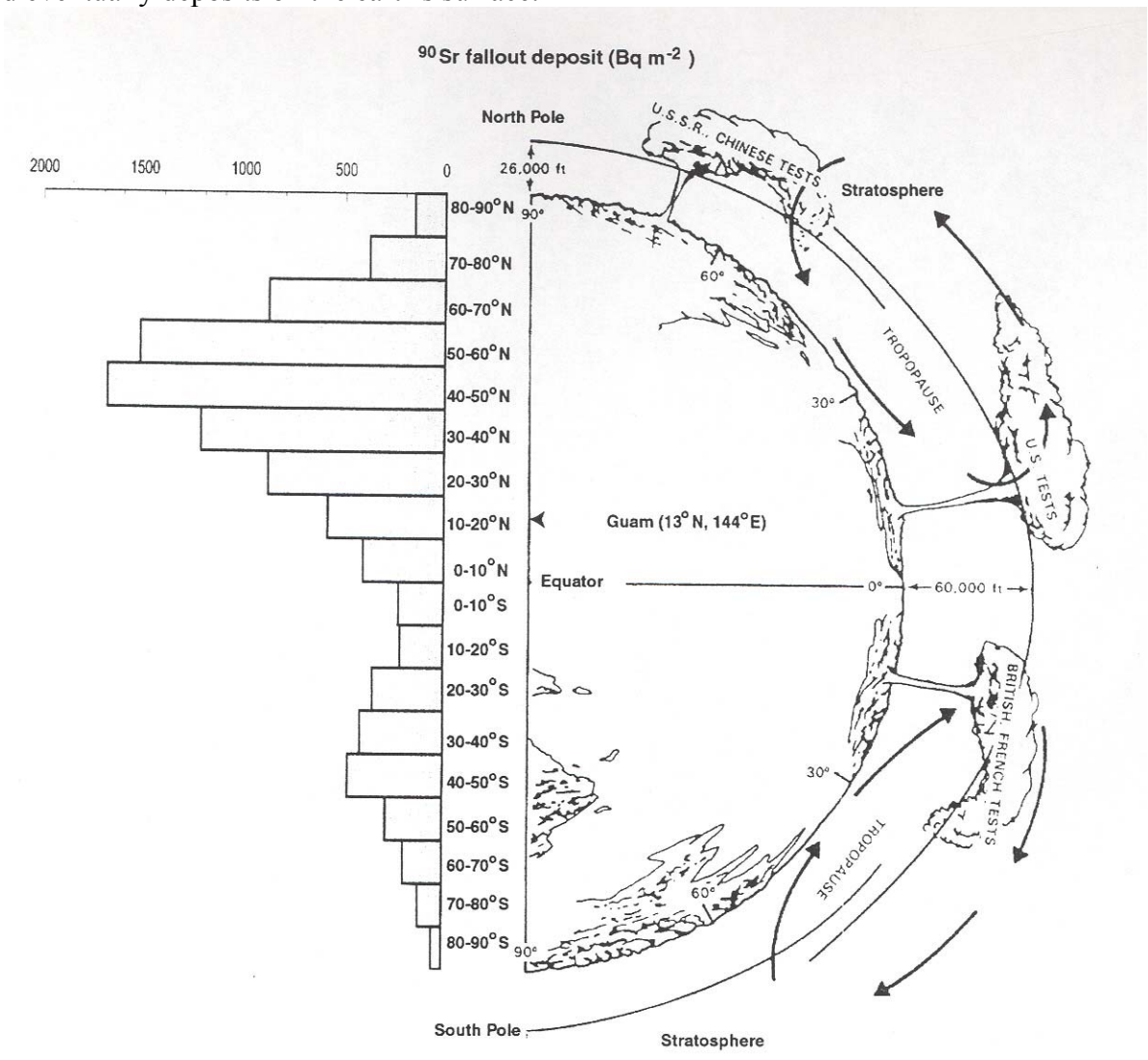

Figure 3. Hemispherical air circulation patterns and associated latitudal ^{90}Sr deposition densities on earth (modified after Kathren, 1984).

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 (~3.7 × 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 around the globe 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 gives the worldwide 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 denotations peaked in 1962, and as shown in the Table 3, produced a peak in the annual ^{90}Sr deposition on earth 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 that the annual deposit. The cumulative global ^{90}Sr deposit at the end of 1990 was approximately 311 PBq. 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 ^{90}Sr deposit occurs in the Southern Hemisphere where less than 10% of the total number of nuclear weapons tests were conducted.

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

	Northern Hemisphere		Southern Hemisphere		Global	
Year	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.

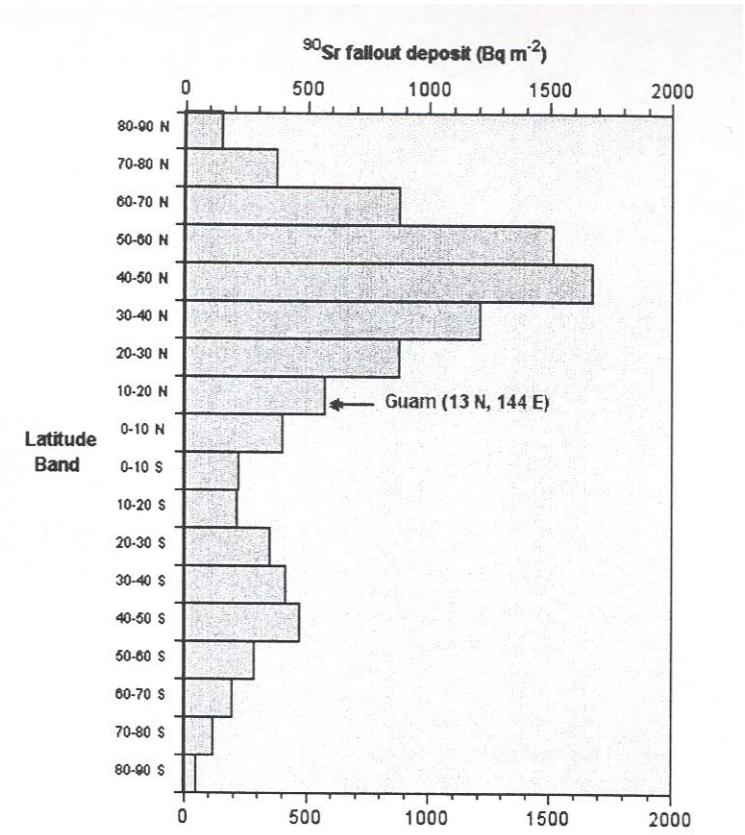

Figure 4. Integrated deposition density of ^{90}Sr versus latitude band (taken from Hamilton *et al.*, 1996).

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 ^{90}Sr (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., ^{131}I) at the time of the test 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). ^{131}I, 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 Babelthaup 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).

^{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 a slightly higher northern latitude that Truk and Palau, so would actually expect 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 probably that similar levels of variability occur on other Pacific Islands, and explain the single high value reported for Pandanus fruit on Guam.

No analyses were made of ^{90}Sr in soils collected from Guam. As discussed previously, the production radios 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 of ^{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}Cs/^{90}Sr activity ratio in world wide fallout is around 1.44 which is very close to the theoretical mix of total energy yields due to fission.

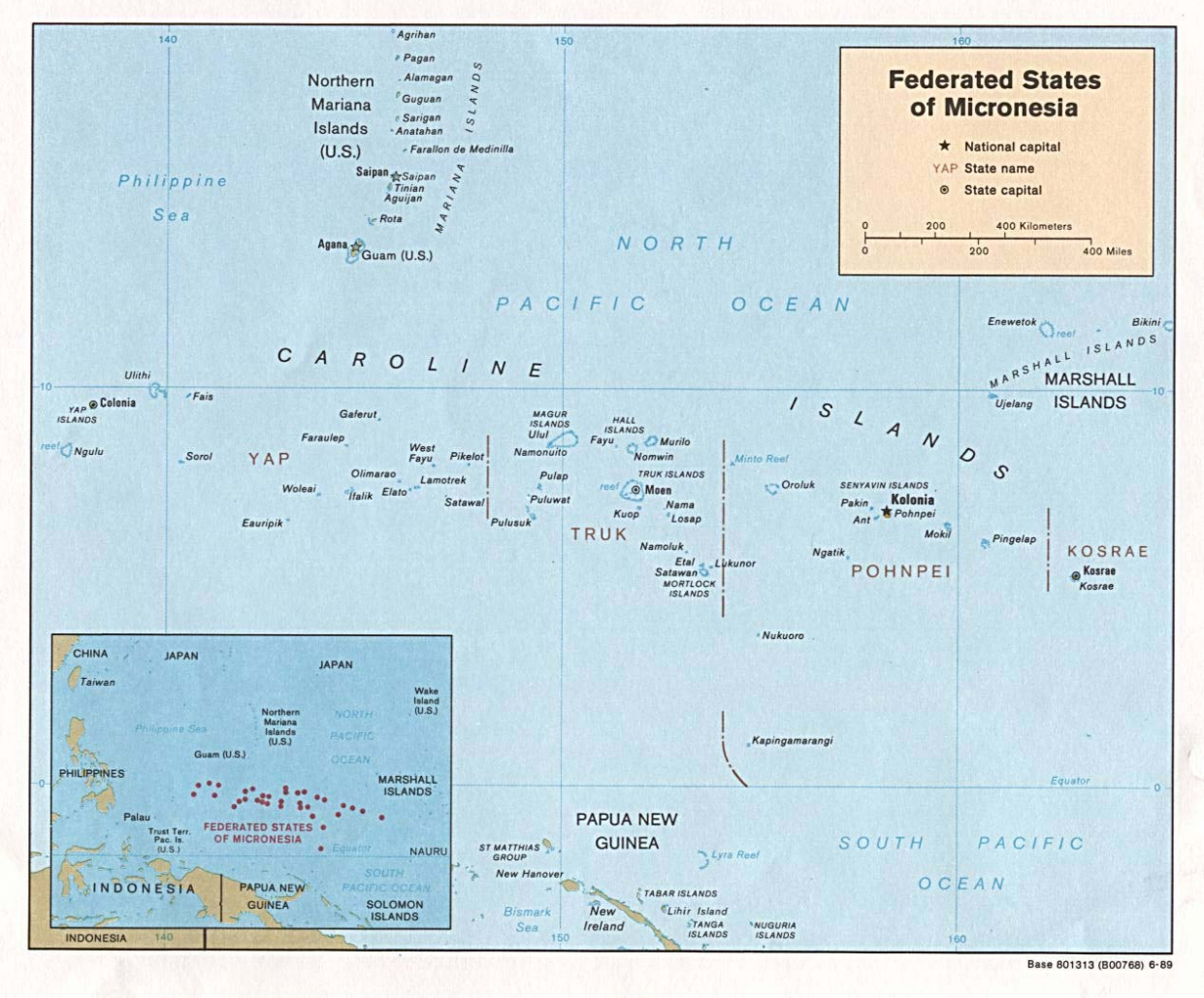

Figure 5. Map of the Federated States of Micronesia and the Mariana Islands.

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 ±- 0.4 pCi g^{-1} (or 0.019 ±- 0.01 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 cm × 0.0 19 Bq g^{-1} × 100 cm × 100 cm × g cm^{-1}). Dividing by the ^{137}Cs/^{90}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 he 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 2.4×10^5 mSv y^1 per Bq m^{-2}). The estimated decay corrected present day ^{137}Cs 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 annual doses in the order of 1002000 mrem (120 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 that what some other isolated populations groups receive in other parts of the world.*

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. Srontium-90 and Cesium-l37 are radionuclides with half-lives of 24,000 years.

Comments. Strontium-90 and Cesiuml37 are considered to be long-lived radionuclides but they have half-lives of 28.5 years and 30.1 years, respectively. ^{137}Cs 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. ^{90}Sr is absorbed into extra cellular fluids and a significant fraction of that ingested and/or inhaled deposited in bone. Beta particles emitted by ^{90}Sr and its daughter products irradiate both calcified bone and adjacent bone marrow. ^{90}Sr 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 alimunisilicates 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 regularly 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 5×10^{-4}/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–^{90}Sr

The ^{90}Sr *air monitoring data from Guam does indicate elevated levels of* ^{90}Sr *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 FSU resumed testing in September 1961, the US also resumed testing in the area of Christmas Island, Johnson Atoll and other Pacific locations. All U.S. tests conducted near Christmas Island and Johnston Atoll were airbursts. *No further tests were ever conducted in the Marshall Islands. During 1962* the U.S. carried out a total of 36 nuclear tests 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 of these tests 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* ^{90}Sr *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 U.S. 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 rest was carried by China in 1980.

The reports issued by ELM on the worldwide fallout are freely available - as such, these reports should not be viewed 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 denotation. However, measurements of* ^{137}*Cs 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* ^{137}*Cs and other short-lived fissions in surface waters within the region. These radionuclides* are also known to be transferred though 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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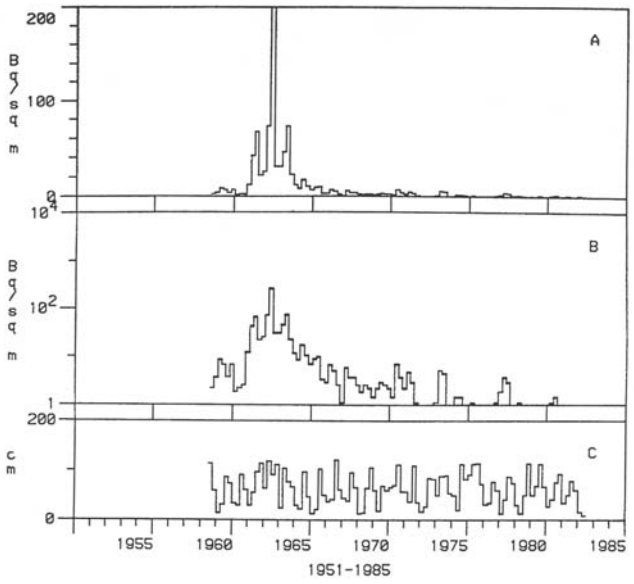
Appendix I

Environmental Measurements Laboratory Worldwide Deposition of ^{90}Sr through 1982, EML 430, EML(Environmental Measurements Laboratory), June 1984.

R. J. Larsen

Refer to graphic showing results of quarterly fallout deposition collections of ^{90}Sr on Guam through 1982.

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 tic 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.



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

University of California
Lawrence Livermore National Laboratory
Technical Information Department
Livermore, CA 94551