The sea turtle wars:
Culture, war and sea turtles in The Republic of the Marshall Islands

Regina Woodrom Rudrud[1], Julie Walsh Kroeker**, Heather Young Leslie**, Suzanne S. Finney**

Abstract

This document considers human-sea turtle ecology in the Republic of the Marshall Islands (RMI) from the perspective of environmental anthropology and outlines the background and rationale for an upcoming project to be conducted by the authors and the College of the Marshall Islands. In particular, the project will examine the:

1. possible use of sea turtles as proxies of human health risks and hazards,
2. potential for sea turtle bone and tissue contaminant levels to back-calculate the initial amounts of toxicants introduced to the area,
3. feasibility of using chromosomal changes resulting from contamination to determine home ranges in areas impacted by nuclear activities, and
4. impact of environmental toxicants such as those related to war and weapons testing on the viability of the sea turtle population, its cultural significance, and its value as a continuing source of food for atoll populations.

The project will also take into account how this cultural valuation can be used to contribute to a sea turtle monitoring programme and population baseline assessment for the RMI. Additionally, in keeping with the concept of *je ilo bok*, literally "write in the book", researchers will document traditional and contemporary Marshallese cultural, ecological and health knowledge regarding sea turtles, describe sea turtle "flows" through marine and human ecosystems (including markets and bartering systems), compare contemporary knowledge of sea turtle ecology, natural history and usage with historical and ethnographic accounts, and put that combined knowledge into preservable formats (in both English and Marshallese) for the use of current and future generations.

By focusing on a culturally, traditionally and nutritionally important species and by investigating potential hazards to these species as well as the human populations that rely on them, this project will allow local participants to help identify and mitigate these hazards as well as gain experience in a wide array of research and investigative techniques that comprise the holistic approach of environmental anthropology.

From ethnographic field techniques to sea turtle biology to maritime archaeology, the long-term benefits of this project will serve to decrease the dependence of the RMI on outside experts and provide potential and creative career skills for a future generation of Marshallese. The success of this project relies on the continual monitoring and testing of sea turtle health and population numbers. This cannot be done without trained experts within the Marshallese community to continue the project beyond what is described here.

This project will result in real knowledge about the risks and hazards to sea turtles in the RMI environment, and real help on how to maintain cultural traditions in ways that support rather than undermine health. Results cannot be predicted, which is why this research is necessary. Possible outcomes include the finding that some portions of turtle cannot be safely consumed, but others can, consumption reserved for only the most special (and rare) occasions is not a risk (in terms of broader whole-system exposures), or that all edible tissues must be avoided. Regardless of the result, this project will develop significant methodologies and establish the capacity and infrastructure for Marshallese-controlled testing/monitoring of native foods.

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[1] Maritime and Fisheries Anthropologist, Ecological Anthropology Program (Marine) specializing in sea turtle conservation biology, University of Hawai'i at Mānoa, 2424 Maile Way, Saunders Hall 346, Honolulu, Hawai'i 96822-2223. Email: ReginaL@hawaii.edu

* PhD Candidate, ABD

** PhD

Introduction

One defining characteristic of the RMI is its involvement throughout the 20th century, and continuing on to today, with war and weapons testing by the US, including 12 years of nuclear weapons testing.

Aquatic organisms inhabiting an environment contaminated with radioactivity receive alpha, beta, and gamma irradiation from external and internal sources; external radiation from radionuclides in water, sediment, and from other organisms in the environment, internal radiation ingested via food and water and from radionuclides absorbed through the skin and respiratory organs. Although most radiation impact studies have evaluated effects at the organism level, assessments of ecological risk are usually concerned with the viability and success of populations. Unlike the case for humans, there is usually no similar concern about the survival of individual organisms in nature. An exception exists for threatened or endangered species such as sea turtles, where the survival of an individual could influence the success of the population (Biayiock et al. 1993).

The sea turtles' longevity, site fidelity and ability to survive extreme injury may make them particularly vulnerable to both acute and chronic exposure to marine contaminants. In addition, because of their position in the food chain, turtles are sensitive to long-term, low-dose contamination (Meyers-Shone and Watson 1990). Slider turtles inhabiting a radioactive reservoir were shown to have genetic damage (mutations) due to long-term exposure to low concentrations of long-lived radionuclides, including cesium-137 (137Cs) and strontium-90 (90Sr) (Lamb et al. 1991). Freshwater turtles in riverine environments contaminated with chemicals and heavy minerals such as strontium-go, 137Cs, cobalt-60 (60Co), and mercury demonstrated single stranded DNA breaks (mutations) (Meyers-Shone and Watson 1990).

Further studies have demonstrated the impacts to sea turtle populations through contamination from heavy metals including: bioaccumulation of heavy metals as the sea turtle ages (Sakai et al. 2000b), mutation in hatchlings related to 137Cs in algae and seagrasses (Vanda et al. 2006), and chemicals have

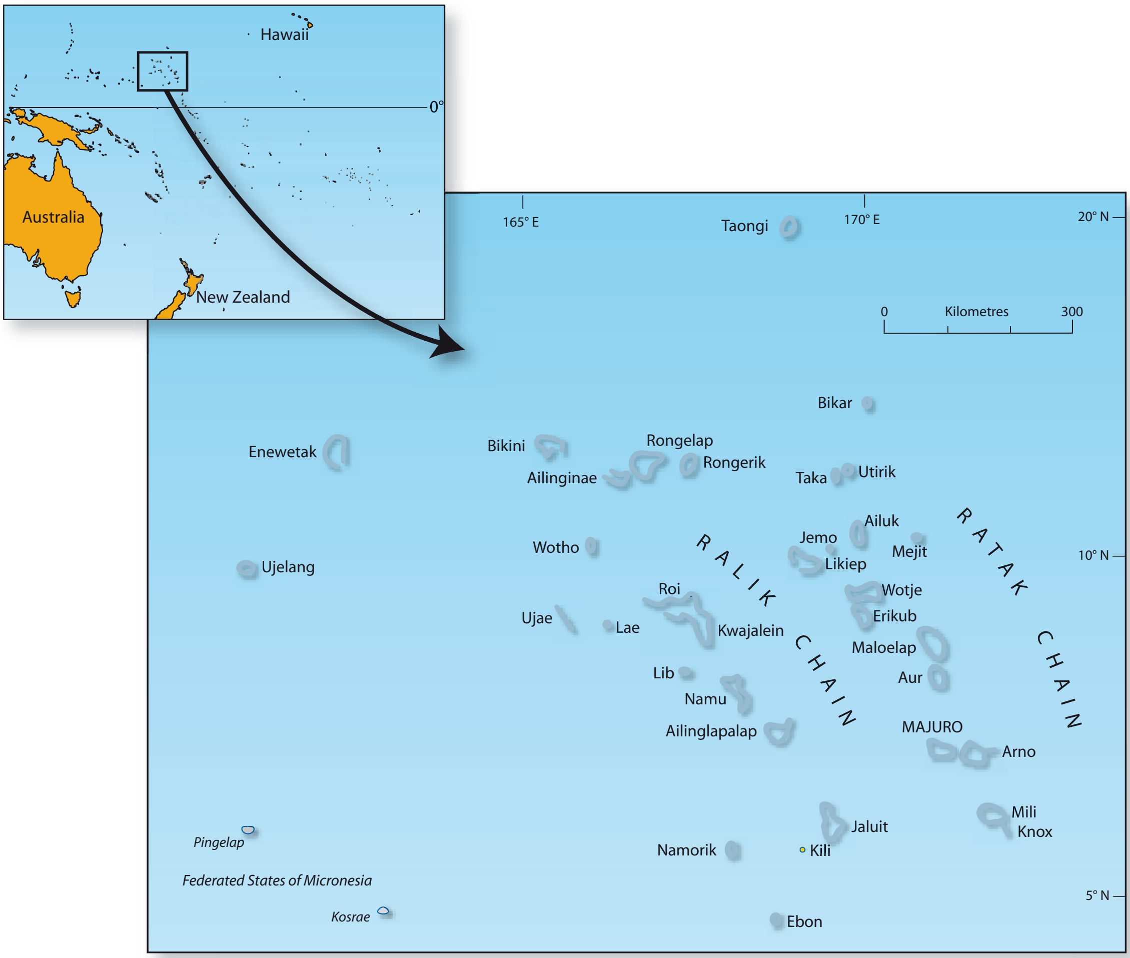

Figure 1. The Republic of the Marshall Islands (RMI)

been demonstrated to affect the sexual differentiation of reptiles such as marine turtles, which demonstrate temperature-dependent sex determination (Keller and McClennan-Green 2004). Metals tend to concentrate in the liver, kidney and muscle (Sakai et al. 2000b) and have also been detected in the blood and carapace tissue, which mimic the levels found in the internal organs and tissues (Wang 2005; Presti et al. 1999). Additionally, a recent study found that in many areas where contaminants are present, "levels of heavy metals and organochlorine compounds measured in sea turtle edible tissues exceed international food safety standards and could result in toxic effects including neurotoxicity, kidney disease, liver cancer and developmental effects in fetuses and children" (Aguirre et al. 2006).

Reports regarding WWII and weapons testing contamination in the Marshalls often discuss estimated fallout levels, expected doses, and cleanup/restoration efforts. But none of the reports, including the biological opinion written for the current Kwajalein missile testing, considered impacts to species that live as long as sea turtles (50–75^{+} years), that can survive grave injury (even the loss of a limb), and that show strong site fidelity to their nesting, foraging and resting sites (often living in the same area for the majority of their lives). Preliminary research into the types and amounts of contaminants that were (and are) deposited into the marine environment suggests that the amount may indeed have been at least, if not greater, than terrestrial contaminants, particularly when the final deposition of the actual equipment is considered; the majority of which went into the lagoons and ocean areas.

War and weapons testing in the RMI

Before considering just how much marine contamination their may have been (or is), it is useful to look first at exactly what took place in the Marshalls as well as statements made by some of the servicemen involved in the testing and cleanup efforts.

World War II

During WWII, the battles to take the Marshall Islands from the Japanese left the islands a "wasteland" of nothing but bombed-out land and debris. The Japanese had military installations on 12 atolls and all of those installations were heavily bombed by US forces. On the main fortifications of Mili (*Mile*), Wotje (*Wōjjā*, Wūjae, Ujae), Jaluit (*Jālooj*, Jalwoj) and Maloelap (*Ṃaļoeļap*), 15,288.70 tons of US bombs and naval shells were delivered. "A US intelligence report following the US capture of Kwajalein Atoll, Marshall Islands, indicates that approximately 50% of the naval shells failed to detonate on impact, an observation reinforced by a statement by the commander of the Japanese garrison made after surrender of Taroa" (Kamada 1947 cited in Spennemann 2006). In addition several of the Japanese-held atolls, once stripped of anti-aircraft capabilities, were used as training grounds for new pilots on their way to other areas and as testing grounds for the effectiveness of new types of weapons: napalm (tested from late 1944 onward), rocket trials (started in mid 1945), and equipment (the fighter-bomber was first developed there), all of which further contributed to the unexploded ordnance load. "Despite initial clean up and a number of subsequent ordnance removal missions there is still an abundance of ammunition located on the islands" (Spennemann 2006:235). The compilers of this document can find no documentation regarding the fate of unexploded ordnance in the lagoons and coastal seas, although we can infer from the island record discussed above that remaining amounts of these materials may be quite large.

By the end of the war, the US had driven Japan out of the Marshall Islands by a series of air, sea and land battles, but the environmental damage continued (ADB 2001). The war left tanks, weapons, ordnance, abandoned fuel and other hazardous materials as well as the wrecks and cargoes of vessels and downed aircraft. "The oil, chemicals and unexploded ordinances still on board many of these vessels pose a grave and imminent danger to the people, marine and coastal environments and fisheries of the region" (SPREP 2002:5). The range of oil impacts includes lethal and sub-lethal toxic effects on fauna and flora and the tainting of edible species (SPREP 2002).

Post WWII, nuclear testing[2]

On 2 March 1944[3], Enewetak (*Ānewetak*, Eniwetak, Eniwetok) was sold by the US Trust Territory of the Pacific (see paragraph below for Trust Territory description) to the US government for the sum of USD 10 (GTTP 1944). On 6 August 1945 the US dropped the first nuclear weapon used in warfare on the Japanese city of Hiroshima; three days later they dropped the second bomb on Nagasaki. These events led to dramatic changes in the Marshall Islands. In November of 1945, the US began to plan operation CROSSROADS[4], a campaign to determine

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[2] The material in the following section, unless otherwise noted, is from: US Department of Energy (DOE). 1982. Marshall Islands: A Chronology 1944-1981. Department of Energy Document 2UF890.m35 c.1. Available online at: http://worf.eh.doe.gov/ihp/chron/A27.PDF

[3] This date probably refers to the first agreement between the Marshallese and the military as there is a handwritten note on the agreement that states: "recorded June 20th 1957 9am".

[4] See declassified film clips for all nuclear testing operations at: The Internet Archive: Universal Access to Human Knowledge: http://www.archive.org/search.php?query= %22marshall islands%22

how US troops, vessels and other military hardware would survive a nuclear attack, and to search for a test site. In January 1946, the US Navy announced that Bikini Atoll (*Pikinni*) fulfilled their requirements. The Bikini chief gave permission, saying "If the United States government and the scientists of the world want to use our island and atoll for furthering development, which with God's blessing will result in kindness and benefit to all mankind, my people will be pleased to go elsewhere" (Mason 1954).

As a result of CROSSROADS, and the Navy's inability to decontaminate the targeted vessels, 23 shipwrecks, contaminated with radioactivity, were added to the waters of Bikini Atoll and 41 radioactive shipwrecks to the waters of Kwajalein (*Kuwajleen*) (Carrell et al. 1991; Delgado et al. 1991; Weitz et al. 1982; USGAO 1985). The underwater Baker shot resulted in about half of the fission products of the bomb remaining in the waters of the lagoon (LANL 1946; Fee 1946; Schubert and Lapp 1957). "Large amounts of radioactive material" were found on the lagoon bottom at Bikini (Berkhouse et al. 1984:159). Further study determined that some marine organisms can concentrate fission products by a factor of 100,000 times the background level in their environment (Hacker 1987 cited in Weisgall 1994). Fission products were found in fish, clams, snails, oysters, corals, sponges, octopus, crabs, sea urchins, sea cucumbers, spiny lobsters, shrimp and algae in the lagoon. Many of the fish in the northwest corner of the lagoon were killed by the explosions (Berkhouse et al. 1984).

> "They called me to go help fight a fire on the aircraft carrier Independence, which was one of the target ships. We went up there three times. . . Right after that, we all went swimming in the lagoon there. . . There were dead fish around there, lots of them . . . " (Smitherman 1983).

On 18 July 1947, the Marshalls became a strategic area trusteeship administered by the US in accordance with a trusteeship agreement with the UN Security Council and the islands were placed under the administration of the US Navy (USDOE 1982). At the end of that year, the move to open Enewetak Atoll as the second test site began.

> "When we first arrived [at Enewetak], we toured the main island and found a number of spent cartridges and shell casings left over from the battle to take the atoll; even at that late date. Also, the island was loaded with construction equipment of every kind . . . bulldozers, cranes, road scrappers, etc. Shortly after, they were all gone; they had been dumped into the ocean. We were told that it was too expensive to ship the stuff back to Hawaii or mainland" (Oakes 2002).

In April of 1948, Operation SANDSTONE — conducted to perform weapon improvements studies — began at Enewetak. Three more atomic weapons were detonated.

> "The Admiral directed that cargo from a previous ship sitting just off the ramp/roadway area be bulldozed into the water and covered over with cement bags and coral rock and sand. I saw at least two brand new 75KW diesel motor-generator sets destroyed in that move" (Johnson 2004). "When we abandoned Eniwetok [at the end of SANDSTONE] . . . we dumped many dollars worth of equipment into the lagoon" (Scott 2001).

> "Practically all of the iron scattered about the islands is radioactive due to neutron capture and/or contamination with fission products. This iron will be collected and dumped on the reef on the oceanside of the Atoll" (Snapp 1949).

This series was followed by Operation GREENHOUSE; completed to test weapon effects and weapon improvements. Three more weapons were tested along with GEORGE — a device to test thermofusion capabilities of hydrogen isotopes.

> "We were warned by Headquarters, 7th Engineer Brigade, Task Group 3.2 before we arrived at Eniwetok that: "At certain times, many of the fish in our area are highly poisonous. The poison is tasteless and there is no way of telling which fish are poisoned." From the time we arrived at Eniwetok the men were not allowed in the water, not even to wade. . . there was still danger of nuclear poisoning in the water from earlier Atomic bomb testing done in the area in 1946-48" (Ingram 2001).

> "I also checked the drone planes that flew through the radiation atomic blast clouds . . . The planes were extremely radiated as they had just returned from the atomic bomb blast . . . Also a B-17 drone letter 'M' (initials were painted on the tail of the bombers) crashed on the island . . . I followed this plane from the point of touch down to its crash site. I stayed with this plane for three hours and allowed only authorized personnel at the site. Specimens were salvaged from the wreckage and the plane was then pushed into the ocean" (McMurtry 1995 cited in Campbell undated)

Once GREENHOUSE ended, the US Atomic Energy Commission (AEC) attempted to reduce residual radioactivity at Enewetak by bulldozing surface dirt away from shot areas into the ocean. "I often think of . . . the equipment, vehicles, planes, steel runway matting all bulldozed off the ocean side" (Palmer 2001). At the end of 1952, the AEC reported that Bikini "is in all probability quite uninhabitable from a radiological point of view" (Dean 1952).

In November 1952, Operation IVY began at Enewetak. IVY included the test of MIKE, the first thermonuclear device — 750 times the strength of that dropped on Hiroshima, more energy than all previous tests combined, including the USSR's. MIKE vaporized the islet of Flora (Elugelab, *Bokombako*) and left a crater a mile in diameter and 175′ deep in the coral (Noshkin 1978). Ujelang (*Wūjlañ*, Ujla) was contaminated with fallout from KING (USDOE 1982). Each of these tests sent surges of contaminated water over the adjacent islets (Noshkin 1978).

From 1–15 March 1954, Operation CASTLE took place on Enewetak and Bikini Atolls atolls. CASTLE included the detonation of six hydrogen bombs including BRAVO, an experimental 15-megaton hydrogen bomb that resulted in the single worst radiation fallout incident of the US testing programme (USDOE 1982). "A recently declassified 1955 Atomic Energy Commission Report documented high radiation levels on ALL [atolls and islands of] the Marshall Islands after the Bravo test and others in its series" (Breslin and Cassidy 1955 cited in Watkins et al. 2006:5). The current dose limit and clean-up criteria specified by the US Environmental Protection Agency (EPA) and adopted by the Nuclear Claims Tribunal is 15 mrem[5] year^{-1} — a number that was exceeded on every atoll by the CASTLE series alone (Watkins et al. 2006).

Testing on 6 March for gamma doses on Rongelap (*Roñļap*) resulted in dose estimates of 37,500,000 mrem h^{-1}. On Utirik: 4,000,000 mrem h^{-1}, and at unpopulated Bikar (*Pikaar*): 16,000,000 mrem h^{-1}. In addition, plutonium (see endnote i) was found in urinalysis of the Rongelapese and 90Sr (see endnote ii) was detected on Rongelap.

> "What was a problem was that in just minutes fallout from the blast covered the ship. There was sand, coral and seaweed all over the flight deck, catwalks, gun tubs and every exposed area" (Summers 2002). " . . . there appeared on the surface of the water various debris as well as dead fish and a whitish scum, most likely pulverized coral" (Bass 2003). "My most vivid memory was . . . the way the sea looked after detonation. The sea had a chalky, milky, simmering kind of appearance, especially one of the detonations that was close to an atoll, we went in pretty soon after the shot and that scene always stuck in my mind, kind of like the sea was boiling" (Williams 2000). "A short while after the explosion we made [an aerial] pass over ground zero at around 10,000 I think. . . the water was still boiling for several miles diameter" (Hasty 2004). " . . . the ocean was covered with leaves, chips of wood, and bark. The ocean was just littered with this stuff, for miles around" (Long 2001). "Whole palm trees were blasted apart, lying and floating everywhere, dead fish everywhere and debris everywhere. It was really unbelievable and what a tremendous sight to all of us" (Kosted and Kosted 1997).

> "Two days later when we returned to our control island [Eneu], the radiation level was still much too high for personnel to remain any length of time. Bulldozers were brought in to scrape off the top soil containing most of the radiation and push it into the ocean" (Clark 1957).

On 26 April 1954, UNION was detonated and Bikini, Ailinginae (*Aelōñinae*, Ailiginae), Rongelap (*Roñļap*), and Rongerik (*Roñdik*) received heavy fallout; on 5 May 1954; the YANKEE test and heavy fallout was again measured at Bikini, Ailinginae, Bikar (*Pikaar*), Rongelap and Rongerik.

In June 1954, contamination at Bikini was found to be 130 times normal 312 miles away from the lagoon, and a Japanese team found contaminants in ocean water and marine life 3000 miles to the west (USDOE 1982). On 14 September 1954, fish in Bikini and Enewetak lagoons were reported to be too radioactive for human consumption, and by 30 January, unsafe amounts of radioactivity were found in shellfish and crabs in Rongelap.

By March 1955, one year after BRAVO, a survey by the US Naval Radiological Defense Laboratory (NRDL) and the US Applied Fisheries Laboratory (AFL) showed that "significant amounts of radioactive contamination," were found in the animals, food plants, water and soil. The highest concentrations were in the marine specimens, which were found to contain: zirconium-95 (95Zr) (see endnote iii), niobium-95m (95mNb), ruthenium-106 (106Ru), and rhodium-106 (106Rh).

> "Profound alterations of the Bikini Lagoon fauna have, of course, already occurred and shortly after March, highly contaminated fish specimens were taken in the Rongelap Lagoon" (Nichols 1944).

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5. A millirem is a unit of radiation dose equivalent to one-thousandth of a rem (which stand for Roentgen equivalent man). It measures the amount of damage to human tissue from a dose of ionizing radiation. The biological risk of exposure to radiation is measured using the conventional unit rem or the SI unit sievert (Sv) (CDC 2003).

Operation REDWING, consisting of 17 nuclear weapons tests, was conducted between 4 May and 21 July 1956. Further contamination of the reef fish at Rongelap and Ailinginae were found from operation REDWNG. In addition, radiation was found in plankton, water and fish near Bikini and Enewetak and fallout was recorded on Parry Island and on Enewetak.

> "11 July [1956] 1300 hours: Entered into the center of the blast area, really a sight around Bikini; palm trees, leaves, plants, dead fish, birds were all over the water and the blast was nine miles from any land. It was set off on a barge by remote control, they say. We weren't allowed ashore because of the radioactivity. Sharks and barracuda were cleaning up the dead fish . . . 12 July 1956 Bikini: Went ashore in Enyu and what a mess! The blast was 20 miles from the atoll and many of the trees were down and a ship sunk in an Atomic blast in 1947 was on the shore; marines guarded it and it had coral and gunk all over it. Fish and sharks were all over the place. 13 July: Fished all day and didn't catch a thing. The bomb really messed things up" (Mead 2000). "I remember swimming in the lagoon and the water was crystal clear and you could look down and see giant clams of which most were dead. Their shells were open" (Long 1998). "The coconuts and the fish were not safe to eat, as they were contaminated from the exposure to the atomic and hydrogen bomb testing. The coconuts were mutated — shaped like bananas, but hard shelled like coconuts" (Francis 1999).

1957 July: Rongelap trees and plants were described as "mutants" because of their extra flowers and limbs and their stem abnormalities — atrophied, or "thickened, swollen" stems covered with cancerous warts (Held 1959:43 cited in Johnston and Barker 2001:33). "People got fish poisoning from types of fish that never caused poisoning in the past, such as *iol* (mullet), and *malok*. Before the tests, only the *jujukop* (barracuda) fish caused fish poisoning" (Johnston and Barker 2001:34). Clams were found to be concentrating high levels of 60Co (see endnote iv).

In May of 1958, Operation HARDTACK I began to develop the weapons themselves and to measure the explosive and radiation effects. This series of 35 weapons tests included the underwater tests WAHOO and UMBRELLA. WAHOO was detonated in the deep open ocean southwest of Boken Island, and UMBRELLA inside the western end of the lagoon at Enewetak.

The MAGNOLIA test further contaminated Ujelang. MAPLE at Bikini further contaminated Ailinginae and Wotho (*Wōtto*). During the QUINCE test on Runit, only the high explosive component of the device was detonated. This resulted in scattering the plutonium nuclear fuel over a large area of the island (Noshkin 1978). To prepare for the FIG event, scheduled 12 days later in the same location, three to five inches of this plutonium contaminated soil was bulldozed from the site and disposed of in the lagoon immediately offshore the center of the island (US DNA 1981 cited in Noshkin 1997; US DOE 1982 cited in Noshkin and Robinson 1997).

> "When OAK detonated . . . when I turned to see the column of water rising out of the lagoon, it was so tremendous that no one spoke. After fifteen or twenty minutes, the water in the lagoon began to recede until the lagoon bottom lay exposed for about two hundred yards from shore . . . The bomb had created a column which sucked up all the lagoon water for fifteen miles around . . . Then it started coming back and I got a sick feeling . . . the lagoon water turned an ugly milk chocolate brown . . ." (Mace 2003). "Rising up off the lagoon floor was a large funnel of water, sand and coral rock. Out at the edges of the cloud you could see large chunks of burning coral rock falling back to the water below" (Hampton 2004). "Very soon after we moved into ground zero and retrieved what the Scientist called "Corpsuals " they were fiberglass buoys with antennas on top. We were amazed to see cooked fish floating as we got close to the target area retrieving the corpsuals" (Wixon 1999). "There were nets set up so if we wanted to swim we didn't have to worry about sharks, although I never saw a fish, except for dead ones floating after a bomb went off and jelly fish everywhere" (Clayton 2007).

Radiation

The end of nuclear testing by no means meant the end of its effects on the marine environment. In 1994, the US Geological Service (USGS) put out a synthesis of the technical literature on radionuclides in the environment and their effects on notably fish, wildlife, invertebrates and other natural resources (Eisler 1994). Several aspects of that report are relevant here.

"Fallout can occur years after an explosion injected material into the atmosphere . . . high acute doses of ionizing radiation produce adverse biological effects at the molecule, cell, tissue-organ, whole animal, population, community, and ecosystem levels

. . . Typical adverse effects of ionizing radiation include cell death, decreased life expectancy, increased frequency of malignant tumors, inhibited reproduction, increased frequency of gene mutations, leukemia, altered blood-brain barrier function, and reduced growth and altered behavior . . . Overall, the lowest dose rate at which harmful effects of chronic irradiation have been reliably observed in sensitive species is about 1.0 Gy[6] year^{-1}; this value for acute radiation exposures is about 0.01 Gy . . . Ionizing radiation can harm marine organisms directly through death to the irradiated organism as well as through reduced vigor, shortened life span, and diminished reproductive rate as well as by the genetic transmission of radiation-altered genes "that are most commonly recessive and almost always disadvantageous to their carriers" (Bowen et al. 1971 cited in Eisler 1994). Eisler (1994) also found that gross radiation injury to marine organisms has never been studied.

In 1961 fish with "black spots" on their abdomens were discovered at Rongelap. By February 1962, additions to the known radioisotope load included 95Zr-95Nb, 103Ru and 106-103Rh and 106, Tungsten-181 and 185 (181W and 185W), 65Zr, and 137Cs (see endnote v). Increased concentrations of radioactive Iron-55 (55Fe) were found in goatfish liver (Beasley et al. 1970 cited in Johnston and Barker 2001).

A survey in August 1964 found 60Co in all samples of marine invertebrates and it was determined to be the major radionuclide in the marine environment. Radioactive manganese-54 (54Mn) was also found in all samples, and 106Ru and antimony-125 (125Sb) were found in groundwater, soil, animals and plants. Bismuth-207 (207Bi) (T1/2=38y) and cerium-144 (144Ce) were detected in marine algae, soils, and land plants. Iron-55 was comparatively high in vertebrates, and plutonium-239 (239Pu) was found in the soil and in the skin of rats and birds (Welander 1969 cited in Eisler 1994). In 1965, testing showed that the long-lived gamma-emitter 137Cs had moved down into the soil on all exposed atolls and was considered the limiting factor in repopulating the atolls.

A 1969 study by Held revealed there was still no measurable difference between the 1967 and 1969 values of radionuclides for edible marine animals and those values were not expected to change. In addition, Held found an increasing concentration of some radionuclides with increasing age of fish and clams and an increase as they move up the food chain. Where the animal fed was also determined to be a factor, the tissues of bottom feeders contained 10 times more 60Co than herbivores or plankton feeders. For the first time, the gamma emitter silver-108m (108mAg) (T1/2 = 418 y) (see endnote vi) was found associated with fallout, in the hepatopancreas of the spiny lobster (Held 1969).

In October of that year, the AEC released an aerial radiation survey of Enewetak. Runit Island, the site of 18 nuclear tests — and contaminated with high concentrations of unexploded plutonium — was quarantined for 140,000 years. The AEC located surface plutonium contamination on Runit that included a plutonium-bearing sand layer outcropping on the ocean side of the mid-island area, plutonium fragment sand grains on the island surface, and contaminated scrap metal throughout the island. Most disturbingly they found high alpha contamination as well: alpha, when internalized, is the most damaging of the three types of radiation (alpha, beta and gamma). The next year, the US proposed dumping radioactive soil and debris from the other islands in Enewetak into an atomic bomb crater on Runit Island. The radioactive material would then be mixed with cement to form a massive concrete dome. In response the EPA stated, "The fact that crater entombment is only a semi-permanent solution should be recognized" (USDOE 1982: 25).

> "Minute amounts of plutonium are expected to be released through the geological formation (dome on Runit Island). These, however, will be small and insignificant compared to the amounts already in the lagoon" Defense Nuclear Agency, EIS, April, 1975 (USDOE 1982: 34).

Almost 20 years after testing stopped, radioisotope levels at Bikini were found to be higher than ever previously recorded. Plutonium 239 and 240 measured highest by a factor of five. By 1976, 239Pu and 240Pu levels were higher than in 1971 by a factor of two on Rongelap, Rongerik, Ailuk (*Aelok*), Wotje and Utirik (*Utrōk*).

In May 1977, the US began its proposed cleanup of Enewetak. The cleanup removed an estimated 125,000 cubic yards of "non-contaminated" debris, which was dumped into the ocean, and about 100,000 cubic yards of soil and debris contaminated with plutonium and other radionuclides — placed in the bomb crater on Runit Island and sealed with a cement cap.

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[6] When a person is exposed to radiation, energy is deposited in the tissues of the body. The amount of energy deposited per unit of weight of human tissue is called the absorbed dose. Absorbed dose is measured using the conventional rad or the SI Gy. The rad, which stands for radiation absorbed dose, was the conventional unit of measurement, but it has been replaced by the Gy. One Gy is equal to 100 rad (CDC 2003).

> "I remember some of the ideas our superiors would come up with on transporting these tons of radiated soil to another Island so we could cap them off in a large pit, and also to our surprise we would have a large barge in the middle of the lagoon to dump these soils into the lagoon after we had cleared a large portion of earth from a contaminated Island" (Celestial 2000).

> "We would take all the metal debris either back to Medren and put it in a huge pile that Japanese ships would come and pick up or we would dump it into the lagoon at its deepest part, which we thought was counter productive, but what did we know, we just did what we were told. One job we had which was one of the most tedious and infuriating was to pick up metal chips from the beaches of one small island. We would go out all day and fill sand bags with these quarter to half dollar size chips of metal then load these bags on the LARC 60 which was this big amphibious army vehicle, then drop them over the side on our way back to the main island. After the waves would wash over the beach during the night and expose more chips you just wanted to scream because you would do it all over again" (Jackson 2005).

> "Then I was moved to Eniwetok to work on Medrain with the [Navy] seals removing the remnants of the trucks and other equipment that had been run into the channels between the islands. This metal was loaded on maggies (LMUs) to be taken to Reunit or to the deep water in the center of the lagoon and deep sixed" (Savage 2001).

During this time, wells on Bikini were found to contain 90Sr and, according to Lawrence Livermore Labs, Enewetak Lagoon was determined to be the largest reservoir of transurenics (see endnote vii) in the atoll, and little alteration should be expected over the next few decades.

A survey of Enewetak Atoll conducted during the mid 1970s concluded that measures designed to reduce plutonium contamination in the marine foodchain would have little impact due to its long halflife — plutonium would remain in the marine environment long after the other major radionuclides had decayed (Wilson et al. 1975).

Fish specimens from Ailinginae, Rongerik and Utirik were found to have radionuclides in their tissues (Nelson 1977). Cobalt-60 and 55Fe were found to be predominant in the Rongelap marine environment (USDOE 1977). Noshkin (1978) found that due to the high level of radioisotope deposition in the marine environment, Enewetak had become its own transuranic source as radioisotopes are continually remobilized, suspended, assimilated, and transferred through the environment by physical, chemical and biological processes. A further report during that year found very high concentrations of plutonium in the bone, viscera and gills of fish (Robinson et al. 1978).

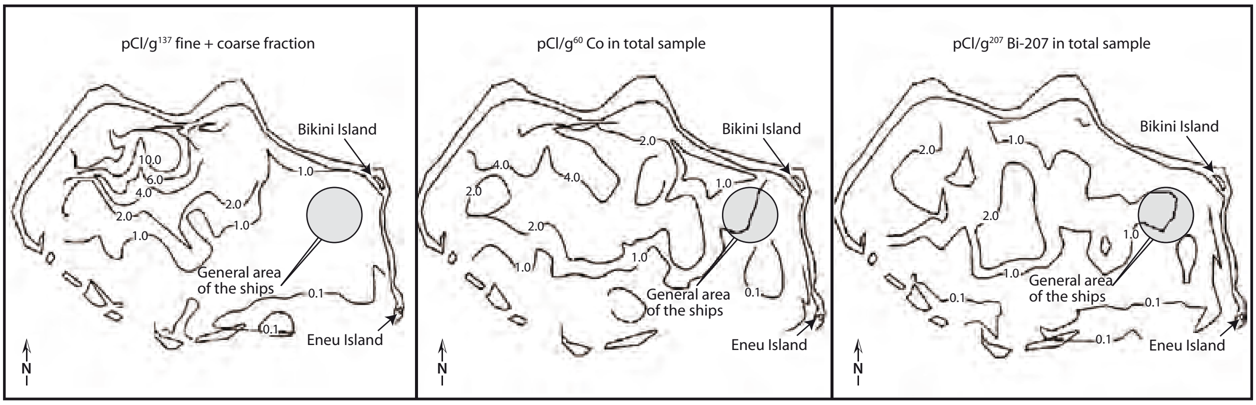
Twenty years after nuclear testing stopped (August 1978), the US admitted that another 10 atolls — Ailinginae, Ailuk, Bikar, Jemo (*Jāmǫ*), Likiep, Mejit (*Mājeej*), Rongerik, Taka (*Tǫke*, Tŏkā), Ujelang, and Wotho — received intermediate fallout. One year later, the DOI states, "...The new data reaffirmed that Bikini Island could not be used by the people of Bikini for at least the next 30 years and possibly the next 60 years ...The Island of Eneu must be placed off limits...for at least another 20–25 years." That same year the Runit Island dome was completed and determined to be extremely radioactive and dangerous for at least the next 24,000 years (Rowa 2006).

> "I had the pleasure of swimming in one of the large bomb craters, I think it was the one that was filled in, the size sounds the same, 30 feet deep and 350 feet wide, there was a smaller crater near by but we saw a very hungry shark in it. The crater we swam in had mutated sea creatures, by this I mean much larger than the ones in the lagoon, spiny sea urchins in the lagoon would be about the size of a baseball with spines about 6 inches long, but in the crater these same urchins were the size of a volley ball and had spines over a foot long, the same with sea anemone, they were much larger in the crater" (Ingram 2002).

> "Vegetation grew on Runit just like on other islands, but near the twin craters, some of the vines were orange. . . . " (Collins 2000).

By 1979 the radioactivity levels of americium-241 (241Am) (see endnote viii) in Enewetak Lagoon were determined to be 20–25% higher than determined by previous measurements. In 1985 it was discovered that the lower levels of sediment in the lagoon (>20 cm down) contained elevated radioisotope levels that were being redistributing into the lagoon waters by the burrowing activities of ghost shrimp (Crustacea: Thalassinidea) (McMurtry et al. 1985).

In 1991, a study by the US National Park Service, Submerged Cultural Resources Unit, looked at the radioisotope levels remaining on the sunken vessels in Bikini Atoll from Operation CROSSROADS in order to determine any hazards that the opening of



Cesium-137 concentration contours in the lagoon surface sediments at Bikini Atoll in 1979.

Cobalt-60 concentration contours in the lagoon surface sediments at Bikini Atoll in 1979.

Bismuth-207 Concentration contours in the lagoon surface sediments at Bikini Atoll in 1979.

Figure 2. 137Cs, 60Co, and 207Bi concentrations in Bikini Lagoon sediments in 1979 (Source: Delgado et al. 1991:191-193).

the area to recreational diving might impose — 44 years after CROSSROADS and 32 years after the last test at Bikini (Delgado et al. 1991).

The radionuclides described as present in the lagoon sediments and on the islands were: 137Cs, 90Sr, 60Co, 239Pu, 240Pu and 241Am. Additionally, europium-155 (155Eu) (see endnote ix), and 207Bi were reported as common in lagoon sediments but not on the islands (Delgado et al. 1991; Jernström et al. 2005; Unterweger 2002).

The 137Cs concentrations ranged from 100 pCi kg^{-1} in the southern end of the lagoon to 10,000 pCi kg^{-1} in the northwest portion of the lagoon.[7] Cobalt-60 concentrations ranged from 100–4,000 pCi kg^{-1} and 207Bi concentrations ranged from 100–2,000 pCi kg^{-1} (Fig. 2) (Delgado et al. 1991).

The levels in the area of the target ships were deemed non-hazardous to divers because the gamma rays they emit would dilute as they moved through the water and would be negligible by the time they reached recreational diving depth. No determinations regarding the alpha or beta particle emissions were included in the report.

Further study of Enewetak in 1997 found that the inventory of plutonium in the lagoon was constantly replenished by remobilization of sediments and seepage from the Runit crater and currently "overshadows by orders of magnitude" the total amounts of radioactivity buried under the dome. In addition, concentrations of transuranics in fish were found to be no different than they were at pre-cleanup levels 20 years earlier (Noshkin et al. 1997).

Robinson et al. (1998) looked specifically at the radioactive fission and particle activated products, and unspent radioactive nuclear fuel that entered the marine environment and found that in 1998 the sediments and waters in the Bikini and Enewetak lagoons were still reservoirs for 100s of trillions of Becquerels (Bq) of radionuclides.

Johnston and Barker (2001:35–37) present additional information regarding the radioactive contamination of the marine environment with emphasis on Rongelap:

> . . . University of Washington researchers involved in the radiation ecology studies at Rongelap determined that the highest con-

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[7] Different units of measure are used depending on what aspect of radiation is being measured. For example, the amount of radiation being given off, or emitted, by a radioactive material is measured using the conventional unit curie (Ci), named for the famed scientist Marie Curie. When the amount of radiation being emitted or given off is discussed, the unit of measure used is the conventional unit Ci or the SI unit Bq.
A radioactive atom gives off or emits radioactivity because the nucleus has too many particles, too much energy, or too much mass to be stable. The nucleus breaks down, or disintegrates, in an attempt to reach a nonradioactive (stable) state. As the nucleus disintegrates, energy is released in the form of radiation.
The Ci or Bq is used to express the number of disintegrations of radioactive atoms in a radioactive material over a period of time. For example, one Ci is equal to 37 billion (37 X 109) disintegrations per second. The Ci is being replaced by the Bq. Since one Bq is equal to one disintegration per second, one Ci is equal to 37 billion (37 X 109) Bq. Ci or Bq may be used to refer to the amount of radioactive materials released into the environment" (CDC 2003).

> centrations of radiation were found in the herbivore and omnivore species of fish, such as the parrotfish (Donaldson 1950 DOE #340: l45). Increases in gross beta radioactivity in fish were measured on Rongelap between 1954 and March 1958 (Palumbo 1959 DOE #292; UW 1958 DOE #312) . . .
>
> From radiation levels monitored in the bird populations, United States government researchers concluded that the fishing area in southern Rongelap where the people were resettled had higher radiation concentrations than fish in the restricted northern islands . . . The birds from southern Rongelap also had higher levels of radiation than birds from the north of Rongelap (AFL 1955 DOE #342). According to researchers, this "unexpected" finding of "higher levels of radioactivity in the tissues of the southern birds suggest the availability of a supply of food fish with a higher average radioactive content in the southern area compared with that of northern Rongelap" (AFL 1955 DOE #342:43) . . .
>
> United States researchers monitored open sea marine plankton and its role in transporting fallout in the marine food chain (University of California undated DOE #34:17). Researchers observed that plankton was "the most sensitive indicator of radioactivity in the sea" (Seymour et al. 1957 DOE #332:55). Radiation readings in plankton were considered "representative of that available to marine food chains" (Palumbo and Lowman 1958 DOE #348:64). In a 3300 mile survey area in the Pacific Ocean," radioactive materials were found in the plankton samples from every station" (Seymour et al. 1957 DOE #332:9).
>
> By 1958, university researchers discovered that fish may be concentrating radioactivity by as much as "a thousand fold" because of the radioactive plankton they consume (Palumbo and Lowman 1958 DOE #348:59) . . . Researchers also observed that "the lagoon would tend to hold radiation within its system of circulation" (Author not available 1961 DOE #380:85) and that radiation would concentrate in the lower levels of the lagoon where fish, such as the sturgeon fish . . . would concentrate high levels of cesium (author not available 1961 DOE #380:118).
>
> . . . As late as 1962, "the highest levels of gross beta radioactivity were found in samples of algae, fish liver and muscles, and sea cucumber muscle" at Rongerik (Donaldson 1962 DOE #299:11)
>
> The Rongelapese observed that many species of fish that did not cause fish poisoning before the nuclear tests became poisonous afterwards, and some species were poisonous in some locations, but not in others. Some scientists have suggested a relationship between fish poisoning and nuclear testing with damaged reefs supporting abnormally high numbers of the plankton *Gambierdiscus toxicus*, a dinoflagellate that produces ciguatera toxin. Fish feeding on the reefs absorb this plankton, ciguatera toxins accumulate in the fish, which in turn are eaten by larger fish that concentrate the ciguatera toxin in their flesh. Humans who eat these fish suffer from vomiting, diarrhea, loss of balance, and rarely, death. The Marshall Islands and French Polynesia (the area where the French test nuclear weapons) have the highest incidence of fish poisoning in the Pacific (Ruff 1989 cited in May 1989:249).
>
> In the mid-1990s the RMI Nationwide Radiological Survey tested thousands of soil, plant, and occasionally marine samples collected throughout the nation and confirmed the existence of unsafe levels of radiation at dozens of islands.

Just last year (2006) terrestrial radiological survey values were adjusted for 2005 and showed dangerous levels of radioactive 137Cs still contaminating as many as 20 islands (Table 1) (Watkins et al. 2006). Recall the current dose limit and clean-up criteria specified by the USEPA and adopted by the Nuclear Claims Tribunal of 15 mrem year^{-1} for all radioisotopes. In 2005 this number was exceeded on every island by 137Cs alone.

The preparers of this document can find no current information on remaining marine contamination but due to the long-lived nature of the transurenics with half-lives in the hundreds and thousands of years such as 108mAg, 238+239Pu and 241Am, which have been identified in the marine environment, we argue that much of it remains to this day.

Testing after the nuclear period

Operation HARDTACK ended the nuclear test period, but not weapons testing by the US. In 1959, Kwajalein was chosen as the test site for the NIKE-ZEUS anti-missile tests and Roi Namu Island was selected as a center to study missile re-entry characteristics. In the 1960s, Enewetak's lagoon was the target and impact area for tests of Intercontinental Ballistic Missiles (ICBMs) fired from Vandenberg Air Force Base in California (Rowa 2006). In 1964, the testing of a system for shooting down Soviet satellites began.

Table 1. 2005 Radiocesium (137Cs) levels in mrem per day
(Source: Watkins et al. 2006)* [322: (Simon and Graham 1994); 323: (Mauro et al. 2002)].

Source	1994 nationwide Radiological Study322				2002 SC&A Report323	
Diet assumption	2484 kcal day^{-1} diet 75% local food		2484 kcal day^{-1} diet 18% local food		3208 kcal day^{-1} diet 100% local food	
Predicted exposure range	Low	High	Low	High	Low	High
Bikini-Bikini	16	1600	80	400		
Northern Rongelap	120	800	40	240		
Enewetak-Enjebi	63	400	16	160		
Rongelap	40	240	12	80		
Bikini	40	240	12	80		
Rongerik	40	240	12	80		
Southern Rongelap	40	240	12	80		
Northern Enewetak	32	200	12	60		
Enewetak-Aoman	24	160	7.9	40		
Enewetak	16	120	6.3	40		
Bikini-Eneu	16	120	6.3	40		
Enewetak-Bijiri	12	90	5.6	32		
Enewetak-Lojwa	12	90	5.6	32		
Ailinginae	7	60	1.6	16		
Utrik	5	50	1.6	12		
Enewetak-Runit	5	50	1.6	12		
Ailuk	2	16	1.6	8	5	22
Mejit	1.6	12	0.6	5	5	21
Likiep	0.2	2	0.2	2	5	21
Wotje	0.2	2	0.2	2	4	18

* Values adjusted for 2005 by using the cesium-137 half-life of 30 years.

"In the summer of 1968, the Deseret Test Center conducted a series of tests known as DTC 68-50 from the USS Granville S. Hall, anchored off Eniwetok Atoll. This test series involved the atmospheric dissemination of "PG" — *Staphylococcal enterotoxin* Type B — a toxin that causes incapacitating food poisoning that causes flu-like symptoms that can be fatal to the very young, the elderly, and people weakened by long term illness. *Staphylococcal enterotoxin* B was disseminated over a 40–50 km downwind grid, and according to the Final Report, a single weapon was calculated to have covered 2400 square km, an area equal to 926.5 square miles" (Johnston and Barker 2001:31).

Also in 1968, the US Air Force experienced a high order explosion while testing a high-energy upper stage (HEUS) rocket motor at Enewetak. The explosion contaminated Engebi with a significant amount of the highly toxic substance, dispersed Beryllium (see endnote x) (Dickman 1972).

The Pacific Cratering Experiments (PACE), which began on Enewetak in September 1971, included more than 220 tons of explosives brought to the atoll to simulate nuclear bomb blasts. In April 1972, the US announced it would end its use of Enewetak by the end of 1973 — after completion of certain unspecified tests, which included 190 holes drilled into reefs and land for explosive charges in 86 trenches as well as the detonation of six tons of explosives. Ongoing US weapons testing is also part of the current military impact on the Marshall Islands. Testing of the US National Missile Defense System sometimes called Star Wars or Son of Star Wars at the US Army's Ronald Reagan Ballistic Missile Defense Test Site on Kwajalein Atoll continues to this day. Over 113 missiles have been fired and over 66 rockets have been launched from Kwajalein since its designation in 1959 (Parsch 2002-2004, Wade 1997-2007).

> "Back in the days when we had no television, our entertainment sometimes included sitting

> out on the north sand spit . . . This area was the best place to watch the incoming ICBM missile payload section from Vandenberg Air Force Base as it reentered the Earth's atmosphere . . . In pre-1996 days, the Army Zeus interceptor rocket would take off from Launch Hill down at the south end of Kwajalein . . . The display was a brilliant cataclysmic array of light unlike any Fourth of July celebration I have ever seen. Sometimes the display was bright enough to photograph and even get a colored film time exposure. We were not supposed to be outside our concrete houses, just in case something might fall out of the sky. The rule was never enforced, and you could always count on around 500 people out on the sand spit whenever a Vandenberg Special came down the pike" (Sims 1999-2007).

WWII, the nuclear testing program, chemical and biological weapons testing, missile testing, rocket test firings, and the cratering experiments program caused and continue to cause serious environmental damage to the marine environment of the Marshall Islands. This is most clearly demonstrated at Enewetak Atoll, where five islands — Bokombako (Elugelab), Louj (Lidilbut), Bokaidrik, Boken (including a small unnamed islet to the west of Boken) and Eleleron — were completely or partially vaporized (Rowa 2006).

> "A few days later we returned to the site to find that part of the atoll was gone and in its place was a very large crater. They say the size of the bomb was 10 megatons. I would never want to go through that again" (Guido 2001).

> "After the explosion, the islands where the bomb was detonated disappeared, they were gone, no more, nada" (Marquez 2007).

> "When I rotated back to Hickam, we flew over the test site I'd seen earlier when they were building the 100 foot tower. Around the barrier reef was the deep purple coloring of the ocean. Inside of the reef was the pale green coloring of the shallow water. Where the 1OO toot tower had been placed on this small island there was no tower, there was no island! Instead there was a hole the same color as the deep ocean surrounding the reef! All of us on the plane sat there staring at that hole" (Sapp 2000).

These activities have all resulted in a large amount of submerged cultural materials, such as military equipment, unexploded ordnance, shipwrecks and sunken aircraft, as well as radioactive debris, which remain largely undocumented to this day.

Sea turtles

Let us now consider why sea turtles may be particularly susceptible to these contaminants. Sea turtles, particularly green sea turtles (the most populous species in the RMI), rely on certain foods (such as algae and seagrass) that bioaccumulate metals and radiogenic contaminants. This may pose a special risk given the unexploded ordnance load, the sheer number of wrecks and other submerged materials, the archipelago-wide fallout from nuclear weapons testing and the historic and current environmental threats posed by ongoing testing at Kwajalein and related Kwajalein base activity (especially contaminants in the reef and marine food chain like perchlorate, the primary ingredient of solid rocket propellant), and radiogenic deposition in the lagoon sediments.

In 1952, US scientists first published reports that perchlorate inhibited the uptake of iodine in Marshallese research subjects. The 1953 test series studies documented bioccumulation in biological organisms (Atkins undated cited in Johnston 2003; Atkins et al. 1974 cited in Johnston 2003). In 2001 perchlorate contamination was documented by the US Department of Defense in the water supply and coral reef/lagoon ecosystem in and around Kwajalein (USAF et al. 2001 cited in Johnston 2003).

> "One of the many shocking aspects of reviewing US research in the Marshall Islands was finding evidence that the US DOD [Department of Defense] has produced scattered yet substantive documentation of non-radiogenic toxic hazards introduced by military testing, and yet to the best of my knowledge no comprehensive environmental impact assessment has ever been undertaken. The toxins are many, and their effects, especially on radiologically exposed and immune-system compromised populations, are serious" (Johnston 2003).

Samples of algae were taken from several of the sunken target ships by a Navy dive team in 1989 (Delgado et al. 1991) and were analyzed for radioisotopes (Table 2).

Levels of all contaminants, including the extremely high levels of 241Am and 239+240Pu were dismissed as a human diving hazard because the emanating radiation is totally absorbed in a few millimeters or less of water, which was suggested to be closer than a diver would approach. This limitation would not exist for sea turtles that regularly eat organisms growing directly on shipwrecks such as algae and sponges. Plutonium-239+240 and 241Am are described as containing the highest risk of inhalation exposure in disturbed lagoon sediments (Del-

Table 2. Radioisotope concentrations in algae samples taken from sunken ships at Bikini Lagoon in pCi kg^{-1} (Delgado et al. 1991).

Ship	60Co	137Cs	90Sr	155Eu	270Bi	241Am	239+240Pu
Gilliam	<10	<10	11	<190	<10	3450	4140
Pilot Fish	360	110	121	90	420	90	108
EOD Collection Pilot Fish	240	140	154	150	500	2300	2760
Carlisle	490	80	88	<40	470	1400	1680
Saratoga	200	470	517	<290	180	<400	480
Arkansas	380	140	154	170	490	1700	2040
Nagato	410	260	286	170	290	3300	3960

Note: For 238+239Pu + 241Am combined, the DIL for all components of the diet is 54 pCi kg^{-1}.
DIL = US Nuclear Regulatory Commission Recommended Derived Intervention Level.

gado et al. 1991). This pathway may be important for turtles when feeding on benthic organisms such as invertebrates, shellfish and sea grasses.

The radioisotope levels in the area of the target ships in Bikini Lagoon were deemed nonhazardous to divers because the gamma rays they emit would dilute as they moved through the water and would be negligible by the time they reached recreational diving depths. Such depth restrictions, as well as location restrictions (the shipwrecks off Bikini Islet) would not be observed in the sea turtle population as normal resting behavior makes the cracks and crevices of wrecks and other submerged materials ideal resting locations, and neither their foraging nor resting habitats would be restricted to the southern end of the lagoon.

It is important to note that sea turtles show site fidelity to both their resting and foraging sites (i.e. remain in or return to the same location over and over), so those resting or feeding off of toxic materials may have been doing so every day for many decades (depending upon the age of the turtle).

As discussed previously in this document, the limiting factor for both occupation and consumption of terrestrial foods due to radioisotope levels is the continued presence of high levels of the long-lived radionuclide, 137Cs in the soil of the atolls and "there is a continuing inventory of 137Cs and 90Sr in the fresh water portion of the groundwater at all contaminated atolls" (Robinson et al. 2003). Due to this factor, the consumption of food grown in the soil of the most highly contaminated islets has been vastly restricted and several atolls (Rongelap, Rongerik, and Ailinganae) have been categorized as "no-gathering" sites. Again it must be pointed out that sea turtles would not abide by these restrictions. Nesting sea turtles as they dig a few feet down into the sand in order to lay their eggs and as air breathers expending considerable amounts of energy as they do so, may take in large amounts of resuspended particles. All of the sites previously reported as first, second, or third for number of sea turtle nests are contaminated with these radioactive elements, some at extremely high levels (Fig. 3).

This is also significant because sea turtle eggs have been shown to take up contaminants found in the nest environment, which is generally located a few feet down into the sand above the high tide mark, with some turtle species, such as hawksbills, nesting as far up as the vegetative areas (Acuna et al. 1999; Campos et al. 1996).

In addition, several northern islets of the atolls with the high levels of contamination were previously set aside by the chiefs as sea turtle reserves due to the high number of turtles in these locations; these included Taongi (*Bok-ak*, Bokak, Pokak, Pokaakku), Bikar, Taka, Erikub (*Ādkup*, Erikup), and Ailinginae atolls, Jemo Island, Wōnwōt (*Wōnoot*) and Pekram (*Pekdaṃ*) islets of Kwajalein Atoll, Lijeron Islet (*Ledjiok*) of Jaluit, and several uninhabited northern islets of Enewetak (Tobin 1952; Lessa 1984; Fosberg 1990). When the National Resources Assessment Survey team surveyed Rongelap Atoll (*Roñļap*) in 2003, "the reefs surveyed were found in mostly pristine conditions, with a large number of fish, coral, algae and other species present and abundant. The team found abundant and large size fisheries target fishes, and recorded abundant mega-fauna such as sea turtles, whales, and rays" (NRAS 2003). Due to their unique ability to survive tremendous injuries that would result in death to humans, such as loss of limb and even portions of their torso, an abundant population of large size turtles would not mean they suffered no impacts from WWII and the weapons tests. It is entirely possible that the turtles that were alive during these periods are still alive today having experienced both the high levels of acute exposure as well as chronic exposure at lower levels as dilution and decay take effect. Should

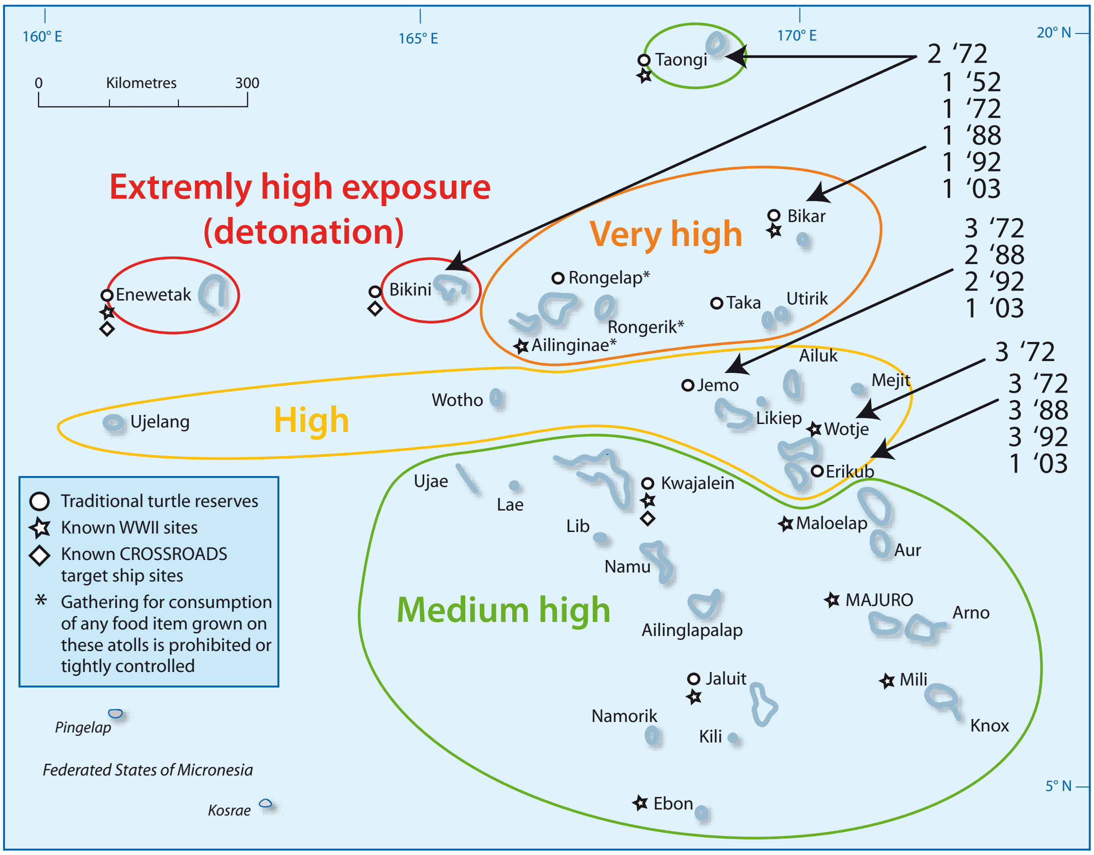

Figure 3. Atoll rankings by number of sea turtle nests in previous studies.
Diagram compiled from the following sources: Tobin 1952; Thomas 1989; Maragos 1988; Fosberg 1990; Puleloa and Kilma 1992; McCoy 2004; dose figures extracted from Table 2 above.

similar abundances also be found for the remainder of the aforementioned contaminated areas with historically high sea turtle numbers, it could have far-reaching consequences should it be determined that the contamination at those atolls is contaminating the tissues of sea turtles born, foraging and resting in those locations and migrating throughout the country and the region.

The environmental contamination of sea turtle flesh and eggs as well as the human health risks associated with their consumption has been well documented. Yasumoto (1998) reports on the fatal intoxication from the consumption of a green sea turtle that caused by the turtle feeding on contaminated blue-green algae. Human poisoning from consuming hawksbill, green, leatherback, loggerhead and olive ridley turtles over a 65-year period was determined to be due to the toxicity of the food consumed by the turtles (Robinson 1999 cited in Strainchamps 2000). Ranaivoson et al. (1994) reported that six people died within five days from eating a sea turtle that was in ill health. "Observers reported that the turtle, when caught, was weak; upon being butchered, it was reported to have gut contents smaller than usual; there was a strong smell of urea/urine in the gut, and the meat was unusually soft" (Ranaivoson et al. 1994:1).

It is important to remember the quarantine of Runit Islet and the tremendous load of transuranics in Enewetak Lagoon as well as the quarantine of the northern islets of many atolls. Contaminant levels in these locations were not determined to limit consumption of marine species due to what surveyors described as the non-migratory nature of the species tested as well as dose estimates using their "edible" tissues. Our doubts about the validity of this conclusion are too many to be considered here, but it must be pointed out that the migratory nature of sea turtles and the fact that the Marshallese reportedly eat all rather than only some of their parts, with women even sucking the marrow out of their bones, would again make such determination irrelevant. Neither location of, nor the short life span of, nor the edible tissues tested in marine species to date, would apply to sea turtles that may well be nesting, foraging and resting, perhaps living 98% of their very long lives, in these highly contaminated areas.

Also important to note are determinations of what level of contaminant remains in the environment today as well as the half-lives of the radioisotopes. Neither of these determinations would be relevant to the sea turtle population as it is entirely possible that some of the current stock of reproductive adults were present during the actual nuclear testing events (ended 50 years ago) and even as far back as WWII (65 years ago) as frequently estimates of sea turtle longevity are 50-75$^+$ years — the Hawaiian green sea turtle population for example is not estimated to even reach the age of first reproduction for 30 or more years (Zug et al. 2002).

Conclusion

We argue that research into this situation is essential as we have found a high probability that there are toxicants remaining in the RMI environment and that due to the long life (50$^+$ years receiving low-dose radiation and other contaminants) and normal habits of sea turtles, such as site fidelity to certain resting areas and resting in submerged resources such as irradiated shipwrecks (among others), site fidelity to certain foraging areas and several species eating organisms that may be growing directly on toxic surfaces (such as algae and sponges), and embryo development and metamorphosis taking place a few feet down in contaminated sand, their contamination from those products is highly probable. In addition, we suggest that due to the migratory nature and reproductive patterns of sea turtles, which often have nesting areas thousands of miles away from their feeding and developing areas, the possible threat to sea turtle populations may be regional rather than strictly limited to the RMI environment. Finally, we assert that as the non-human animal most likely to have experienced the same war and weapons testing events as the human population, if not more so, sea turtles may be viable candidates for determining with accuracy the initial, subsequent, and long-term contaminants that existed and still exist today. The results of this research will be important not only to the Marshallese but to all nations whose sea turtle habitats are subject to the impacts of war and weapons testing, including but not limited to the nation-states of Kiribati (testing by UK and US) and Australia (testing by the UK), and the territory of French Polynesia (testing by France).

Project summary: Phase I

The essential first step to the development of this project is the collection of local indigenous knowledge in order to gain an understanding of the complex array of cultural, ecological, historical and economic elements that form the present state of affairs and inform attempts at mitigation. We intend to identify priority research areas within the country with high sea turtle activity and submerged cultural resources through the collection of local knowledge. Furthermore, a good understanding of human interests, practices and aspirations is also critical to effective conservation and resource management. Presently, despite national and international protections as endangered species, sea turtles remain prestigious, desirable and ceremonially important food sources for atoll populations; the relatively new and international science of sea turtle conservation does not counter Marshallese traditional valuation and uses of sea turtles. As locally available and prestigious meat with huge cultural significance, as a valuable exchange item (meat and handicrafts), and as an activity that helps people "feel native," sea turtles are very special to the Marshallese; yet sea turtles are also risky, subject to caution (potential contamination), legal conservation-oriented measures, and at risk of extirpation.

Some ethnographic information regarding sea turtles' importance has been documented in the RMI. Information is fragmentary but hints at complex cultural elaboration and acute ecological knowledge that has ramifications for Marshallese health and social identity even today: Tobin (2002) describes numerous legends collected in the 1950s that document the high cultural value placed on turtles; Erdland (1914) reported that among the Marshallese "tortoise shell was a prominent magical charm, and in fact the neck plate of the upper shell had greater magical power than the tail plate."

This symbolism is related to Lijebake (*Jebake*) (a giant turtle who once was a goddess) who features in two common Marshallese legends regarding sea turtles. In one legend Lijebake (adored and respected female hawksbill turtle) then living at Bikar, is visited by her two sons, also gods. They receive power from her in the form of pieces of her turtle shell: a shoulder piece to her preferred son and a tailpiece for the other (McCoy 2004). In other legends (see Downing et al. 1992 and Spennemann 1998), Lijebake rescued her granddaughter from mistreatment in Kiribati and swam with her to Jemo Island, thereby becoming the "Great Mother Turtle," and causing turtles to prefer Jemo Island from thereafter. Other versions of the legend have the girl turning into a seabird and flying away above her grandmother to Bikar (Tobin undated), and the grandfather turning into a frigate bird and along with Lijebake fleeing with their granddaughter to Jemo (Kane 1995). Lijebake's feat is so well integrated into Marshallese identity that in 1995, the RMI government issued a USD 0.32 stamp depicting Lijebake with her granddaughter on her back.

The sea turtle was such an important cultural resource to the Marshallese that as mentioned above, until the mid-20th century, several islands and atolls were set aside by the chiefs as traditional sea turtle reserves, protected by the Marshallese concept of "*mo*" or taboo areas. In order to obtain turtles from these islands strict rituals were observed. Earlier reports describe such visits to the *mo* (Staff Anthropologist [Jack Tobin] 1957:8–9; Johannes 1986:24–25).

In 1978 when the green turtle was listed as threatened and endangered under the US Endangered Species Act (ESA) of 1973, USFWS and NMFS adopted a special rule containing a provision for the continued subsistence taking of green turtles (*Chelonia mydas*) from below the low water mark for nutritional reasons by residents of the Trust Territory, " . . . if such taking is customary, traditional, and necessary for the sustenance of such resident and his immediate family" (Balazs 1983). The Trust Territory was the sole area to receive an exemption for subsistence use as defined above. The rationale for this action was that many of the inhabitants follow a traditional way of life in villages on small remote islands that are limited in natural food resources; therefore, the risk to the turtles' survival from subsistence use had to be balanced against the nutritional and cultural needs of the people (Balazs 1983).

After internal self-government was established under a constitution in 1979, the RMI promulgated their own Endangered Species Act for protection of endangered and threatened species. However, only the hawksbill and the leatherback were specifically covered by the Act. The RMI gained independence linked to a Compact of Free Association with the United States in 1986. In 1988 they instituted the Marshall Islands Marine Resources Authority Act: "An Act to regulate fishing and protect endangered species in the Republic and for matters connected therewith" (FFA undated). This new act contained the following:

> § 3. Limitations on taking of turtles.
>
> (1) No hawksbill turtles or sea turtles shall be taken or intentionally killed while on shore, nor shall their eggs be taken.
>
> (2) No hawksbill turtle shall be taken or killed except whose shell is at least twenty-seven (27) inches (68.6 cm) when measured over the top of the carapace shell lengthwise; no green turtle shall be taken or killed except whose shell is at least thirty-four (34) inches (86.4 cm) when measured over the top of the carapace shell lengthwise.
>
> (3) No sea turtle of any size shall be taken or killed from the first day of June to the thirty-first day of August inclusive, nor from the first day of December to the thirty-first day of January inclusive.
>
> (4) Notwithstanding any provisions of this Section to the contrary, taking of sea turtles and their eggs shall be allowed for scientific purposes when specifically authorized by the Cabinet.
>
> § 6. Penalties for violation. A person violating any of the provisions of this Chapter for which a different penalty is not otherwise provided shall be guilty of an offense and shall upon conviction be liable to a fine not exceeding $100 or to a term of imprisonment not exceeding six (6) months, or both.

In 1997, the act was amended as follows (FFA undated);

> § 3(2) on size restrictions was amended to add an exception for subsistence fishing,
>
> § 3(3) on seasonal limits was deleted,
>
> § 3(4) which gave permitting authority to the Cabinet was changed to make the Marshall Islands Marine Resource Authority (MIMRA) the permitting authority for scientific taking.

It also added a new provision to § 3: "no turtles or turtle products may be sold, purchased, displayed for sale, offered for sale or otherwise marketed,"

In addition, it increased the penalties for violation: to a fine of not more than $10,000 or imprisonment of up to six months, or both.

The actual level of cultural take is unknown, although there are a few reports that give us some indications (McCoy 2004, Eckert 1992, Thomas 1989, Maragos 1988, Fosberg 1951).

1951 There is no sea turtle fishery on Arno, although the natives frequently catch turtles in the stone fish traps.

1988 The nesting turtles and their eggs of Erikub appear to be subject to heavy harvesting pressure. "Recent human footprints were found along all beaches where turtle tracks were reported. Numerous nest marker sticks, temporary camps, and the remains of sea turtles and their eggs were also conspicuous."

1989 "The Wotho islanders harvest the turtles only infrequently for special or ceremonial occasions, usually during the summer months off the beaches of uninhabited islands. The villagers seem very conscious of "*ine* vulnerability of the nesting turtle population and limit this harvesting practice accordingly" (Thomas 1989).

1992 A rough estimate of annual take was around 100 turtles from the reefs around Wotje islet.
One inhabitant of Wotje estimated that roughly 1000 turtles were captured annually on Wotje and Erikub.

Hunting trips to Erikub to collect turtles for a large "liberation day" feast resulted in 20–30 turtles (nesting females as well as "several males" caught in shallow water). It was estimated that more than fifty sea turtles would be eaten during the course of the celebrations.

A family spent the better part of the summer on Erikub and captured 13 turtles, estimating that two escaped for each one captured. All were large, mature turtles, 9 males and 4 females. Ten were to be sold in Majuro, three to be eaten.

2003 Approximately 40 turtles per year were captured on Wotje consisting mostly of the larger sizes and captured in the lagoon and while nesting

Those interviewed agreed that more turtles are taken in the eastern and southern portions of Ailinglaplap Atoll where seagrasses and mangroves are present and where a majority of the population resides.

A compilation of responses from various informants resulted in an estimate of the average annual take to be around 30–50 green turtles for the entire atoll: Katiej and northwestern islets 1–2; from Buoj to Airok 10–15; from Jeh and Eastern islets 10–15; from Woja and western islets 10–15; from uninhabited islets 2–5 nesting females (Total 33–52).

Because of the significance of the sea turtle to the Marshallese, a major portion of this research will be aimed at documenting, from a Marshallese perspective, the cultural knowledge and everyday importance of sea turtles in order to determine the possible ramifications of project findings (such as finding that all or some parts of sea turtles cannot be safely consumed), including:

- the importance of non-commercial, non-imported foods (sea turtles, marine foods, other foods) in regular and preferred diet;
- specific cultural knowledge regarding sea turtles' protection and conservation;
- specific cultural knowledge regarding sea turtles as culturally significant (including mythic) beings;
- specific cultural knowledge regarding sea turtles as food and medicine;
- specific cultural knowledge regarding techniques for protecting and conserving sea turtles and their locations;
- specific cultural knowledge regarding finding, and harvesting sea turtles and eggs; and
- cultural importance of sea turtles to the Marshallese peoples' sense of identity and place.

A second aspect of this research segment will be aimed at documenting the potential impact on market forces from a change to non-consumptive sea turtle uses (by Marshallese and others). Surveys will be conducted to understand:

- content of local foods markets;
- locals' food preferences (and fears); and
- importance of sea turtles to tourists and tourism operators.

A third, interconnected aspect of this research segment will use GPS mapping to augment cultural and ecological documentation of key sites. We will:

- record local ecographies;
- draft verbal snapshots of sea turtle and other places significant to the Marshallese; and
- map sea turtle locations and ecographies to GPS coordinates

Including the collection of local knowledge as a big part of the project will provide insight into the broad social context that frames the challenge of effectively managing the sea turtle resources in the RMI. Studying the cultural and historic development of the different economic activities that were established in the region by the indigenous settlers, their culture and social aspects will help us to analyze the types of social problems and cultural issues that relate to sea turtles in the region. We will study and assess the methods being used for harvesting and processing of sea turtles for food and income and will study the ethical issues regarding the interplay of sea turtles as important cultural resources and their possible contamination with war and weapons testing. We will also examine the consequences and implications of different models of resource distribution and will explore the impact on sea turtle and human health.

Combined methods (quantitative and qualitative) data will be collected and analysed (see methods outlined below). Participatory ethnographic methods, drawing on a combination of phenomenological and social interactionist techniques, and survey instruments created for this project will be employed. Basic ethnographic and qualitative information about local perceptions of sea turtles will be collected. The methods will include semi-structured interviews, group discussions, participant observation, verbal snapshot and GPS mapping of sea turtle locations, ecographic and cognitive mapping, active listening, observing and analyzing the landscape, tourist surveys, market and local foods study, life history interviews, time allocation studies, food preference surveys, and the collection of turtle recipes for food and medicine, among others. The population target will be different social and age groups to have a comprehensive vision about local perceptions. Researchers will interact with and among atoll householders, elders, cultural specialists, turtle harvesters, market vendors, food preparers, and other local experts as identified by the community. We will rely on partnership with local Marshallese as well as cultural competency, active listening, photo-documentation and unstructured interviews with community groups and key individuals, to gather information in the most naturalistic, culturally sensitive methods possible.

We intend our research to include involvement of local participants at every step of the process and in order to accomplish this, the ultimate utility, relevance, and meaning to the local community must be taken into account. Doing so will ensure that the proposed research is not solely of "external" value. Of course this also implies a willingness to bend toward community interests, the involvement of the community in initial discussions, an exchange of resources during the research period, and full disclosure regarding the benefits and requests to be made of the local community.

Fully integrated into the research process will be careful consideration, in conjunction with community members, of the possible uses and impacts of research results — since no outsider can fully judge or predict how information may be damaging to local research participants. Of course, all participation must be voluntary and anonymous, as spelled out in the federal regulations regarding research on human "subjects".

The collaborative nature of the proposed fieldwork will be emphasised and made public. Training, mentoring, and compensating assistants are examples of the type of reciprocal exchange of knowledge and skills we have planned. Committing oneself to such work during the research period is a critical collaborative activity. The relationships that develop through work in meaningful local contexts, rather than detract from research, enhance it tremendously. Local work enables community members to value individual researcher's contributions, and allows researchers to know them in ordinary environments. Participants contribute their time, effort, and knowledge. That offering must be respected, acknowledged, and returned with a commitment in kind.

This exchange of information and resources allows the researchers to be better known by community members, makes them more accessible and more understandable. As this exchange takes place, personality, desires, and interests grow more transparent. Viewing this contribution as obligatory rather than supplementary is a challenge we hope to have met through our research design. Building in a time commitment to research participants makes us accountable not only through our research, but also as individuals. We commit our time to their self-defined needs, and their livelihoods, as they do to ours. We come to know them as whole beings, not just interviewees. We open ourselves to being known and making our strengths and weaknesses obvious. We pledge to be professionally and ethically accountable by protecting the anonymity of participants, and by being as accurate as possible. Once field research is completed, the final results will be presented in accessible and meaningful ways to the local communities with limited use of technical jargon and discipline specific terminology.

The value of sharing research outcomes in a community-accessible product is immeasurable. Eliminating academic terminology and clearly stating theoretical interests is not only an opportunity to give back, but to show how valuable the participation of the community is to a deeper understanding of the research topic. It provides an opportunity for the researcher to be responsible to the community for praise, criticism, and further discussion. Once local audiences have access — in the local languages, idioms, and images — to works written about them, they are sure to comment and to be recognized as co-creators and collaborators.

> *"We see a future where generations of Pacific Island people will have choices about how they use and interact with sea turtles. This dream will come true if we take action now to ensure that sea turtle populations recover to become healthy, robust and stable. Sea turtles will be fulfilling their ecological role and be harvested by Pacific Islander people on a sustainable basis to meet their cultural, economic and nutritional needs."*

-- The Vision Statement of the Strategic Plan for Marine Turtles of the South Pacific, drafted by participants of the Strategic Planning Meeting of the Regional Marine Turtle Conservation Project, June 1996, Apia, Western Samoa

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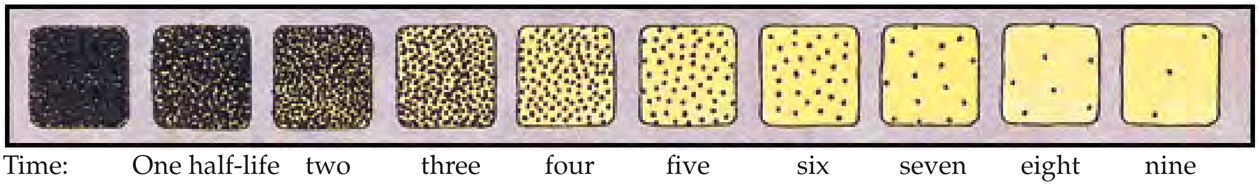
Endnotes

i The time in which half the atoms of a radioactive substance disintegrate to another nuclear form is known as the half-life (T1/2). As a general rule of thumb, 7–10 half-lives can indicate how long an isotope could be expected to remain radioactive as it decays into its daughter isotope, which also remains radioactive for 7–10 half-lives as it decays into its daughter isotope and on and on until it decays to a stable isotope (ANV and USDOE 2007). In hazard assessments, all radioactive members of a decay series must be considered. This concept of half life is illustrated below (from the Uranium Information Center, Melbourne, Australia, www.uic.com.au/ral.htm):

Decay rate of radioactivity: After 10 half-lives, the level of radiation is reduced to one thousandth



238Pu, 239Pu, and 240Pu are isotopes of plutonium, and have half-lives of 87 years, 24,065 years, and 6,537 years, respectively. As plutonium decays, it releases radiation and forms decay products. For example, the decay products of 238Pu and 239Pu are uranium-234 (234U) and uranium-235 (235U), respectively. The half-life for 235U is 710 million years and is 250,000 years for 234U. Radiation is released during the decay process in the form of alpha and beta particles, and gamma radiation. When mixed in soil on the ground these plutonium isotopes have a potential risk that is predominantly from the inhalation and ingestion pathways. Plutonium may remain in the lungs or move into the bones, liver, or other body organs. The plutonium that is not readily extracted stays in the body for decades and continues to expose the surrounding tissue to radiation. Plutonium inhaled or ingested will increase a person's chance of developing cancer, but such cancer effects may not become apparent for several years (US EPA 2006). When uranium gets inside the body, radiation and chemical damage can lead to cancer or other health problems, the major target organ of uranium's chemical toxicity is the kidney (US EPA 2006).

ii. Strontium-90 (90Sr) has a half-life of 29 years and emits beta particles of relatively low energy as it decays. Strontium-90 decays to yttrium-90 (90Y). The isotopes of yttrium emit beta particles as they decay. Beta particles can pass through skin, but they cannot pass through the entire body. 90Y has a shorter half-life (64 hours) than 90Sr, but it emits beta particles of higher energy. Strontium in the environment can become part of the food chain. After 90Sr is ingested, 20–30% of it is absorbed from the gastrointestinal tract, while the rest is excreted. Of the portion absorbed, virtually all (99%) of the 90Sr is deposited in the bone volume or skeleton. The balance is distributed among the blood stream, extracellular fluid, soft tissue, and bone surface, where it may stay and decay or be metabolized and excreted in urine and fecal matter. Strontium-90 behaves like calcium in the human body and tends to deposit in bone and blood-forming tissue (bone marrow). Thus, 90Sr is referred to as a "bone seeker" and exposure to it will increase the risk for several diseases including bone cancer, cancer of the soft tissue near the bone, and leukemia (US EPA 2006).

iii. Zirconium 95 (95Zr) is among the long-lived radionuclides with a physical half-life of 65 days. It decays to niobium-95 (95Nb), which has a physical half-life of 35 days (aquatic plants have a rapid uptake of soluble zirconium) (KAERI 2000). Zirconium can be taken into the body by eating food, drinking water, or breathing air. Gastrointestinal absorption from food or water is the principal source of internally deposited zirconium in the general population. Of the zirconium that reaches the blood, half deposits in the skeleton with a biological half-life of 8000 days and the other half deposits in all other organs and tissues of the body where it is retained with a biological half-life of seven days (per simplified models that do not reflect intermediate redistribution). Since zirconium is not a major constituent of mineral bone, the amount deposited in the skeleton is assumed to remain on the bone surfaces and not be absorbed into the volume of bone. While inside the body, zirconium presents a health hazard from the beta particles and gamma radiation, and the main concern is associated with the increased likelihood of inducing cancer (ANV and USDOE 2007).

iv. Most of the radiation from the decay of cobalt-60 (60Co) is in the form of gamma emissions; some is in the form of beta particles. Beta particles are generally absorbed in the skin and do not pass through the entire body. Gamma radiation penetrates the body. The half-life of 60Co is about 5.2 years. Cobalt-60 can be swallowed with food or inhaled in dust. Once in the body, some of it is quickly eliminated in the feces. The rest is absorbed into the blood and tissues, mainly the liver, kidney, and bones. This cobalt leaves the body slowly, mainly in the urine. Because 60Co releases gamma rays, it can affect health even if not ingested or inhaled. Exposure to low levels of gamma radiation over an extended period of time can cause cancer (US EPA 2006).

v. Cesium-137 (137Cs) is significant because of its prevalence, long half-life (30 years), and its potential effects on health. After 137Cs is ingested, it is distributed fairly uniformly throughout the body's soft tissues. Slightly higher concentrations are found in muscle; slightly lower concentrations are found in bone and fat. Exposure to radiation from 137Cs can result in malignant tumors and shortening of life. Cesium-137 emits beta particles as it decays to the barium isotope, barium-137m (half-life = 2.6 minutes), which emits gamma radiation of moderate energy. Gamma photons emitted from the 137mBa, are a form of ionizing radiation that can pass through the body, delivering doses to internal tissue and organs (US EPA 2006).

vi. In fish and amphibian toxicity tests with 22 metals and metalloids, Silver was the most toxic tested element as judged by acute LC50 values (dose at which 50% mortality occurs). In solution, ionic Silver is extremely toxic to aquatic plants and animals. Among all tested species, the most sensitive individuals to silver were the poorly nourished and young and those exposed to low water hardness or salinity. It is emphasized that silver-induced stress syndromes vary widely among animal classes. Silver, as ionic Ag+, is one of the most toxic metals known to aquatic organisms in laboratory testing. Signs of chronic silver intoxication in tested birds and mammals included cardiac enlargement, vascular hypertension, hepatic necrosis, anemia, lowered immunological activity, altered membrane permeability, kidney pathology, enzyme inhibition, growth retardation, and a shortened life span. Repeated exposure of animals to silver may produce anemia, cardiac enlargement, growth retardation, and degenerative changes in the liver.

vii. Transuranics are "elements of a higher atomic number than uranium (92), most transuranic isotopes are highly toxic alpha-emitting radionuclides with great biological significance which do not occur naturally in any significant quantities, but which are an artificial product of the fission process and emit radiation having much higher energy than other radionuclides. The transuranic nuclides of the greatest significance are neptunium-237, plutonium-238, 239, 241, americium-241, and curium-242, 244" (RADNET 2007). Alpha radiation is difficult to detect and its effect is lasting for years. It has a range of only a few inches in the air, however is a primary hazard when absorbed internally.

viii. The half-life of americium-241 (241Am) is about 432 years. As americium decays, it releases radiation and forms "daughter" elements. The first decay product of 241Am is neptunium-237 (237Np T1/2=2,144,000 years), which also decays and forms other daughter elements. The radiation from the decay of 241Am and its daughters is in the form of alpha particles, beta particles, and gamma rays. Because 241Am emits alpha particles, it poses a significant risk if swallowed or inhaled. Once in the body, 241Am tends to concentrate primarily in the skeleton, liver, and muscle. It generally stays in the body for decades and continues to expose the surrounding tissues to radiation. This may eventually increase a person's chance of developing cancer, but such cancer effects may not become apparent for several years. Americium, however, also can pose a risk from direct external exposure (US EPA 2006). Neptunium-237 is generally more mobile than other transuranic elements and it can move down with percolating water to underlying layers of soil. Neptunium preferentially adheres to soil particles, with the concentration associated with sandy soil particles estimated to be about five times higher than in interstitial water (water in pore spaces between the soil particles). Neptunium is readily taken up by plants, and plant concentrations are typically similar to soil concentrations. Neptunium can be taken into the body by eating food, drinking water, or breathing air. Gastrointestinal absorption from food or water is a likely source of internally deposited neptunium in the general population. After ingestion or inhalation, most neptunium is excreted from the body within a few days and never enters the bloodstream; only about 0.05% of the amount taken into the body by ingestion is absorbed into the blood. After leaving the intestine or lung, about 50% of the neptunium that does enter the bloodstream deposits in the skeleton, about 10% deposits in the liver, about 5% deposits in other soft tissues, and the rest is excreted, primarily in urine. The biological half-lives in the skeleton and liver are about 50 and 20 years, respectively. (This information is per simplified models that do not reflect intermediate redistribution.) The amount deposited in the liver and skeleton depends on the age of the individual, with fractional uptake in the liver increasing with age. Neptunium in the skeleton is deposited on bone surfaces and slowly redistributes throughout the bone volume over time. Neptunium is generally a health hazard only if it is taken into the body, although there is an external risk associated with the gamma rays emitted by 237Np and its short-lived decay product protactinium-233. The major health concern is cancer resulting from the ionizing radiation emitted by neptunium isotopes deposited on bone surfaces and in the liver (ANL and USDOV 2007).

ix. The half-life of euopium-155 (155Eu) is about five years. Europium isotopes decay by emitting beta and gamma particles. Europium can be taken into the body by eating food, drinking water, or breathing air. Gastrointestinal absorption from food or water is the principal source of internally deposited 155Eu in the general population. Europium is not well absorbed into the body after intake, with only about 0.05% of the amount ingested being absorbed into the bloodstream through the digestive tract. Of the 155Eu that reaches the blood, 40% is deposited in the liver, and another 40% is deposited on the surface of the bone, where it can irradiate the bone-forming cells; this deposited 155Eu is retained in the body with a biological half-life of almost 10 years (3500 days); an additional 6% of the absorbed 155Eu is deposited in the kidneys, where it is retained with a short biological half-life of 10 days (per simplified models that do not reflect intermediate redistribution). The remainder of the absorbed 155Eu is excreted. While in the body, europium poses a health hazard from both the beta particles and gamma rays, and the main health concern is associated with the increased likelihood of inducing cancer in the liver and bone (ANV and USDOE 2007).

x. Because it is an element, beryllium does not degrade nor can it be destroyed. Inhalation of beryllium can result in two types of respiratory disease, acute beryllium disease and chronic beryllium disease (also referred to as berylliosis). Both forms can be fatal. The acute disease usually occurs after exposure to high levels (more than 1 mg m^{-3}) of the relatively soluble forms of beryllium, with symptoms ranging from inflammation of the nasal passages to severe chemical pneumonia. Some people can get chronic beryllium disease from breathing low levels, occurring in less than 15% of those exposed to more than 0.0005 mg m^{-3}. This disease is a type of immume response only observed in sensitized individuals, and it involves the formation of granuloma and development of fibrosis of the lung. There can be a protracted latency period (up to 25 years) before the onset of any symptoms following exposure. The USEPA describes beryllium as a probable human carcinogen (ANV and USDOE 2007).