THE LEGACY OF U.S. NUCLEAR TESTING IN THE MARSHALL ISLANDS

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Imprint

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05/2025

Acknowledgements

This report is an attempt at a comprehensive look at the legacy of U.S. nuclear testing in the Marshall Islands. It includes an examination of the governmental radiological and military assessments of testing, official scientific analyses and medical sources from July 1945 up to the present. Nearly eight decades after the first tests there, there remain unaddressed scientific issues. It is an account, in historical context, of a transition from the time in 1944 when the Marshallese were relieved that the United States had ended the ruthless Japanese rule during World War II to the period of disease, displacement and contamination that continues.

Among the many troubling aspects of the legacy is that the United States had concluded, in 1948, after just three tests that the Marshall Islands was not "a suitable site for atomic experiments" because it did not meet the required meteorological criteria. Yet testing went on. Also notable has been the lack of systematic scientific attention to the accounts by many Marshallese of severe malformations and other adverse pregnancy outcomes like stillbirths. This was despite the documented fallout throughout the country and the fact that the potential for fallout to cause major birth defects has been known since the 1950s.

I am deeply grateful to Holly Barker, Bernd Franke, Bob Richmond, Shaun Burnie, and Tim Mousseau for their reviews of this report and to Glenn Alcalay who provided me with the results of his survey of pregnancy outcomes in the Marshall Islands. Their reviews helped to greatly improve this report; however, as the author, I alone am responsible for any errors that may remain and for the report's contents and conclusions more generally. This report was funded by Greenpeace Germany.

Arjun Makhijani, Ph. D.

May 2025

Executive Summary[1]

The Marshallese had credited American missionaries who brought Christianity to them in the mid-nineteenth century for bringing *meram*, the enlightenment that ended warring between atolls. They had welcomed American soldiers who, in early 1944, ended the brutal wartime Japanese rule that had starved them, and even forbidden them, sometimes on pain of death, from gathering coconuts from their own trees. The Americans had brought food and doctors. The Bikinians were grateful. When Commodore Ben Wyatt made a biblical appeal after church on Sunday 10 February 1946 and asked them to leave their homes "for the welfare of all men", they could not bring themselves to refuse. The scene, filmed Hollywood-set style, was apparently performative; the U. S. government had already decided the month before to test nuclear weapons there, with a focus on naval impacts and strategy.

The United States conducted 67 nuclear tests in the Marshall Islands, at Enewetak Atoll (44) and Bikini Atoll (23) between July 1946 and August 1958. The total explosive force was 108.5 megatons, more than one hundred times greater than that of all the atmospheric nuclear tests at the Nevada Test Site. It was equivalent to one Hiroshima-size bomb every day for 20 years. U. S. nuclear testing created serious radiological, environmental, health, and economic harms throughout the country; its impacts persist to the present time. Within months of their displacement to the much smaller Rongerik Atoll, the Bikinians were starving.

Findings

1. **By U. S. military criteria, the Marshall Islands was an unsuitable nuclear test site.** The extensive radioactive fallout due to the 16 July 1945 plutonium bomb "Trinity" test in New Mexico during the Manhattan Project had led the Chief of Radiological Safety, Colonel Stafford L. Warren, to recommend that a similar-size test not be carried out within 150 miles (240 kilometers) of human habitation. At 180 kilometers, Rongelap was closer than that to Bikini, the first chosen test location; Ailinginae was even closer. By 21 April 1948, after just three tests, the U.S. military had concluded that the "Marshall Islands in the main" did not meet the meteorological criteria required of "a suitable site for atomic bomb experiments". The tests went on nonetheless, with some having explosive power hundreds of times greater than the Trinity test.

2. **The United States continued nuclear testing after the United Nations designated it the "trustee" of the Marshall Islands in 1947, and obligated it to "protect the health of the inhabitants."** The 1947 Joint Chiefs assessment of the July 1946 underwater barge test at Bikini (Test Baker) had concluded that the accompanying fallout was so intense that a similar explosion in wartime could be used to induce terror in the population of an adversary: "Of the survivors in the contaminated areas, some would be doomed by radiation sickness in hours, some in days, some in years." The high fallout areas "would be irregular in size and shape...and have no visible boundaries. No survivor could be certain that he was not among the doomed...." However, this assessment was not applied to the Marshall Islands. Of the 67 tests in the Marshall Islands, 37 were barge tests.

3. **U.S. government radioactivity measurements and dose estimates show that the entire country was impacted by fallout, but it has recognized only three atolls for medical cancer screening.** Gamma radiation levels at Majuro, officially considered a "very low exposure" atoll, were tens of times, and up to 300 times, more than background in the immediate aftermaths of the thermonuclear tests in the Castle series at Bikini and Enewetak in 1954. Thyroid doses in the so-called "low exposure atolls" averaged 270 milligray (mGy), 60 percent more than the 50,000 people of Pripyat near Chernobyl who were evacuated (170 mGy) after the 1986 accident there, and roughly double the average thyroid exposures in the most exposed counties in the United States due to testing at the Nevada Test Site. U. S. government

scientists have estimated at different times that the Marshallese would suffer between 170 and 500 excess cancers. On a per person basis, this range would be equivalent to between 2 million and 6 million cancers in the U.S. population of the 1950s. Only a small fraction of the population has been officially recognized as exposed enough for screening and medical attention; even that came with its own downsides, including people being treated as experimental subjects.

4. **There is documentary evidence that U. S. scientists decided to treat the people in the most contaminated areas as experimental subjects.** The minutes of a 1956 meeting of the Advisory Committee on Biology and Medicine of the U.S. Atomic Energy Commission noted that Utrik Atoll was "by far the most [radioactively] contaminated place in the world". They decided "to go back and get good environmental data…; what isotopes are involved and a sample of food changes in many humans through their urines, so as to get a measure of the human uptake when people live in a contaminated environment." Human "data of this type has never been available", the minutes noted. "While these people [the Marshallese] do not live, I would say, the way Westerners do, civilized people, it is nevertheless also true that that these people are more like to us than the mice." Mice were, and continue to be, the objects of radiation exposure experiments.

5. **Testing in the Marshall Islands created radiation exposures globally.** Atmospheric by five nuclear-weapon states created global radioactive fallout. The 1954 Castle test series was no exception; it created hotspots as far west of the Marshall Islands as Colombo, Sri Lanka and as far east as Mexico City. About one-fourth of the global fission and activation product fallout is attributable to U. S. testing in the Marshall Islands. On a proportional basis, it is estimated to result in roughly 100,000 excess cancer deaths worldwide (rounded). Because of latency periods between exposure and cancer occurrence, some of these the excess cancers would occur in the 21st century.

6. **Many Marshallese women have reported very adverse pregnancy outcomes, but no systematic scientific assessment has been done.** In interviews and one 1980s country-wide survey, women have reported many adverse pregnancy outcomes. They include stillbirths, a baby with part of the skull missing and "the brain and the spinal cord fully exposed", and a two-headed baby. Many of the babies with major birth defects died shortly after birth. Some who lived suffered very difficult lives, as did their families. Despite extensive personal testimony, no systematic country-wide scientific study of a possible relationship of adverse pregnancy outcomes to nuclear testing has been done. It is to be noted that awareness among U. S. scientists of the potential for major birth defects due to radioactive fallout goes back to the 1950s. Hiroshima-Nagasaki survivor data has also provided evidence for this problem.

7. **The occurrence of still-births and major birth defects due to nuclear testing fallout in the Marshall Islands is scientifically plausible but no definitive statement is possible at the present time.** The nuclear tests in the Marshall Islands created vast amount of fission products, including radioactive isotopes that cross the placenta, such as iodine-131 and tritium. Radiation exposure in the first trimester can cause early failed pregnancies, severe neurological damage, and other major birth defects. This makes it plausible that radiation exposure may have caused the kinds of adverse pregnancy outcomes that were experienced and reported. However, no definitive statement is possible in the absence of a detailed scientific assessment.

8. **Harms have occurred across all areas of social and personal life.** Displacement and exile continues for the people of Bikini and Rongelap. This has created a variety of problems, including loss of connection to traditional lands and jobs. Lack of oncological treatment facilities in the Marshall Islands has meant great travel expense for treatment. The National Nuclear Commission of the Marshall Islands has concluded that "The absence of cancer care facilities and its link to forced migration are deplorable, and it means that the violence of the testing program continues despite the cessation of weapons testing…."

9. **Remediation of contaminated areas is complex, costly, and difficult, as illustrated by the fate of the "Runit dome".** Resettlement of Bikini and Rongelap was temporary, resulted in exposures, and was ultimately unsuccessful. In the 1970s, the U. S. government decided on a partial, plutonium-centered remediation of Enewetak Atoll to promote resettlement. The radioactive waste accumulated in the process was disposed of in an unlined nuclear test crater on Runit Island and is thus in contact with ocean water and the tides. The waste contains only a tiny fraction of the total plutonium in the atoll – one-fourth of a kilogram in the dome compared to an estimated 30 kilograms in Enewetak lagoon. In plutonium-related U.S. military accidents in Spain (1966) and Greenland (1968), the most contaminated waste was repatriated to the United States. But in the Enewetak cleanup, all the waste was put into the Runit dome. It has cracks, but has been declared safe by the U.S. Department of Energy.

10. **The Marshall Islands lacks technical capacity in a number of fields crucial to health, environmental protection, and possible resettlement.** The Marshall Islands does not at present have sufficient technical capacity in a number of relevant fields – oncology, field measurements of radioactivity, laboratory facilities for analyzing soil, water, and food samples, and radioecology. As a result, the Marshall Islands has little recourse but to commission independent work by non-resident experts or to rely on the United States, in addition to the travel necessary for cancer treatment outside the country.

11. **Trans-Pacific cooperation may reduce the difficulties of creating the capacity and infrastructure.** The Marshall Islands has a small population spread over a vast area, with many young people migrating out of the country. Building a health, remediation, technical infrastructure, and educating and training personnel to run it would be a difficult and costly endeavor. Several Pacific region countries have been impacted by nuclear testing, including Kiribati, French Polynesia, and Australia, where indigenous lands and people were disproportionately affected. A collaborative program might be explored to increase the financial feasibility of creating the needed infrastructure.

1. Prelude to loss

"There is nothing in my life I want more than to go home to Bikini….I want to go back to my paradise where God had intended us to be."
Reflections of Bikinian elder Kilon Bauno in exile, circa 1983 (translated from the Marshallese in Stone 1988, min. 49:40)

The people of Bikini had been there for thousands of years before the United States military evacuated them and burned their homes to make room for the infrastructure and logistics base for the first nuclear bomb explosions after the 9 August 1945 destruction of Nagasaki (Stone 1988).

The total explosive power of the tests at Bikini and Enewetak was 108.5 megatons, equivalent to one Hiroshima bomb every day for 20 years, more than a hundred times greater than all the atmospheric tests conducted at the Nevada Test Site combined. The explosions poisoned the scarcest resource, land, and the abundant resource – lagoons. They have destroyed islands and surrounding coral reefs and have displaced people.

The severe consequences of the 1954 thermonuclear tests at Bikini, especially the Bravo test, inspired global calls for disarmament, including the 1955 Einstein-Russell Manifesto (Born et al. 1955) – and resistance by the Marshallese who "are asserting their right and ability to take control of their destiny" (Barker 2013, p. xiii). This report seeks to put forward the scientific facts about the legacy of U.S. nuclear testing in the Marshall Islands and to sketch what the ability "to take control" by the Marshallese people might involve. A significant part of the task is to elucidate the scale of the problem and of the scientific and technical resources needed to enable reestablishment of local control of the protection of health and the environment for the present and future generations.

For about 400 years after the 1452 Papal Bull (Nicholas 1452) set in motion the devastation of the non-European world, the atolls now known as the Marshall Islands were relatively unharmed. Secure in the vastness of the Pacific Ocean, their first continuous intercourse with the West was with missionaries and traders in the mid-nineteenth century. It was agreeable enough that when Germany planted its imperial flag in 1885 to claim sovereignty, European style, the Marshallese were not alarmed. Their social organization, constructed around their scarcest resource, land, did not seem threatened.[2] On the contrary, they had "every reason to believe that it would bring them new economic advantages"; after all, their country was already "the richest source of copra in Micronesia" (Hezel 1995, p. 45).[3]

That would change in sixty short years.

a. Rule by Germany and Japan

Germany ruled the Marshall Islands for trade and profit via the Jaluit Company, named after the atoll where it was headquartered. The authority of the iroij, the traditional chief, was reinforced relative to the people; the iroij prospered along with the Germans in the copra trade. Yet, the Germans were now the top authority. They had the power to tax; they were also the arbiters of disputes among the iroijs. A principal consequence of formal German sovereignty was that the Marshall Islands would, thenceforth, become entangled in disputes among European powers, Japan, and the United States.

There was already tension between Japan and the United States in the early part of the twentieth century; both were expanding in the Pacific region. The United States had conquered the Philippines and taken possession of Hawai'i. Japan had conquered Korea, made an alliance with Britain, and waged a successful war against Russia. All the major imperialist powers were already in China, where Japan's ambitions were also growing. As Britain's ally when World War I broke out in Europe, Japan declared war on Germany in 1914. In contrast to the four long, blood-soaked years that turned parts of Europe into mass graveyards for young men, the Jaluit Company surrendered quickly to Japan before the sun had set on 1914. The war's end saw Japan in practical full control of the country (Hezel 1995).

Japan's aim was the incorporation of the island countries it controlled, subjugating them much in a manner of the European powers – control of land, colonization by emigration (especially during the Great Depression), introduction of Japanese as a medium of instruction in schools, and increasing trade and monetization of their economies (Hezel 1995). Japan embarked on its conquest of China in the 1930s; its goal was the subjugation of Asia under the rubric of a "co-prosperity sphere". The Marshall Islands went from being an economic outpost to a strategic possession in the equatorial Pacific.

> *"By 1938, Japan considered the Marshall Islands a closed military area and restricted foreigners' movement in the territory. The Marshallese describe the Japanese regime as strict, but effective; the Japanese built schools and roads and provided formal education to the Marshallese."* (Barker 2013, p. 18)

Japanese rule would become a cruel nightmare during World War II. The U. S. had an amphibious strategy of landing troops and conquering Japan's strategically located possessions in the Pacific. This squeezed Japan's remaining island possessions as the war wore on. Both the Japanese and Marshallese were starving. But the Japanese were in charge; on some atolls, the Marshallese were denied access even to their own coconut trees (ironically deemed as stealing though it was the Japanese who were the occupiers):

> *"Starvation was particularly pronounced on the atolls of Mili, Maloelap, and Wojte, where the Japanese based their troops. The Japanese gathered all existing food resources for their own use, while the Marshallese were starving as a result of the meager rations they received and were hung, beaten, and even beheaded for attempting to steal or climb trees at night in search of food. The Japanese forbade the Marshallese from taking even a single coconut or other morsel of food from their trees."* (Barker 2013, p. 19)

It was natural, then, that "[m]any Marshallese served as scouts to help the United States plan strategic attacks against the Japanese" (Barker 2013, p. 19).

b. The United States takes over

> *"To the degree that the United States is the arsenal of the Democracies it will be the final arsenal at the moment of victory. It cannot throw the content of that arsenal away. It must accept world responsibility. … The measure of our victory will be the measure of our domination after victory."* (Council on Foreign Relations 1944, in Shoup and Minter 2004, p. 163)

> *"Ernest King, and the Commanding General of the Army Air Corps, H. H. Arnold, said the Marshall Islands were important to the future security of the United States and should remain in American hands. 'The future peace of the world,'* they said, *'indeed, the fate of mankind may depend on it.'"* (Meade and Meade 2018, p. 20)

Figure 1-1 shows a map of the Marshall Islands.

By early 1944, the United States had prevailed in Enewetak and Kwajalein; both soon became U. S. naval bases. The Marshall Islands were on their way to becoming a key part of a post-war strategy in which the United States would aim to *"*hold unquestioned power*"*; military primacy was a prerequisite (Chomsky and Robinson 2024, Chapter 1; Shoup and Minter 2004, Chapter 4).

Even before the war's end, nuclear weapons were emerging as an essential element of post-war U. S. power. On April 25, 1945, Henry L. Stimson, Secretary of War, briefed the newly installed President Truman who did not yet know about the Manhattan Project. Stimson pointed to their potential for annihilation, but also suggested the United States might wield them for control of the post-war world:

> *"On the other hand, if the problem of the proper use of this weapon can be solved, we would have the opportunity to bring the world into a pattern in which the peace of the world and our civilization can be saved."* (Stimson 1945)

Figure 1-1. Map of the Marshall Islands. Kili, one of the places of exile of Bikinians, is circled. Source: macumba 2008, Wikimedia Commons.

In the 1980s Kilon Bauno, a Bikinian elder, recalled being told much the same thing in 1946 about the purpose of the Operation Crossroads when his people were evacuated from Bikini:

> *"They said they needed to do this [test the atom bomb] to keep all the other nations in control. This is why they dropped the bomb on my island."* (Stone 1988, 22:50)

2. Marshall Islands Enters the Nuclear Age

Despite their varied opinions on the use of atomic bombs on Japan in the immediate aftermath of the destruction of Hiroshima and Nagasaki, U.S. military leaders realized that it was a new world. Military strategy would have to be adapted. Yet, during the war most of them did not even know about the existence of the Manhattan Project. General MacArthur was not part of the decision to use the bombs, or even of targeting decisions. He was only informed a few days before that the atom bombs would be used on Japan (Alperovitz 1995).

To situate themselves in the atomic world, U.S. military leaders had to know much more about the potential impacts of nuclear weapons; they had a sense of urgency about it. By December 1945, the United States had decided to test nuclear weapons so as to have the data for post-war strategy.

> *"Early determination of the full effects of atomic explosives against naval vessels and other military targets...is essential in order to appraise the strategic implications of the application of atomic energy and to make such readjustments in the military program of the United States as may be indicated to assure best continuing provisions for natural security."* (Joint Chiefs of Staff 1945a).

For instance, atomic weapons had increased the "premium" of a Pearl Harbor type of attack in starting a war. "This emphasizes the importance not only of readiness for immediate defense, but also of striking first, if necessary, against the source of the threatened attack" (Joint Chiefs of Staff, 1945b). The Navy had not been part of the Manhattan Project. The three atomic bombs exploded in wartime had been over land. Naval matters were at the center of the first post-war tests. They wanted to find out the impact of nuclear weapons on various types of ships. They wanted to understand how nuclear weapons would fit into overall naval strategy. There were to be two or three tests – the plutonium bomb dropped on Nagasaki would be the design used.[4]

The test site had to be suitable for anchoring naval vessels; it had to be remote from the United States but yet controlled by it. It had to be close enough to air bases and to locations of ships captured from Japan and those surplus to the United States; many of them became "target" ships positioned in Bikini lagoon. The Marshall Islands seemed to fit the bill. In the mid-nineteenth century, Protestant missionaries from the United States, accompanied by Hawaiians who had already converted, convinced most Marshallese to convert to Christianity. They had changed their clothing and some customs; there had been some important benefits:

> *"The Marshallese credit American Protestant missionaries with bringing meram, or 'enlightenment,' to the islands by ending the warring and fighting between atoll populations and teaching people to embrace the values in the Bible."* (Barker 2013, p. 20)

The U.S. defeat of "the brutal Japanese military regime" had been a relief (Barker 2013, p. 20); the setting was propitious for Commodore Ben Wyatt's biblical appeal, filmed Hollywood-set style (Stone 1988), after church services on Sunday, February 10, 1946:

> *"[Wyatt] drew upon the Bible...and delivered a short homily. According to Wyatt's own account, he 'compared the Bikinians to the children of Israel whom the Lord saved from their enemy and led to the Promised Land.' He described the power of the atomic bomb and 'the destruction it had wrought upon the enemy,' and he told the people that the Americans 'are trying to learn how to use it for the good of mankind and to end all wars.' The Navy had searched the entire world for the best place to test these powerful weapons, and Bikini was it. Wyatt then asked, 'Would Juda and his people be willing to sacrifice their island for the welfare of all men?"* (Weisgall 1994, p.107)

Juda, an elder whose forebears had been the original settlers of Bikini thousands of years before, only said *"Everything is in God's hands." It was hard to refuse a request outright from the United States who had "liberated them from the brutal Japanese regime" (Barker2013, p.20). Bikinians "were also grateful to the Americans, who had brought them food and doctors and had constructed several community buildings on Bikini"* (Weisgall 1994, p. 108).

The Bikinians agreed to be moved; many thought it would be temporary (Weisgall 1994, pp. 107-109). Evacuation meant the loss of their homes, their ancestral lands, and the associated traditions. They did not agree that the new place was a promised land. A few months after the evacuation, when asked, they stated they preferred their own atoll and wanted to return home (Weisgall 1994, p. 308 and p. 310).

The stage was set for Operation Crossroads. The two tests, Able and Baker, on 1 July and 26 July1946, became a tragic coming-out party of the bomb, attended by dignitaries from around the world (Stone 1988), that gave the Joint Chiefs what they wanted – military data:

"The tests fully accomplished two major purposes:

- *They provided data essential to future military planning, giving bases for the calculation of the conditions under which the maximum destructive effects of an atomic explosion will be obtained under various types of land and water targets and against living organisms....more than 30,000 pages of technical reports have been written with others in preparation.*

- *The tests gave to those upon whom falls the responsibility of various phases of atomic warfare planning, the incalculable benefit of first-hand knowledge of the bomb in action, and advantage theretofore possessed by very few persons."* (Joint Chiefs of Staff Evaluation Board, 1947, p. 66)

3. An unsuitable place

Bikini was known to be an unsuitable place by at least one critical criterion before it was selected as a test site. Colonel Stafford L. Warren, a medical doctor and Chief of radiological safety for Operation Crossroads, had served in the same role at the July 16, 1945 Trinity test in New Mexico. His assessment of the Trinity test fallout contained a recommendation for future tests. In his memorandum to General Leslie Groves summarizing the serious radiological fallout that persisted over populated areas for days far from the test site, he recommended that any future test of similar magnitude be done in a place "preferably with a radius of *at least 150 miles without population*...." (Warren 1945, italics added)

That would have ruled out Bikini as a test site for a nuclear weapon of the same explosive force: Populated Rongelap Atoll was about 110 miles (180 kilometers) away as the crow flies; Ailinginae atoll was even closer. On 1 March 1954, both atolls would become tragic sites of the worst radiological disaster in U.S. testing history.

The bombs tested during Operation Crossroads were essentially the same as the one tested at Alamogordo in 1945. The majority of the tests in the Marshall Islands after that had far larger explosive power than the Trinity test. The largest, Bravo, in 1954, was about 700 times the explosive power of the Trinity test. For reference, we note that essentially the entire Marshall Islands is within a radius of about 1,200 kilometers from Enewetak, about five times the recommended radius without population for a 21 kiloton test. What would have been the minimum radius without population for a test like Bravo, which was seven hundred times as powerful?

Problems were evident almost from the start. Test Baker, the second in Operation Crossroads, was an underwater test; the bomb was suspended underwater from a barge. It was a radiological disaster to the point that the 1947 Joint Chiefs evaluation concluded that the radioactive poisoning from such explosions in wartime could be used to induce radioactive terror in an adversary's population:

> *"We can form no adequate mental picture of the multiple disaster which would befall a modern city, blasted by one or more bombs and enveloped by radioactive mists. Of the survivors in the contaminated areas, some would be doomed by radiation sickness in hours, some in days, some in years. But, these areas, irregular in size and shape, as wind and topography might form them, would have no visible boundaries. No survivor could be certain he was not among the doomed, and so added to every terror of the moment, thousands would be stricken with a fear of death and the uncertainty of the time of its arrival."* (Joint Chiefs of Staff Evaluation Board 1947)

The Joint Chiefs concluded that "the unknown, the invisible, the mysterious" spread of radioactivity had the "potentiality to break the will of nations and of peoples... by the stimulation of man's primordial fears..." (Joint Chiefs of Staff Evaluation Board 1947). The implication, not discussed by the Joint Chiefs, was that Bikinians may also experience such primordial fears, should they return.

In 1946, the Marshall Islands was under U.S. military control. The United Nations had not yet dealt formally with the matter of the governance of territories that had been held under League of Nations' mandates by the defeated imperialist powers, as was the case with the Marshall Islands. The U.S. government had decided that the tests would be done in the Marshall Islands in the month before Commodore Wyatt's meeting with the Bikinians (Hezel 1995, p 271); the homily only seemed to ask for permission.

The attitude of Admiral William H.P. Blandy, who headed Operation Crossroads, was dismissive of the Marshallese people and their land. "We wish to acquire ... a few miserable islands of insignificant economic value, but won with the precious blood of America's finest sons, to use as future operating bases," he said. "All that can be raised on most of these islands is a few coconuts, a little taro, and a strong desire to be somewhere else" (Weisgall 1994, p. 311).

In 1947, the United States formally assumed new responsibilities that would explicitly obligate it to go beyond caring for American blood spilled in the war to defeat Japan. At U. S. request, the U.N. Security Council made the United States a "trustee" of the Marshall Islands. The United States now had the right, under international law, to "establish naval, military and air bases and to erect fortifications in the Trust Territory." But it also had obligations. The U.S. government committed itself under international law, among other things, to

- "protect the inhabitants against the loss of their lands and resources;"

- "protect the health of the inhabitants;" (United Nations 1947).

Continued nuclear testing was, by its nature, at cross purposes with these commitments. The detailed evaluation of the radiological consequences of Test Baker for military strategy, quoted above, makes it clear that the United States was aware of that reality.

There were no tests in 1947. By April 21, 1948, United States had concluded that the Marshall Islands was "in the main" a meteorologically unsuitable testing site:

"From a meteorological standpoint, there are three basic requirements for a suitable site for atomic bomb experiments. These are:

- *"a. There should be a reasonable frequency of occurrence of cloud or weather conditions to meet the operational requirements for the experiment....*

- *"b. Wind conditions from the surface to stratospheric levels should be such that there can be no possibility of subjecting personnel to radiological hazards or surrounding land or water area to unintentional radioactive contamination....*

- *"c. The mechanism of meteorological processes for the site should be adequately understood and the weather predictions for the site demonstrated to be of a high and reliable accuracy.*

- *"The Marshall Islands in the main do not meet these meteorological requirements."* (Rear Admiral Parsons 1948, quoted in IPPNW and IEER 1991)

Between Operation Crossroads and the April 21, 1948 date of Admiral Parsons' assessment, just one additional test had been done, a 37-kiloton tower explosion at Enewetak on 14 April 1948 (U.S. Department of Energy 2015). The United States as a trustee of the Marshall Islands had concluded the Marshall Islands was "in the main" unsuitable as a test site when the cumulative explosive power of the tests there was at most 0.079 megatons.[5] By the time testing ended in 1958, the total explosive power would rise to 108.5 megatons – 1,373 times greater, spreading radioactivity throughout the Trust Territory. That tests were done subsequent to the military's conclusion of the meteorological unsuitability of the Marshall Islands as a test site raises questions about the seriousness of the United States Trusteeship commitment to protect land, resources, and health.

4. Testing summary, radioactivity, and cancer

a. Explosive power and overall radioactivity amounts

The United States conducted 67 nuclear tests in the Marshall Islands between 1 July 1946, the date of Test Able at Bikini, and Test Fig (Operation Hardtack I) at Enewetak on 18 August 1958. The total explosive force amounted to 108.5 megatons (SCOPE 2000, Chapter 3, Table 3.1), more than one hundred times greater than that of all the atmospheric nuclear tests at the Nevada Test Site. The 15-megaton Bravo test at Bikini on 1 March 1954 alone was about 14 times greater than the Nevada total. A frequent comparison is that the power of the bombs exploded in the Marshall Islands were equivalent to one Hiroshima-size bomb every day for 20 years.

The tests ranged from plutonium dispersal tests with nominally zero nuclear yield (the Quince test at Enewetak on 6 August 1958) to the 15 megaton hydrogen bomb exploded at Bikini on 1 March 1954. Vast amounts of fission products were created by the explosions, deposited locally and also dispersed all over the Marshall Islands and, in many cases, the world. Activation products, like carbon-14 and tritium (hydrogen-3), were created by the impact of fission neutrons on non-radioactive elements in the environment. Unfissioned plutonium was also dispersed throughout the environment.

Many fission products have short half-lives – seconds, hours, or a few days. Intensely radioactive iodine-131, of great concern because it concentrates in the thyroid, has a half-life of about 8 days, which means that its radioactivity decays to very low levels in a few months. Other radionuclides have much longer half-lives. Strontium-90 and cesium-137, which are produced in abundance, have half-lives of 28.8 and 30.1 years, respectively, meaning that they persist in the environment in significant amounts for hundreds of years.[6] Most plutonium-239, the stuff of the Nagasaki and Operation Crossroads bombs, remains unfissioned and dispersed in the environment; it has a half-life of 24,110 years. Carbon-14 oxidizes and becomes radioactive carbon-14-dioxide,which is taken up by plant life, and all living beings that have plants in their food webs directly or indirectly; it has a half-life of 5,730 years. Tritium, with a half-life 12.3 years, enters living beings when ingested as radioactive water or breathed in as radioactive water vapor or ingested as organically bound tritium (OBT) in food.

The residual amounts of five major radionuclides due to U. S. nuclear testing in the Marshall Islands, decay-corrected to 2020, are as follows:[7]

- Cesium-137 (half-life 30.1years): 90,000 terabecquerels;
- Strontium-90 (half-life 28.8 years): 60,000 terabecquerels;
- Carbon-14 (half-life 5,730 years): 70,000 terabecquerels;
- Tritium (H-3;half-life 12.3 years): ~ 1.2 million terabecquerels);
- Plutonium-239 (half-life 24,110 years): 370 terabecquerels (160 kilograms).

Tritium is especially worth noting since it was produced in particularly copious amounts by nuclear testing, notably in thermonuclear weapons tests and is generally little commented upon. Global tritium production from testing up to 1984 is estimated to be about 240 exabecquerels (UNSCEAR 2000, Volume I, p. 49). The vast majority of this amount was due to atmospheric testing. The amount attributable to U. S. testing in the Marshall Islands is about 20 percent of this total, amounting to about 48 exabecquerels of tritium. The amount decay-corrected to 2020 was about 1.2 million terabecquerels – more than five times greater than residual cesium-137, strontium-90, carbon-14, and plutonium-239 combined.

Tritium from nuclear testing is dispersed mainly as radioactive water (HTO) throughout the world, diluted by repeated evaporation, rainfall, and snowfall over the decades; it resides mainly in the oceans. While tritium has been estimated to produce only 3.49 percent of the cumulative global population radiation dose due to atmospheric testing up to the year 2000 (IPPNW and IEER 1991,Table 3), its impacts on reproductive systems of living beings, including humans, have largely been ignored (see Section 5.b below).

b. Fallout in the Marshall Islands

While much of the fallout from U.S. testing in the Marshall Islands was dispersed (unevenly) throughout the world, much is concentrated inside the country on its land and in its lagoons. Before narrowing the focus to explore the impacts of two test series in detail, it is useful to summarize the U.S. testing program by size and type of test, notably in light of Colonel Stafford Warren's recommendation that a test similar to Trinity should not be repeated within 150 miles of a populated area. It is to be noted that Colonel Warren's recommendation was based on radiological surveys within a limited area in New Mexico. Recent work has shown that the Trinity test had cumulative fallout over 120 hours on the order of 1 million Bq/m^2 over distances several times greater than 150 miles (Phillipe et al. 2023, Figure 2). Such distances would essentially cover the entire Marshall Islands for tests at Bikini or Enewetak. For instance, Majuro, Kili, and Jaluit, in the southern part of the Marshall Islands were considered as "[v]ery low exposure" areas in the 2004 National Cancer Institute study. Yet, they are about 800 kilometers (500 miles) from Bikini and about 1,000 kilometers (600 miles) from Enewetak. Surface and tower tests – that is, tests similar to Trinity in terms of fallout production – may well have produced significant fallout even in those atolls. Larger tests certainly did (see Section 4.b.ii below).

Table 4-1 shows approximate distances of some atolls from Bikini and Enewetak. Note that Utrik is generally acknowledged as an atoll that received high fallout (see below in this chapter).

Distance to	Distance from Bikini	Distance from Enewetak
Rongelap	110 miles (180 km)	340 miles (550 km)
Utrik, Likiep (rounded)	300 miles (480 km)	500 miles (800 km)
Kwajalein	260 miles (520 km)	410 miles (660 km)
Majuro, Kili, Jaluit (rounded)	500 miles (800 km)	600 miles (1,000 km)

Table 4-1: Distances to various atolls from Bikini and Enewetak

Yield range	Number of tests	Type of test
0 to <1 kiloton (Note 1)	4	Balloon (high alt., at 26,000 m) - 1; airdrop - 4; underwater - 2; barge - 37; surface - 10 tower - 13
1 to 25 kilotons	19	
25+ to 100 kilotons	10	
100+ to 1,000 kilotons	15	
>1,000 kilotons	19	

Table 4-2: Number of tests in the Marshall Islands by yield range and type of test. Note 1: The four low-yield tests had the following yields: zero, zero, 20 tons, and 190 tons. All four were done at Enewetak: one in 1956 and three in 1958. Source: DOE 2015.

Table 4-2 shows the number of tests in various categories of explosive power of the tests done in the Marshall Islands from 1946 to 1958 and the type of test.

We focus here on Test Baker in 1946 and on Operation Castle (1 March 1954 to 14 May 1954)[8], which consisted of a series of thermonuclear bomb tests amounting to 44 percent of the total explosive power of U.S. tests in the Marshall Islands and more than one-third the megatonnage of all atmospheric U.S. tests. Within Operation Castle, a more detailed look at the 15-megaton Bravo test is also provided.

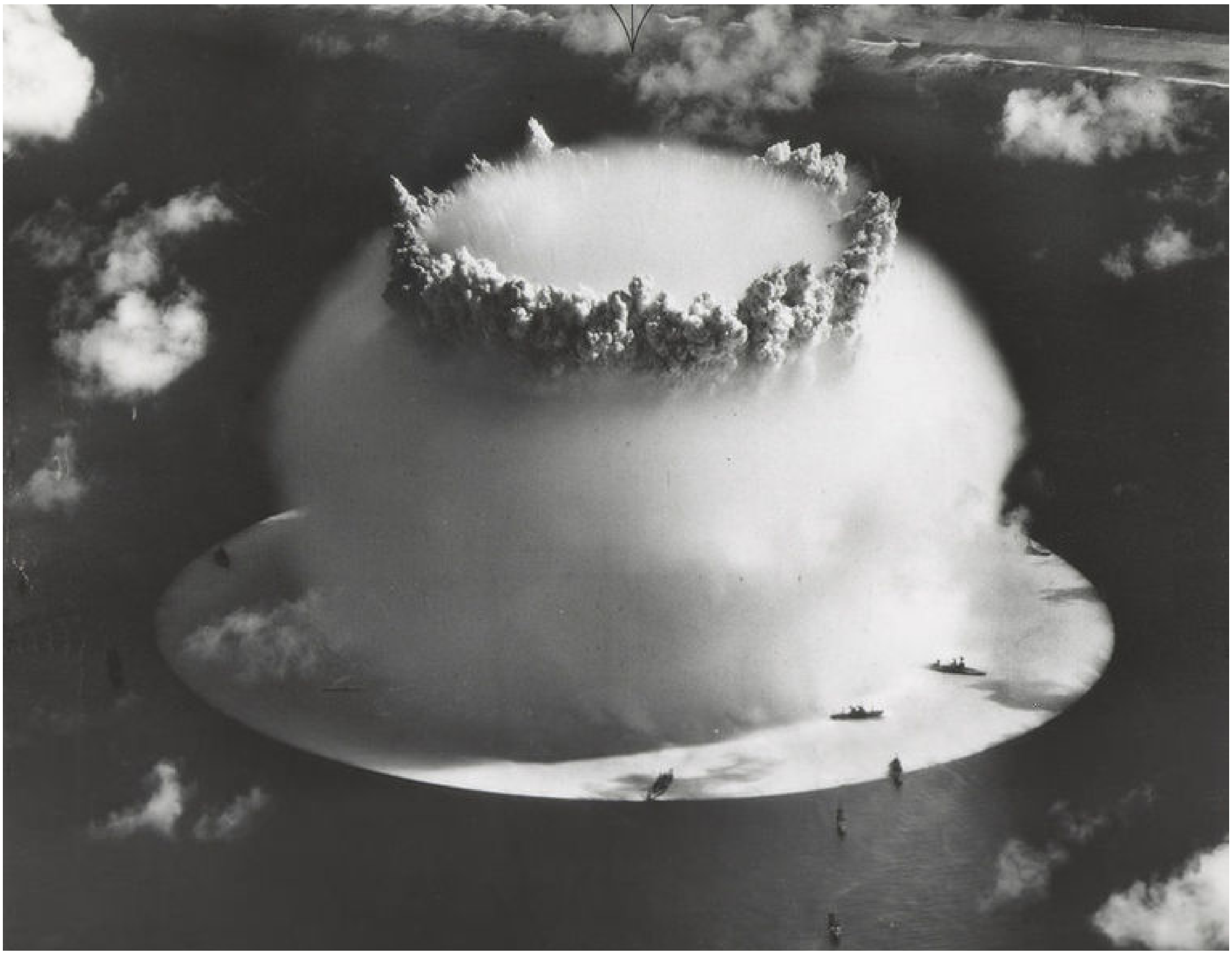

Figure 4-1: Test Baker, Operation Crossroads, Source: U. S. Army Photographic Signal Corps 1946

i. Test Baker, 26 July 1946

The Nagasaki-size bomb, suspended under a barge, disgorged several million tons of water from Bikini lagoon. The water column was two-thirds of a kilometer in diameter; its top was almost three times as high. Copious amounts of sodium-24 were created when neutrons from the fission process struck the salt in the water. Sodium-24 (half-life, 15 hours) is extremely radioactive.

Figure 4-1 is a photo of the explosion; its size is apparent from the relative size of the target ships. Figure 4-2 shows another photo at a later time.

The intensely radioactive water fell back down on the target ships and on Bikini Island. A number of radiation readings were taken on Bikini and other places on 29 August 1946, more than one month after Test Baker. "Sand on Bikini near officers' landing" measured 1.5 milligray per day (mGy/day) of gamma and 2.4 mGy/day of beta radiation.[9] There were hot spots. "Debris was found with" 2,000 mGy/day of beta and 300 mGy/day of gamma. "Rafts beached on Enyu" island read 24,000 mGy/day of beta and 4,800 mGy/day of gamma. The radiation survey also found that the "Whole north end of Bikini Island from the waters [sic] edge was very hot on 8/30/46 with a tolerance time of 3 to 5 hours" (Morgan 1946). The tolerance dose during the Manhattan Project was set at 1 mGy/day; the inference is that the beach area dose rate was in the range of roughly 5 to 8 milligray per day (rounded).

It is critical to note that radiation decays rapidly in the aftermath of tests. For instance, it would decline by about 100 times in 48 hours relative to the first hour after the test.[10] At the time of the above measurements, over a month after Test Baker, the radioactivity would have declined by thousands of times. This indicates that the Bikini and Enyu were intensely impacted. Personnel who went ashore or

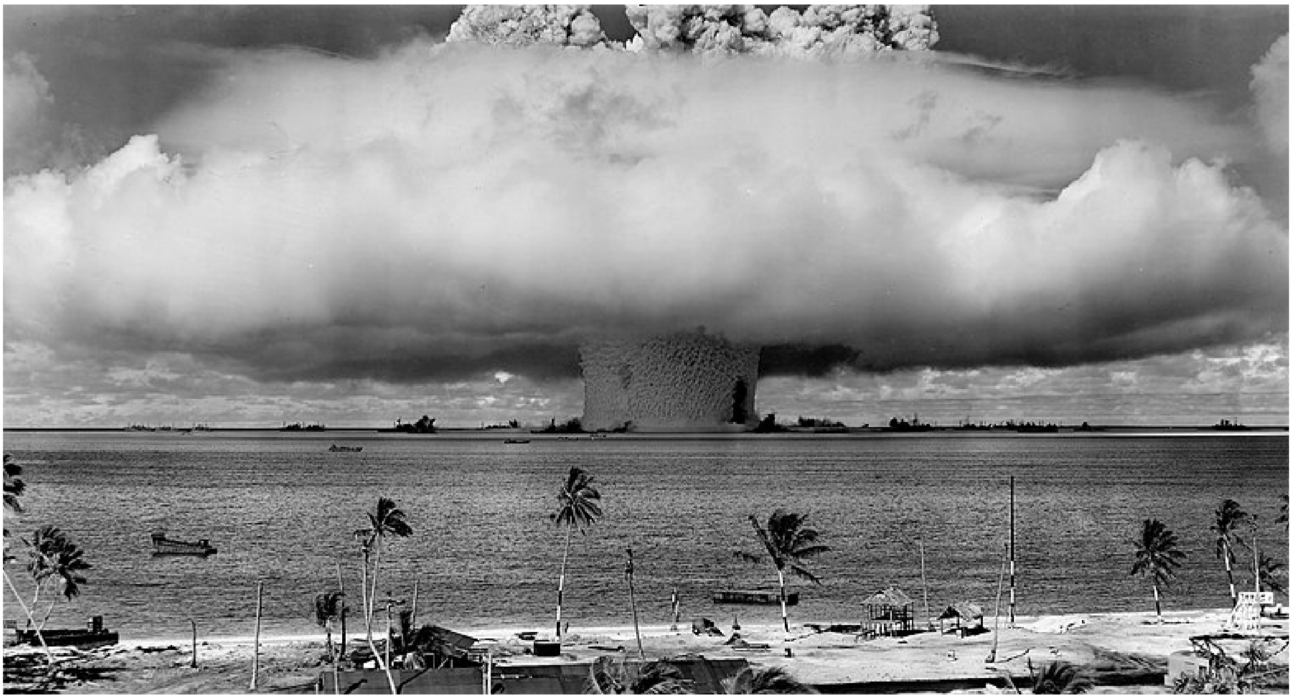

Figure 4-2: Test Baker, Operation Crossroads, 26 July 1946. Source: United States Department of Defense, 1946.

boarded target ships soon after the tests would have experienced variable and sometimes high levels of radiation exposure (Makhijani and Albright 1983), depending on where they went, when they went there, and what they did once there.

The survey provides the scientific basis for the conclusions that (i) there was substantial radiation on Bikini and Enyu in the aftermath of the test, and (ii) that the contamination was extremely variable. That was likely a part of the basis for The Joint Chiefs of Staff Evaluation Board's conclusion that radiation from such an explosion and the uncertainty about highly radioactive hot spots could sow terror among people living in contaminated areas ("No survivor could be certain he was not among the doomed…." (Joint Chiefs of Staff Evaluation Board, 1947).

Finally, it is important to note that reliable instruments to measure unfissioned plutonium in the field were not available to the radiation safety team. Yet, plutonium was present on target ship surfaces and in the mists and dusts created by decontamination attempts. Colonel Warren, the Chief of Radiological Safety, stated that "contamination of personnel clothing, hands and even food can be demonstrated readily in every ship in increasing amounts day by day." (Makhijani and Albright 1983, p. 3).

In sum, Test Baker severely contaminated Bikini atoll. Test Able was an airdrop. Though disproportionately impacting Bikini atoll, including the lagoon, most of its radioactivity dispersed over a wide area. Overall, the main impact was on Bikini atoll.

ii. The Castle test series

Table 4-3 shows the tests in the Castle 1954 series, totaling 48.2 megatons. All except the last one, "Nectar", were exploded at Bikini. The test series contaminated the entire Marshall Islands and created hot spots around the world. The very first test, Bravo, was the largest; at 15 megatons, it was the largest of all U. S. tests, exceeded only by several Soviet thermonuclear tests in Novaya Zemlya, in the Arctic north; "Tsar Bomba" at 50 megatons, was the largest.

A 2018 review by the Los Alamos National Laboratory of U. S. testing in the Marshall Islands had the following two conclusions about the Castle test series:

> *"Technically, Castle was a tremendous success. Each Los Alamos test validated a design that could quickly be weaponized and placed in the national stockpile …".*

Name	Date	Type of bomb	Placement	Location	Explosive power
Bravo	1.3.54	Thermonuclear	Surface	Bikini	15 Mt
Romeo	27.3.54	Thermonuclear	Barge	Bikini	11 Mt
Koon	7.4.54	Thermonuclear	Surface	Bikini	110 kt
Union	26.4.54	Thermonuclear	Barge	Bikini	6.9 Mt
Yankee	5.5.54	Thermonuclear	Barge	Bikini	13.5 Mt
Nectar	14.5.54	Thermonuclear	Barge	Enewetak	1.69 Mt

Table 4-3: Tests in the 1954 Castle series. Note 1: The Koon test failed to achieve the target yield of a megaton or more (Meade 2021, p.6). Source: U. S. Department of Energy 2015.

> *"Environmentally, Castle was a disaster. The phenomenology of fallout from thermonuclear tests was not well characterized. The theory of stratospheric trapping, accepted without experimental proof, and generalized without question to include all thermonuclear detonations, was disproved by Bravo. Bravo's fallout injured many Marshallese and severely contaminated the atolls of Rongelap, Rongerik, and Utirik; the Japanese fishing trawler, the Lucky Dragon; and even ships of the Castle task force."* (Meade and Meade 2018, p. 76)

These Castle tests spread fallout across the entire Marshall Islands.[11] The 2004 National Cancer Institute study of radiation doses in the Marshall Islands listed the country's southern atolls as "low exposure" or "[v]ery low exposure". The former category included Kwajalein; the latter included Majuro, Kili, and Jaluit. But those are relative terms. Figure 4-3 shows gamma radiation rates in Kwajalein for the Union and Yankee tests (6.9 megatons and 13.6 megatons respectively); Figure 4-4 shows gamma radiation rates in Majuro, over the entire Castle test series. Majuro was designated by the National Cancer Institute as a "very low exposure" atoll (NCI 2004, Table 1). Gamma radiation rates in Majuro increased by up to 300 times relative to background gamma radiation levels,[12] as the fallout clouds arrived in the aftermath of the major tests. They increased by tens of times after the Koon test, which failed to reach its megaton-level yield goal by an order of magnitude. Comparing the gamma radiation impact of the Union and Yankee tests on Kwajalein and Majuro shows that the impact on Kwajalein was far greater, at least for those two tests. It should be noted that these radiation levels only include external exposure. Radiation doses due to inhalation and ingestion are in addition to external exposures.

The Castle test series had global impact, which was measured at U. S. stations that recorded at places throughout the world. There were hot spots as far east as Mexico City and as far west as Colombo Sri Lanka. Figure 4-5 shows fallout in the Pacific region; Figure 4-6 in the Atlantic and Indian Ocean regions.

The radioactivity in fallout decays rapidly after a nuclear test.[13] This means that the radioactivity deposition in the immediate aftermath of the tests was far greater than indicated in the maps below, which are decay-corrected to 1 July 1954. The official U. S. fallout maps above show that the Castle series of tests deposited fallout worldwide in a highly uneven manner, with hotspots scattered all over the globe. All atolls of the Marshall Islands were impacted – almost all of them are within the 200,000 d/m/ft^2 isopleth, decay-corrected to July 1 shown in Figure 4-5. The people of the Marshall Islands would have breathed contaminated air; local foods would have been contaminated; the impact was uneven across the country (see Section 4.c).

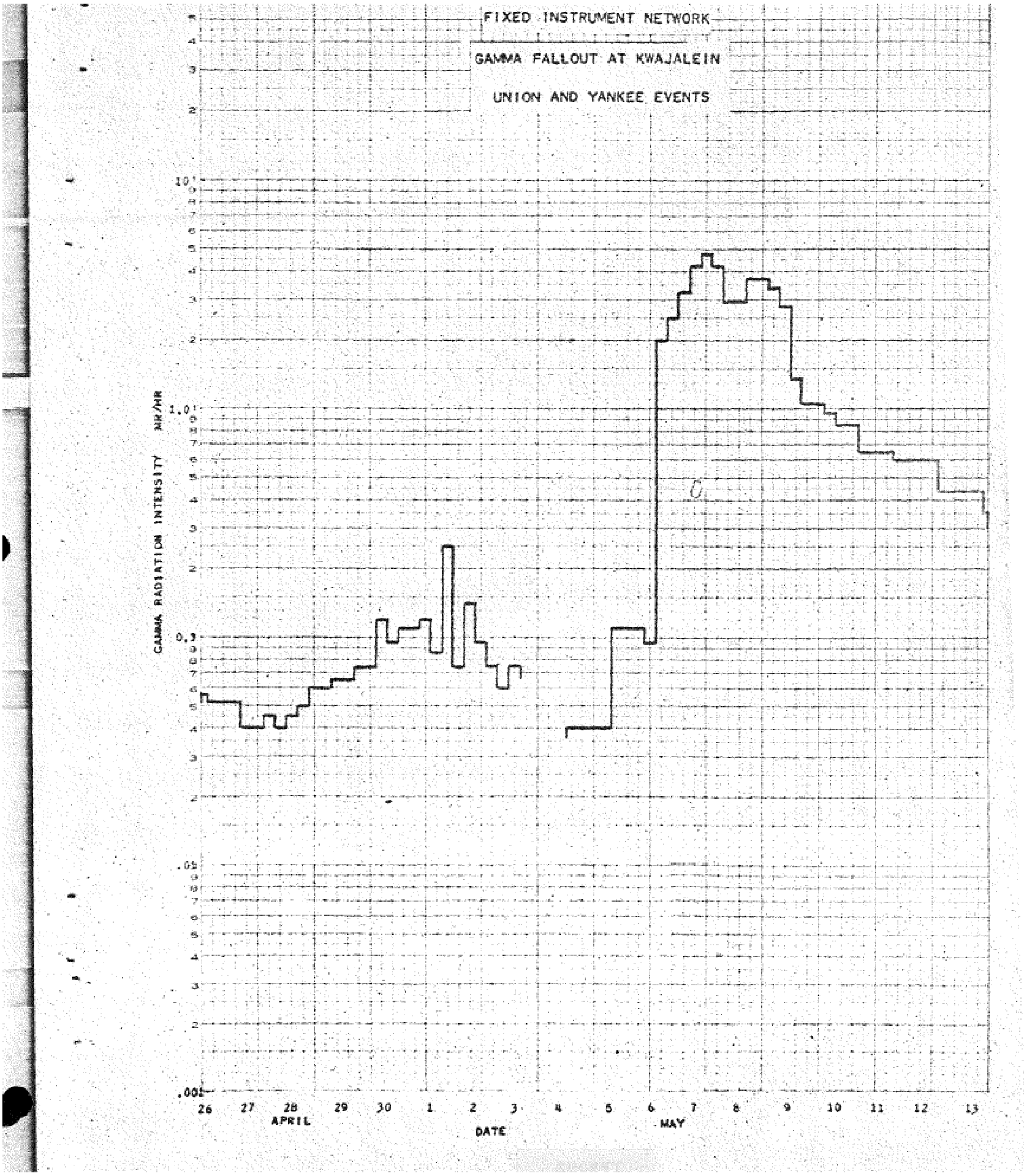

Figure 4-3: Gamma radiation rates at Kwajalein due to the Union (6.9 megatons) and Yankee (13.5 megatons) tests. Source: Breslin and Cassidy 1955, p. 23.

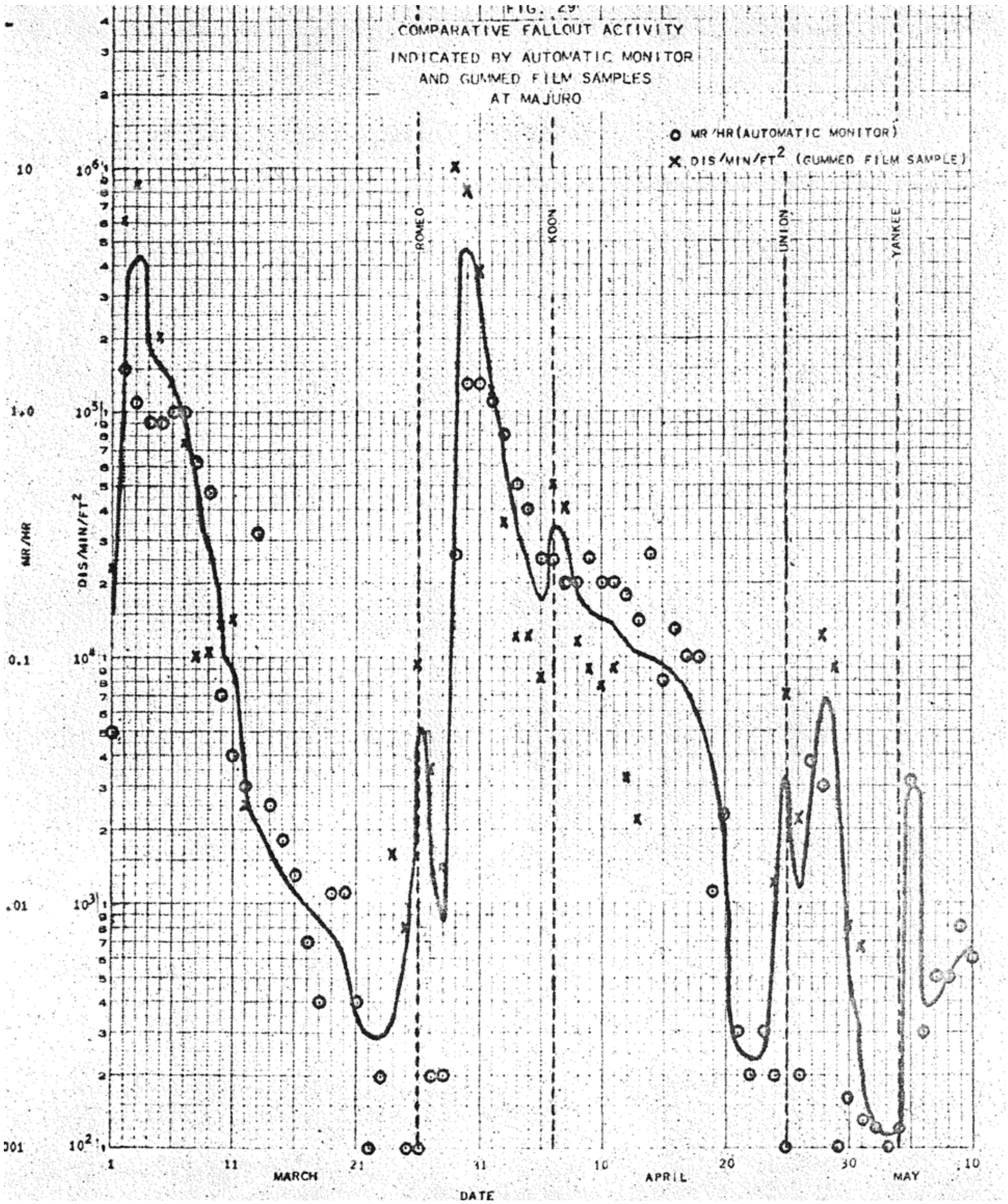

Figure 4-4: Gamma radiation at Majuro over the 1954 Castle test series.
Source: Breslin and Cassidy 1954, p. 45.

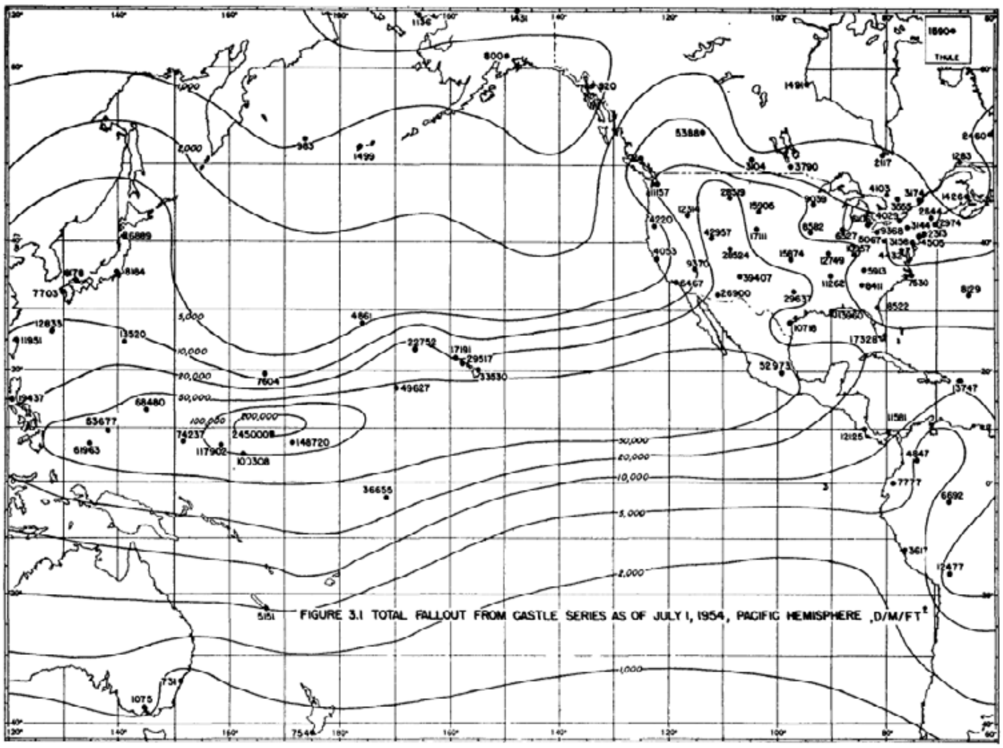

Figure 4-5: Fallout deposition isopleths in the Pacific region, in disintegrations per minute per square foot due to all six Castle series thermonuclear tests, decay-corrected to 1 July 1954. Source: List 1955 pdf p. 20

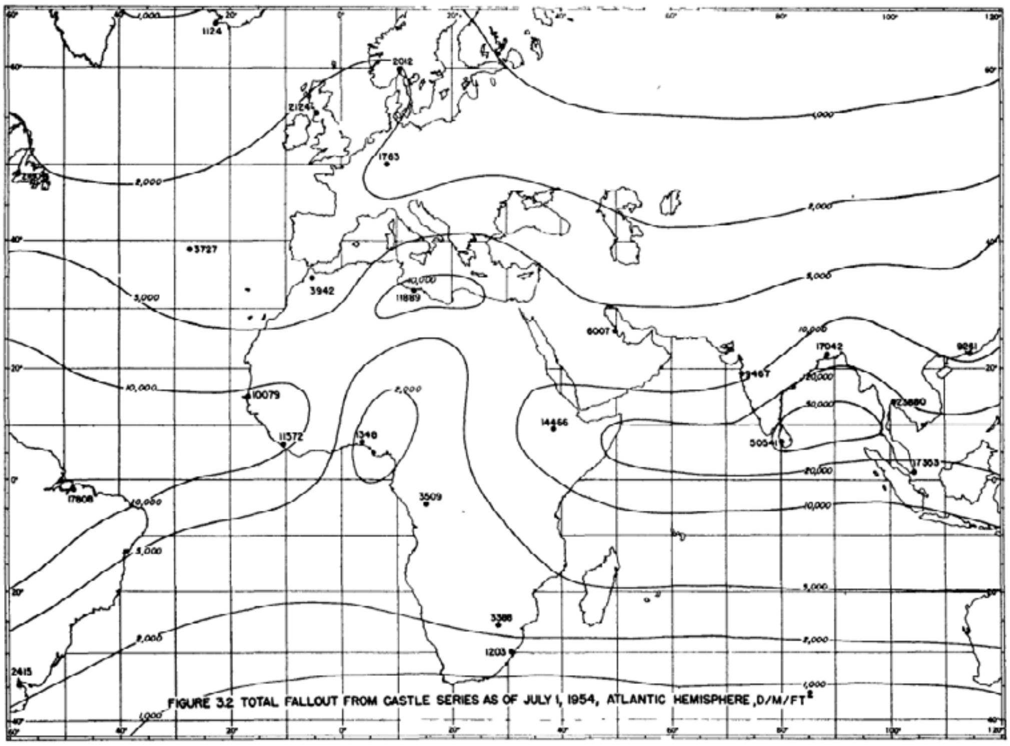

Figure 4-6: Fallout deposition isopleths in the Atlantic and Indian Ocean regions, in disintegrations per minute per square foot due to all six Castle series thermonuclear tests, decay-corrected to 1 July 1954. Source: List 1955, pdf p. 21

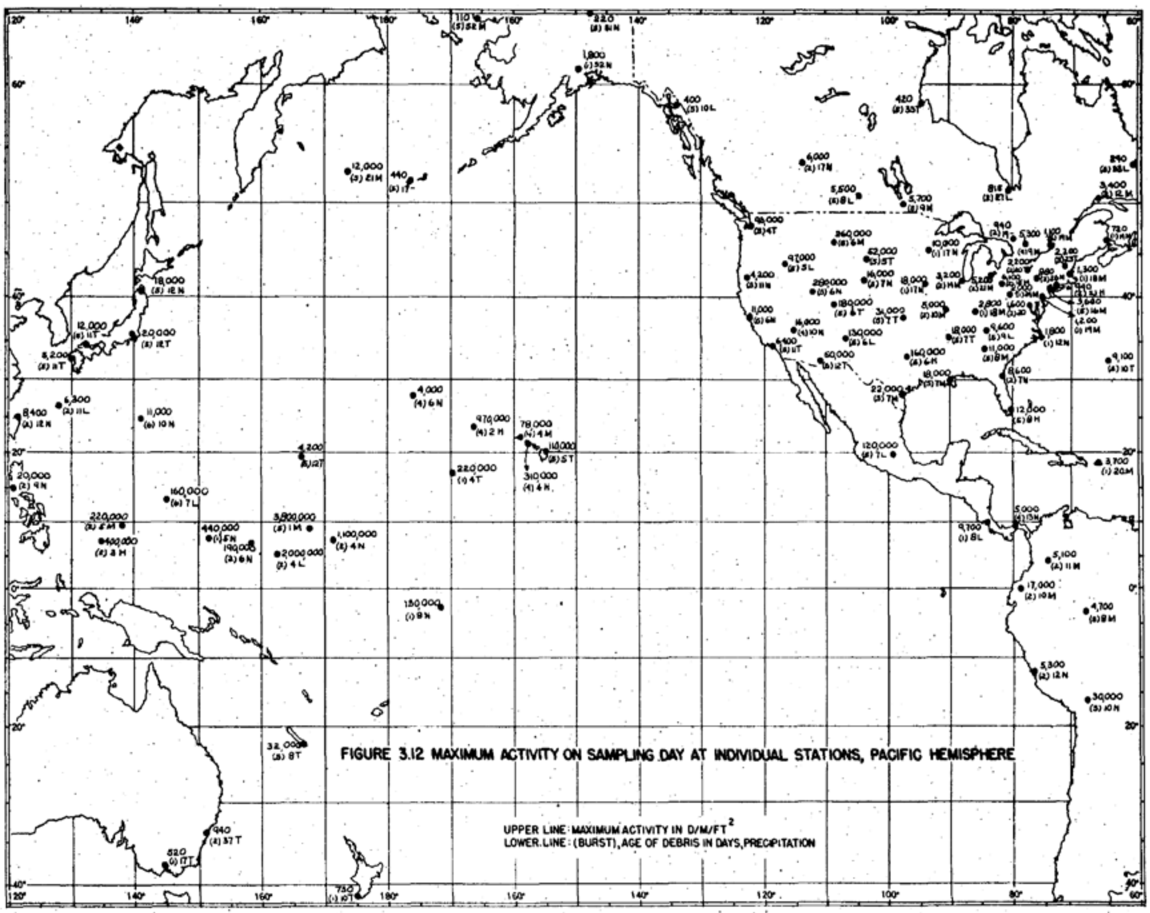

Figure 4-7: Fallout deposition as measured on the day of sampling from the test with the highest sample result. Tests have serial numbers in the sequential order in which they were done. The 3,800,000 d/m/ft$_2$ value for Kwajalein, for example, is for test #5, Yankee (13.5 megatons). Source: List 1955, pdf p. 35

Indeed, most of the populated areas of the world were impacted by the Castle test series in varying degrees. Despite unequivocal evidence of significant fallout all over the Marshall Islands – and its own estimates of cancer risks even in the "low exposure atolls" (see section 4.d below), the U. S. government has recognized people on only three atolls – Rongelap, Ailinginae, and Utrik – as eligible to receive cancer care (Moss-Christian 2021).[14]

Figure 4-7 shows the results of fallout sampling on the day of sampling.

Note that the results of the sampling are for a single test – the one that resulted in the largest deposition at a particular location. A comparison with Figure 4-5, which shows decay-corrected cumulative deposition gives an approximate idea of the degree to which decay-correction impacts the numerical results shown. The decay-correction in Figures 4-5 and 4-6 is for 48 days for the last test on 14 May and 122 days for the first test on 1 March. Billings, Montana had a 1 July 1954 decay-corrected cumulative deposition of 28,519 disintegrations per minute per square foot (d/m/ft^2) for all Castle tests combined. The sampling day measurement for the Yankee test alone was almost ten times higher at 260,000 d/m/ft^2.

Finally, it should be noted that the results for some sampling stations in the Pacific region, including Kwajalein, are underestimates, as described in the Castle series fallout report:

> *"It should be noted that it is likely that Kusaie, Ponape and Kwajalein received their maximum activity following the Bravo burst, however, these stations did not start gummed film observations until about two weeks after this burst and the values given probably do not represent the maximum fallout for the Castle series."* (List 1955, pdf p. 34)

c. The Bravo test

The Bravo test, at 15 megatons, was the most powerful of all U. S. tests; it also caused the largest radiological disaster. Officially, the severe fallout on populated areas due to the Bravo test has been deemed accidental and unexpected, even decades after the event. For example, the following description is from a 2018 Los Alamos National Laboratory report on U.S. testing in the Marshall Islands:

> *"Within seconds, Bravo's blast wave swept over the entire atoll destroying and contaminating everything in its path. The six-man firing party, housed in a steel and concrete bunker nearly thirty miles from ground zero, became seasick because their bunker moved as if riding on ocean swells. Unexpectedly, Bravo's radioactive fallout rained down on Rongerik, Rongelap, and Utirik Atolls, forcing emergency evacuations of each atolls' inhabitants."* (Meade and Meade 2018, p. 65).

However, there were clear indications of danger in the hours before the test, when weather forecasts took a turn for the worse:

> *"At the 1800 weather briefing, the predicted winds were less favorable; nevertheless, the decision to shoot was reaffirmed, but with another review of the winds scheduled for 2400....*
>
> *"The midnight briefing indicated less favorable winds at 10,000-to 25,000-foot (3.05- to 7.52-km) levels. Winds at 20,000 feet (6.10 km) were headed for Rongelap to the east. The predicted speed of these winds was low enough to be of no concern, although it was recognized that both Bikini and Eneman islands would probably be contaminated....The decision to shoot was reaffirmed, at least until the 0430 briefing. A burst-day flight to search for transient shipping was added at this time ..."* Martin and Rowland 1982, p. 202)

Barker (2013) has drawn on declassified documents to expand on the situation:

> From declassified documents, it is clear that meteorologists predicted in advance that the winds would push Bravo's radioactivity toward inhabited atolls east and southeast of Bikini. Colonel Lulejian, a U. S. government meteorologist determined that 'the [inhabited] islands of Rongerik, Rongelap, and Bikar are clearly in the fallout area even when...a simple extrapolation is used' (Lulejian 1954)." (Barker 2013, p. 40)

In any case, U. S. military personnel on Rongerik, farther east than Ailinginae and Rongelap, "saw a mist 4 h after the blast. Seven hours later, the needle of a radiation-measuring instrument went off scale at 100 mR h-1)" (Cronkite et al. 1997). It was more than two days before Ailinginae and Rongelap were evacuated.

The radiation levels at Rongelap and Ailinginae were near-lethal, as they were also on the Japanese fishing vessel, the Daigo Fukuryu Maru (Lucky Dragon No. 5). The people of Rongelap were evacuated roughly a day after U. S. personnel were evacuated from Rongerik (Cronkite et al. 1997, Table 1). In the meantime, they received high radiation doses. Dr. Tilman Ruff has described the fallout as follows:

> *"Two islands and part of a third were vaporized in the explosion, and fallout rained down on the food crops, water catchments, houses, land and bodies of children, women and men going about their daily activities. Children played with the unknown "snow" and rubbed it in their hair and on their skin. The residents of Rongelap, Ailinginae and Utrik Atolls were finally evacuated two and a half days later, after having received near-lethal doses of radiation, the highest following a single test in the history of nuclear test explosions worldwide."* (Ruff 2016)

Figure 4-8 shows the Bravo radiation dose isopleths as per the Atomic Energy Commission. The lethal and near-lethal levels are clear. The present U. S. government estimate is that 6 to 8 gray (600 to 800 rad) in a short time will result in death with high probability. It also estimates that 3.2 to 4.5 gray of acute exposure will result in death within 60 days for half the exposed population without intensive medical care (known as the LD50/60 dose). (U.S. Department of Energy et al. 2016, p. 3). While other atolls east and southeast of Bikini also had significant fallout, they were not evacuated; the Chair of the National Nuclear Commission of the Marshall

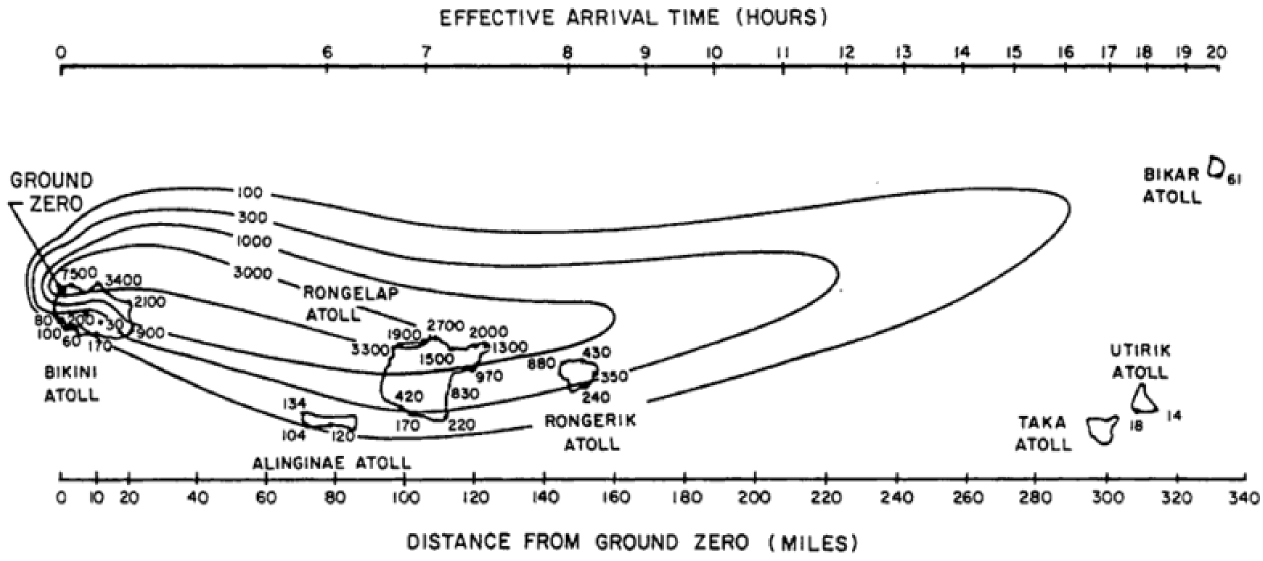

Figure 4-8: Radiation isopleths in rad (divide by 100 to convert to gray) after the Bravo test. Source: U. S. Department of Energy 1954.

Islands, whose mother was on one of those atolls and died of cancer, testified that they should have been. Like the people of Bikini, the people of Rongelap are still in exile.

The crew members of Daigo Fukuryu Maru suffered high radiation doses and were hospitalized. One died seven months later.[15] Its fish were contaminated but were not able to be withdrawn from the market before some were purchased and consumed.
A noteworthy impact of Castle series is indicated by the findings of contaminated fish in 683 Japanese fishing boats detected by Japanese monitoring in 1954. One out of eight had contaminated tuna, totaling 457 tons, above Japanese limits of the time (IPPNW and IEER 1991, p. 78).

The tuna were caught in the open ocean in 1954. No other tests were done by any power in the Pacific region that year. That high fish contamination occurred in the vast Pacific Ocean is indicative of two things: (i) the very high Castle series fallout over large swaths of the Pacific Ocean (Figures 4-5 and 4-6 above); and (ii) bioconcentration of fission products in the marine environment, notably by apex predators like tuna. Fish with contamination below the regulatory threshold were consumed and would have resulted in radiation doses to the Japanese people. In addition, other people of the Pacific region, whose countries were not monitoring fish, would have caught and consumed contaminated fish.

d. Cancer and radiation doses

i. In the Marshall Islands

Estimates of increases in cancer incidence are made by estimating the radiation dose in the population and applying appropriate cancer risk factors.[16] Several very different estimates of radiation doses and cancer impact on the Marshallese people have been made over the decades. Yet, there is a central point of agreement: the entire country was impacted. As is to be expected due to the test locations, the northern atolls were far more impacted by radiation than the southern atolls.

In 2004, the National Cancer Institute estimated total cancer incidence in the Marshall Islands at 500 excess cancers and that 87 percent of them (435) would be in northern atolls that suffered more fallout – about equally divided between the most impacted (Rongelap, Ailinginae, and Utrik) and those farther away from the test locations (Ailuk, Mejit, Likiep, Wotho, Wotje, and Ujelang). The other 65 cancers (13 percent) were estimated to impact the southern atolls (NCI 2004). This was, in effect, an official scientific acknowledgement that the entire Marshall Islands was impacted. This is also clear from fallout measurements (Figures 4-3 through 4-7 above).

An increase of 500 cancers among the approximately 14,000 Marshallese who lived in the 1950s corresponds to roughly a nine percent increase in the cancer rate. The same increase in the United States, adjusted for its mid-1950s population, would have meant six million excess cancers. In 2010, U. S.-government-sponsored research reduced the estimate to 170 excess cancers (Simon et al. 2010). This would still be equivalent to 2 million more cancers in the U.S. population of the time.

These government excess cancer estimates are based on radiation dose estimates. As noted, there were measurements of fallout at the time. But many assumptions are necessary to go from those data to radiation dose. The pathways from the radioactivity released and dispersed to people directly, via food and water, via inhalation and external exposure, via deposition on the skin, and other factors must be considered. Some differences between researchers and some revisions of estimates are therefore to be expected. But the differences between dose estimates published by U. S. government scientists and independent estimates are very large, with serious implications not only for the cancer estimates, discussed here, but also for other health impacts, discussed in Section 5 below.

The Simon et al. 2010 paper that revised cancer estimates downward by about two-thirds estimated "representative" adult thyroid doses on Utrik of 760 mGy, and ten times as high for Rongelap adults. Children's thyroids doses were about three times higher (Simon et al. 2010). Much higher doses were estimated in 1985 by Brookhaven National Laboratory scientists. They estimated average Utrik thyroid dose as 1,650 mGy, more than twice as high as indicated in the 2010 paper. For Rongelap the estimate was 12,000 mGy.

Independent dose estimates are even higher. Table 4-4 compares the 1985 Brookhaven Utrik atoll acute thyroid dose estimates (by Lessard et al. 1985) with the independent estimates made by Sanford Cohen & Associates.

The independent dose estimates were between 4.5 times and 17.4 times higher than the Brookhaven National Laboratory estimates, which in turn were higher than later estimates in Simon et al. 2010.

Rongelap atoll is much closer to Bikini atoll than is Utrik atoll. The people of Rongelap consequently suffered doses estimated to be an order of magnitude higher. In general, the higher estimates are more compatible with the earlier higher cancer estimates made by the National Cancer Institute (NCI 2004). A perspective on radiation doses is that all estimates cited above, including the lowest ones, are high.

Congressional testimony by Sanford Cohen & Associates explored the reasons for the different estimates. One of its senior associates, Dr. John Mauro, who was involved in the research, testified that the government's estimates were lower because it

- "neglected the dose from the passing plume";
- "neglected the whole body dose from fallout that deposited directly on the persons' skin and clothing";
- "did not consider the unique exposure geometry associated with fallout"; and
- "made assumptions regarding the time of arrival of the plume and the duration of fallout that did not give the benefit of the doubt to the people of the Marshall Islands." (Mauro 2005.)

Exposure	DOE (Note 2)	SC&A (Note 3)	SC&A / DOE ratio
External whole-body (mSv)	110	500+	> 4.5
Internal Thyroid (mGy)			
Adult	1,550	27,000	17.4
Child	3,200	34,000	10.6
Infant	6,600	59,000	8.9
Internal (Other than Thyroid)	Note 4		
(mSv-CEDE)			
Adult	76	860	11.3
Child	137	1,120	8.2
Infant	317	1,930	6.1

Table 4-4: Department of Energy Brookhaven National Laboratory acute thyroid dose estimates for Utrik compared to Sanford Cohen & Associates (SC&A) [17] estimates (Note 1)
Source: Franke 2002.
Note 1: Values in the original converted to standard international units.
Note 2: Department of Energy reference is Lessard et al. 1985 (Brookhaven National Laboratory).
Note 3: SC&A reference is Behling et al. 2001.
Note 4: Reported in Franke 2002 as "implied fission product doses that were derived from data of ingested I-131 as cited by Lessard (1985)."

He also testified that the higher dose estimates were compatible with U. S. government medical data, such as blood counts.

Even the southern atolls, where the National Cancer Institute described the doses as "low" and "very low" suffered significant exposures. A perspective on these supposedly low doses is provided by comparing them to the thyroid doses experienced by the U. S. population due to fallout from atmospheric testing at the Nevada test site (NCI 1997). The highest thyroid doses were in four counties in Idaho and one in Montana. It is noteworthy that these are not the closest to the test site. They are on the order of 800 to 1,000 kilometers away. The average doses in these counties were between 120 and 160 mGy. The thyroid doses in "[l]ow exposure" atolls in the Marshall Islands averaged 270 mGy -- roughly double the highest U.S. average values. The "very low exposure" atoll thyroid exposures were estimated to have average exposures of 75 milligray (NCI 2004, Table 1).[18] Infant doses would average several times higher (see Table 4-4 left). A perspective on the thyroid doses in the "[l]ow exposure atolls" is provided by the fact that the average doses of the nearly 50,000 Pripyat residents who were evacuated in the aftermath of the Chernobyl accident were 170 milligray (calculated from UNSCEAR 2000, Volume II, Annex J, Table 21, p. 528). In other words, the people of Pripyat who lived near Chernobyl and were evacuated (though several days after the accident) had average thyroid doses about 38 percent lower than in the atolls described as "[l]ow exposure" in the 2004 National Cancer Institute study (NCI 2004, Table1).

ii. Global doses and cancer impacts

Atmospheric testing created vast amounts of radioactive fallout, which exposed billions of people to radiation doses. Not only was this without informed or, indeed, any consent; they were subjected to risks imposed by powerful countries that were, and remain, members of the United Nations Security Council for their own purposes from which the rest of the world derived no benefits but suffered significant costs. The increase in cancer risk was one of those costs.

Radiation doses came from the external radiation, from direct inhalation of fallout particles, from inhalation of resuspended soil that was contaminated with fallout, and from internal radiation due to ingestion of contaminated food and water. Radiation doses were due to fission products, induced radioactivity (such as carbon-14, tritium, and zinc-65), and unfissioned plutonium. Doses from the longer lived materials have continued past the year 2000; some materials will continue to irradiate people and the environment for periods longer in the future than human beings have existed so far.

In this section, we briefly discuss the excess global cancer risk that can be attributed to testing in the Marshall Islands.

The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR)has estimated cumulative global radiation dose estimates due to atmospheric testing. Based on UNSCEAR's work, the International Physicians for the Prevention of Nuclear War and the Institute for Energy and Environmental Research estimated that there would be about 430,000 excess cancer deaths in the world due to cumulative radiation doses experienced to the year 2000 from atmospheric testing. (IPPNW and IEER 1991, Table 3).[19]

Radiation doses are mainly due to fission and activation products. As a result, a rough estimate of the excess cancers that could be attributed to a specific set of atmospheric tests can be estimated from the fraction of the fission yield of that set. UNSCEAR estimated the total fission yield at 217.2 megatons, of which 72.1 megatons were attributed to the United States (IPPNW and IEER 1991,Table 2). When the tests within the United States, in the Atlantic area, and in other parts of the Pacific Ocean (notably Kiribati) are excluded, the fission yield attributable to tests in the Marshall Islands is about three-fourths of the U. S. total, which is about one-fourth of the global total. Based on that, roughly 100,000 excess cancer deaths worldwide (rounded) for cumulative doses up to the year 2000, could be attributed to U.S. nuclear testing in the Marshall Islands. Because of latency periods between exposure and cancer occurrence, the excess cancers would also occur in the 21st century.

UNSCEAR made simplifying assumptions in arriving at the dose estimates that are the basis of the above cancer risk estimates. This is a necessity, given the complexity of the topic. A key assumption was that fallout would be uniformly deposited within latitude bands. As Figures 4-5 and 4-6 above show, fallout deposition was highly variable even within a particular latitude band from the single Castle test series. For instance, in the general region of the 10_oN latitude, deposition of fallout (decay-corrected to 1 July 1954) varied by roughly two orders of magnitude from 30,000 Bq/m^2 to 3,000,000 Bq/m^2 (rounded). The distribution of cancer risk depends on the distribution of fallout. The specific cancer burden that atmospheric testing by the five permanent members of the United Nations Security Council has imposed in specific areas across the world remains to be investigated in detail. This would especially apply to hot spots, such as those evident in Figures 4-5 and 4-6. Of course, any global effort would also have to take into account patterns of hot spots from the atmospheric testing done by the Soviet Union, Britain, France, and China.

5. Other health impacts of radiation

An official assessment of the medical consequences of the Bravo test by researchers at the Brookhaven National Laboratory (Department of Energy) was published in the journal Health Physics (Cronkite et al. 1997). It separated impacts into short-term and long-term. The focus of U.S. medical attention and research has been on Bravo fallout because it is the only test that resulted in evacuations due to very high radiation levels measured at the time and the scandal in Japan resulting from the large radiation doses and associated tuna contamination aboard the Daigo Fukuryu Maru. We first consider this published evaluation and then discuss the evidence for and possible causes of the more widespread impacts.

Cronkite et al. (1997) reported 252 Marshallese on Rongelap (67), Ailinginae (18), and Utrik (167) as exposed with external gamma doses estimated at 1.9, 1.1, and 0.11 Gy respectively. The first two are well above the usual 0.7 Gy rule-of-thumb threshold for acute high doses. A Marshallese "control" population of 117 is shown in Table 1 of Cronkite et al. (1997); no radiation dose estimate is shown, despite the established fact that the entire Marshall Islands had substantial fallout from Bravo and other Castle series tests. Cronkite et al. do recognize that this was not a true control population in the strict scientific sense.

Consistent with high doses, symptoms of high radiation exposure were reported for people on Rongelap and Ailinginae. Two-thirds of the population of Rongelap "were nauseated for 2 d[ays]. About one-tenth vomited and had diarrhea." Neutrophil, platelet, and lymphocyte counts were depressed. About 28 percent of Rongelapese and 20 percent of those on Ailinginae were assessed to have burning and itching on the skin. Two radionuclides—strontium-90 and iodine-131 – "were near the maximum permissible levels. No effects of any of these absorbed elements except for radioiodine have been detected in the Marshallese people." Thyroid tumors and hypothyroidism were diagnosed, post-evacuation.

So far as pregnancy is concerned, Cronkite et al. (1997) reported the following:

> *"Four Rongelapese were pregnant: two in first trimester, one in second, and one in third. In the Ailinginae group, one woman was in second trimester. The pregnant women had a significant thrombopenia.[[20]] There was no vaginal bleeding. One baby was born dead; the others were normal. Whether irradiation was responsible for the stillbirth is unknown."*

Cronkite et al. (1997) concluded as follows regarding long-term impacts:

> *"...induction of one case of fatal acute myeloid leukemia and a large number of thyroid tumors (benign and malignant) in addition to hypothyroidism in adults and children and two cases of cretinism. The hypothyroidism and cretinism responded well to administration of oral thyroxine. During the first 25 y, there was also much unrest and political agitation initiated by exposed and unexposed Marshallese who were very unhappy as a result of relocation and inability to return to their homelands and feeling that all illness and deaths were due to the mysterious radiation, which they understandably did not understand."* (Cronkite et al. 1997)

These findings are highly inadequate and incomplete, especially as a 25-year retrospective on what transpired in the Marshall Islands:

- Since all Marshallese atolls were exposed to significant levels of radiation, including the southern atolls (see thyroid exposure discussion above), the paper ignored impacts on the vast majority of the population. In fact, the 252 people evacuated and considered radiation impacted were less than 2 percent of the population of the Marshall Islands in the mid-1950s. In other words, the impact on more than 98 percent of the population was not considered.

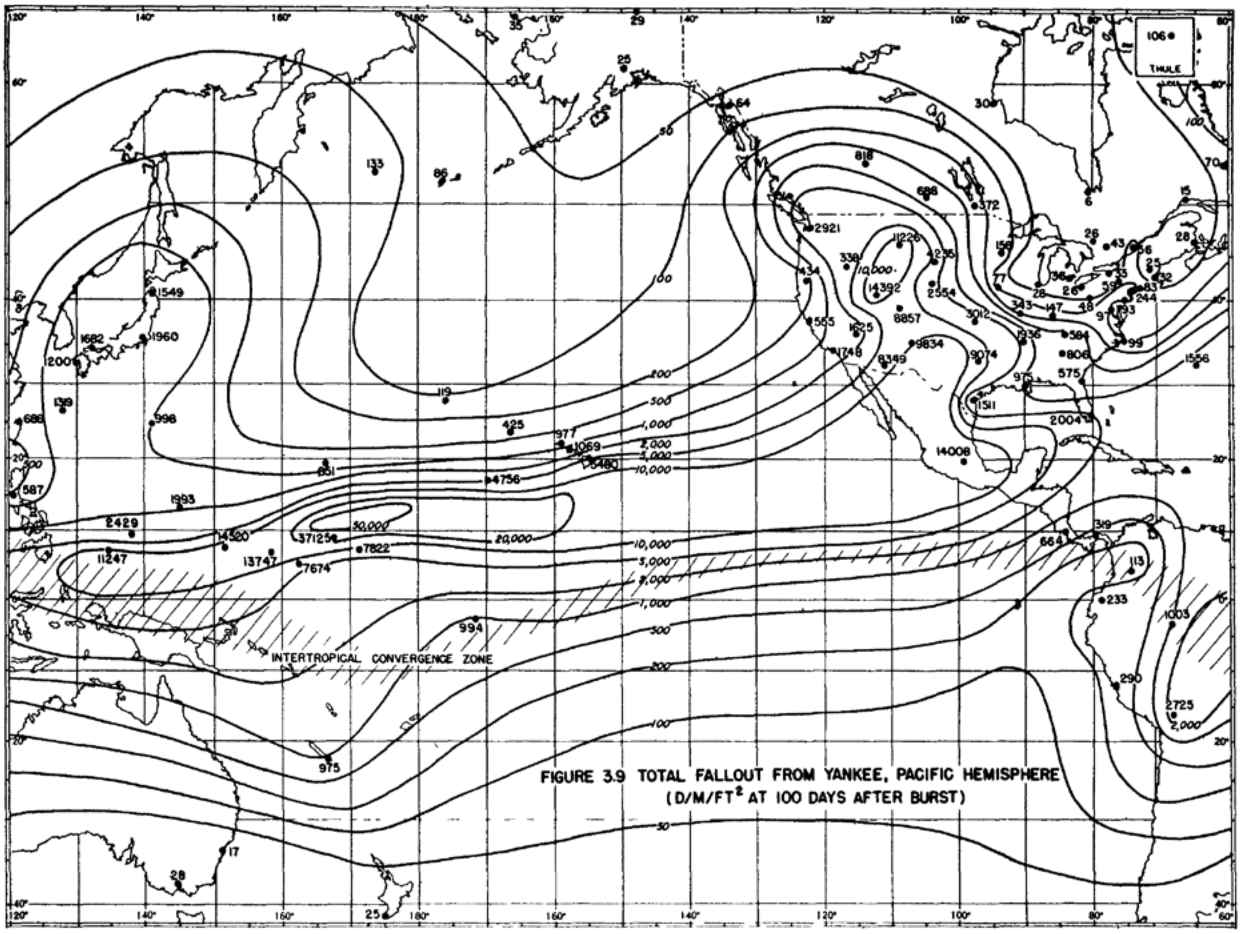

Figure 5-1: Pacific region fallout, Yankee test; decay-corrected to 13 August 1954.
Source : List 1955, pdf p. 35

- Extensive evidence of widespread impacts provided by the testimony of the Marshallese themselves was ignored, and, in fact, dismissed due to the Marshallese being "unhappy" about their displacement and because they "understandably did not understand" "mysterious radiation".

The patronizing attitude had roots in the 1950s when the realization that there was a highly exposed population in an area controlled by the United States led to a decision to study them as experimental subjects. The minutes of the 13-14 January 1956 meeting of the Atomic Energy Commission's Advisory Committee on Biology and Medicine regarding this topic are worth quoting at length for the deliberativeness with which this experimental approach was taken:

> *"We have a few things that we are thinking about for the immediate future and I would like to mention a few of these.*
>
> *"We think that one very intriguing study can be made and plans are on the way to implement this – "Uterik" Atoll is the atoll furtherest from the March 1st [Bravo] shot where people were exposed got initially about 15 roentgens and then they were evacuated and they returned.*
>
> *"They had been living on that island; now that island is safe to live on but is by far the most contaminated place in the world and it will be very interesting to go back and get good environmental data, how many persons per square mile; what isotopes are involved and a sample of food changes in many humans through their urines, so as to get a measure of the human uptake when people live in a contaminated environment.*
>
> *"Now, data of this type has never been available. While it is true that these people do not live, I would say, the way Westerners do, civilized people, it is*

nevertheless also true that that these people are more like to us than the mice. So that is something which will be done this winter." (ACBM 1956)[21]

It is hard to reconcile the official conclusion that Utrik was "safe to live" with the declaration that it was "by far the most contaminated place in the world." While they were regarded as people who "understandably did not understand", the people of Utrik did, in fact, come to understand "that the U. S. government viewed them as experimental subjects and began protesting the visits of U.S. government doctors and researchers. As they did in Rongelap, the U.S. government researchers offered bribes of money and material goods, such as baseball hats, to get the people to cooperate with their studies." (Barker 2013, p. 47).

In fact, the people of Utrik were returned to their atoll only two months after the Bravo fallout severely contaminated their land (Barker 2013, p.47), in the month of the last two Castle series tests. Short-lived isotopes, notably zinc-65 (half-life 244 days), which would persist in the marine environment for a few years, and iodine-131 (half-life 8 days), which would persist for about three months. These exposures via various pathways, including food and resuspended dust, were in addition to those due to long-lived radionuclides.

Figure 5-1 shows that the 13.5 megaton Yankee test (almost the same explosive force as Bravo) on 5 May 1954 produced fallout throughout the Marshall Islands and many other places worldwide. Utrik was well within the isopleth showing the highest fallout. The map indicates fallout deposition levels of more than 9,000 Bq/m^2 in the northern atolls decay-corrected to 13 August 1954. The fallout on the day of the test would have been many times more intense.

a. Some Marshallese health testimonies

There is extensive evidence of and testimony regarding serious and persistent health problems. This section gives some examples regarding adverse pregnancy outcomes; the next section (5.b) examines the possible scientific explanations for such outcomes. The testimonies are as quoted in Barker 2013, Chapter 4.

Testimony 1, Rongelap:

> *"I was not on Rongelap for the Bravo test, but I returned with everyone in 1957….*
>
> *"It was around this time that I had my first pregnancy. My baby had a very high fever when he was delivered….He was so dehydrated….The only thing we knew how to do was to wrap him in wet towels. And so it was that I held him to my body throughout the night, changing towels and willing him to fight for his life. He lost his fight just as dawn broke.*
>
> *"My second son, born in 1960, was delivered live but missing the whole back of his skull….[s]o the back part of the brain and the spinal cord were fully exposed. After a week…he, too, developed a high fever and died the following day….*
>
> *"There is a boy, actually a young man now, whose head is so large his body is unable to support it and his only means of getting around is to crawl backwards dragging his head along –like the movements of a coconut or hermit crab…."*

Testimony 2, Ailuk atoll (not evacuated):

> *"Two [of my children] died. One of them was born defective. It didn't look like a human. It looked just like the inside of a giant clam."*

Testimonies from Likiep atoll (not evacuated):

- *"After the testing, she [my wife] got pregnant. When the baby was born, it had two heads….It breathed for just a short time when it was born. Maybe an hour, only some minutes."*
- *"Some babies that were born resembled a bunch of grapes…"*
- *"Other children born during this time did not have any noticeable deficiencies, and yet lacked the ability to understand anything. Others were incapable of any motor activity although they seemed to comprehend their surroundings. Some of the children in the second category survived for a number of years although as nothing more than human vegetables or adults with the minds of toddlers."*

	Rongelap, northern, ~180 km		Ailuk, northern, 560 km		Jaluit, southern, 830 km	
	Before 1951	1952 and after	Before 1951	1952 and after	Before 1951	1952 and after
Adverse births per woman (miscarriages and stillbirths)	0.067	1.05	0.06	0.83	0.07	0.52
% increase post-1952 relative to pre-1952	1500 %		1300 %		600 %	

Table 5-1: Comparison of adverse birth outcomes before and after the start of thermonuclear tests at Bikini and Enewetak. Distances are from Bikini atoll (site of Bravo test)
Note: The rates of adverse outcomes were read off from charts and are therefore approximate.
Source: Alcalay 1995

The following testimony is from a woman in Utrik (as quoted in Alcalay 1995):

> *"Some women gave birth to creatures like cats, rats, and the insides of turtles – like intestines. Most of the women had 'jibun' (miscarriages), including myself who gave birth to something unlike a human being. Some women gave birth to things resembling grapes and other fruits, and some women even stopped having children, including me. Things are not the same now, and the people are not as active and healthy as before 'the bomb'."*

There is survey data to support these individual testimonies. Glenn Alcalay, an anthropologist who has lived on Utrik and speaks Marshallese did a Marshall-Islands-wide survey on reproductive outcomes. He described his method as follows (Alcalay 1995):

> *"For the survey, I collected detailed reproductive data from ten outer island atoll communities, clustered into two groups, 'northern Marshalls' and 'southern Marshalls' … . I compared those atolls closest to the former nuclear test sites with atolls furthest from the test sites. …"*

> *"Along with census and genealogical data collected, I also solicited detailed information about miscarriages, stillbirths, and children born with serious disorders. Additionally, the survey yielded data about the residence histories of each woman due to the high mobility of the Marshallese people."*

Alcalay grouped the data into reproductive outcomes before 1951 – that is, before the high-yield thermonuclear tests, which began in 1952, and outcomes in 1952 and after. Table 5-1 summarizes the results of his survey for three atolls –two northern, where fall out was high and where radiation doses (and cancer risks) are estimated as higher by the National Cancer Institute (NCI 2004) and one southern atoll, where doses and risks are lower. Unfortunately, the birth years in the period starting in 1952 are not available; the analysis in Table 5-1 must therefore be regarded as indicative of the problem of adverse birth outcomes and of the need to pay serious attention to the testimonies of the people themselves.

The survey indicates that before 1952 (i) adverse outcomes were less than one-tenth per woman in all parts of the Marshall Islands and (ii) that the rates were very similar across the atolls. After thermonuclear testing began, practically every woman in the northern atolls experienced adverse birth outcomes, including Ailuk, which is about three times farther from Bikini than Rongelap. Many adverse outcomes would also be expected in the southern atolls, though both the absolute number and relative increase were found to be much lower than for the northern atolls. The fact that Alcalay checked census records and other data buttresses these results.

b. Was radiation responsible?

For a number of reasons, it is essentially impossible to give a definitive answer to the question of whether severe malformations, miscarriages, stillbirths, and neurological issues, such as inability to understand anything or incapacity for motor activity were caused by testing-related exposure. A great deal of the problem has been the relative lack of research on the impact of radionuclides that cross the placenta in the early phases of pregnancy. For instance, as noted above, the 25-year retrospective did not take into account the health outcomes of more than 98 percent of the population of the Marshall Islands, all of whom were exposed; as a result, they also ignored the adverse pregnancy outcomes they experienced. This gap remains even though the issue of fallout creating malformations not only in the immediate vicinity of tests, but worldwide, was recognized during the period of atmospheric testing. An April 1960 editorial in the University of California [22] engineering alumni magazine, California Engineer, provides some evidence. The editorial had quantitative estimates of major birth defects worldwide due to U. S. nuclear testing. The writers sought to justify inflicting the risks on the whole world because they believed the United States needed a nuclear arsenal to fight "brush fire wars" (such as the Korean war); they anticipated both adversaries may use them, and that, in the event they did, they would exercise strategic restraint:

> *"The Korean conflict demonstrated two things that are pertinent here: our inability to make any headway against a vastly more numerous, though poorly equipped army, which is no less numerous today and better equipped; and the ability of both sides in the conflict to observe limitations on their strategy. We refrained from bombing their bases in Manchuria, they refrained from bombing our bases in Japan, Okinawa, and the Philippines. Therefore, there is no reason not to expect both sides in a future "brush fire" war to keep the nuclear weapons used within tactical limits.*
>
> *"The increase in radiation one receives from fallout is about equal to the increase one receives from cosmic rays when moving from sea level to the top of a hill several hundred feet high. This nevertheless increases genetic and pathological damage, though to a degree not great enough to be measured statistically. It means, though, your babies' chances of having a major birth defect are increased by one part in 5,000 approximately. Percentagewise, this is insignificant. When applied to the population of the world, it means that nuclear testing so far has produced about an additional 6,000 babies born with major birth defects.*
>
> *"Whether you choose to look at "one part in 5,000" or "6,000 babies," you must weigh this acknowledged risk with the demonstrated need of the United States for a nuclear arsenal."* (California Engineer 1960, as quoted in Makhijani 2004, Part 2, pp. 27-28).

The scientific accuracy of this estimate is not the issue here. The central fact is that in the time contemporaneous with atmospheric testing, major birth defects were understood to be a risk at far lower levels of radiation exposure than was experienced throughout the Marshall Islands. The increase in cosmic radiation between sea and a hill several hundred feet high would be on the order of 20 microsieverts per year (assuming "several hundred feet" to be about 200 meters); [23] it would be of the same order of magnitude over a full-term pregnancy. Both genetic and pathological damage to the fetus were recognized at this level of dose increment.

The basis for the risk estimate in the 1960 editorial is at present unclear to this author. But severe brain damage of specific types was discovered in the follow-up of the survivors of Hiroshima and Nagasaki. In a 1986 report, the International Commission on Radiological Protection found that out of 1,599 pregnancies from those two cities that were followed up, thirty children had "severe mental retardation...[which] implies an individual unable to form simple sentences, to solve simple problems in arithmetic, to care for himself or herself, or is (was) unmanageable or institutionalized." This was found to be a statistically-significant excess, with the analysis of the time indicating that there was no threshold of exposure below which the risk would be zero (ICRP 1986).

It is critical to note that there are no systematic studies of Hiroshima/Nagasaki survivors in the immediate years after the bombings. Therefore, the miscarriages, early deaths after a few days or a few weeks, and stillbirths among pregnant women in the days, weeks, and months after the bombings have been missed. A study of pregnancies in the 1948-1953 (inclusive) period showed that for women who suffered radiation doses greater than 0.5 Gy, the mean values of relative risk of "major congenital malformations, perinatal death within 7 days, and perinatal death within 14 days" were greater than one. The lower bound of the 95 percent confidence interval was less than one. An adjustment for error in the dose estimate increased the risk. Similar results were obtained for fathers who were exposed during the bombings (Yamada et al. 2021).

These results of pregnancies three to eight years after the bombings indicate that damage to ova and sperm may produce adverse birth outcomes long after the exposure itself. Moreover, almost the entire radiation dose due the bombings resulted from external gamma radiation and neutrons. Radionuclides incorporated in the body that deposit their energy within the volume of single cells, including tritium and alpha-emitters like plutonium-239, would be expected to produce significantly greater damage per gray of exposure (Makhijani 2023).[24]

The kinds of severe brain impacts reported by Marshallese women are also described in ICRP 1986 and by the Centers for Disease Control and Prevention (CDC). ICRP 1986 noted the failure of neural tubes to close as an impact during the embryonic stage (ICRP 1986, p. 11). The CDC has noted that a failure of neural tubes to close can result in anencephaly – that is when the brain develops only partially or does not develop at all. It can also result in spina bifida, which is when "the backbone that protects the spinal cord does not form and close. This often results in damage to the spinal cord and nerves." (CDC 2024.) These are similar to some of the impacts reported in the testimonies of the Marshallese, some of which are cited above.

Other impacts, including miscarriages and malformations (known medically as "teratogenic" impacts) are also known to occur. Evidence from experiments on laboratory animals done with external radiation indicates a threshold of 0.1 Gy for most teratogenic impacts. The matter becomes more complex when internal radiation exposure is concerned (Makhijani 2023). Alpha-emitters like plutonium (which also crosses the placenta) deposit their energy within a very small volume, generally a single cell, creating a situations where repair to the damage is far less likely.

Tritium, which is copiously produced by nuclear tests (see above) enters every cell in the body in the form of radioactive water, which is biologically indistinguishable from ordinary water, the stuff of life. Rainfall in the aftermath of the tests in the Marshall Islands was likely to have been intensely radioactive with tritium as well as other radioactive materials, including iodine-131. Tritiated water would wash into drinking water cisterns and percolate into groundwater. Atolls where it rained as the fallout cloud passed over would be disproportionately impacted. Rainfall on grazing areas turned out to be a principal factor in thyroid doses when the National Cancer Institute modeled the impact of atmospheric nuclear testing in Nevada. This was a principal reason that none of the five most impacted counties in terms of thyroid dose were close to the Nevada Test Site; rather they were about 1,000 kilometers away. This indicates a need to take a fresh look at the problem of thyroid doses and their potential relationship to adverse pregnancy outcomes throughout the Marshall Islands.

For example, the Castle series alone would have produced on the order of 21 exabecquerels of tritium, which would have become oxidized into tritiated water vapor. An emission of 37 GBq (one curie) of tritiated water vapor from a nuclear power plant in one day has been estimated (by modeling done by the nuclear industry) to result in anywhere from a few hundred Bq/L to more than a million Bq/ L in a 400-meter radius (Sejkora 2006). The inhabited Marshall Islands atolls that received fallout were roughly 200 or more kilometers away. But the amount of tritium produced by the Castle series alone was roughly 570 million times greater than in the calculation in Sejkora 2006. In addition, the other thermonuclear tests during Castle would cumulatively have produced vast amounts of tritium. It is therefore essential to review rainfall-related tritium contamination, in addition to the iodine fallout, for its potential impact on adverse pregnancy outcomes.

The relatively low energy tritium beta particles (average 5.7 kilo-electron volts; range 0 to 18.6 keV) do not penetrate a sheet of paper or the dead layer of the skin. Their impact occurs when tritium is inside the body. The energy of tritium beta particles is generally deposited entirely within a cell, where it splits apart water and creates oxidative stress. Among other impacts, oxidative stress can damage mitochondrial DNA. A single tritium-decay beta particle with average energy can ionize several hundred molecules of water in the cytoplasm. How much more damaging per unit of energy deposited such radiation damage from tritium compared to gamma radiation may be is, at present, not well understood (Makhijani 2023). Mitochondria, of which there are hundreds or thousands in almost every type of human cell, are particularly susceptible to damage to their DNA (mitochondrial DNA, or mtDNA). This is because mtDNA lacks the complex repair mechanisms that nuclear DNA possesses. Mitochondria are, among other things, the energy system of humans and all multicellular animals, plants, and fungi.

There is direct evidence that tritium contamination of water at 500 Bq/liter, which is about 30 percent below the U. S. drinking water limit of 740 Bq/L liter damages and kills fish eggs (carp) in statistically significant levels (Bondareva et al. 2022).

The concentration of tritium in the fetus is about 60 percent greater than in the mother (Makhijani 2023, Table VI-1). Iodine-131, which also crosses the placenta, also has larger concentrations in the fetus than in the mother. Early in the pregnancy, "Iodine is generally distributed throughout the embryo and does not localize in the embryonic stage." Later, in the fetal stage, it concentrates in the thyroid to enable it to produce thyroid hormones (after 13 weeks). (Sikov and Hui 1996, pdf p.84.) The concentration of iodine in the fetus is 20 percent greater than in the mother at three months and 80 percent greater in the second trimester. It is fully 7.5 times greater in the third trimester. Radiation damage to the thyroid causes hypothyroidism. It is an established cause of miscarriage:

> *"Numerous studies have demonstrated a link between hypothyroidism and an increased risk of miscarriage, particularly in the first trimester. Thyroid hormones play a critical role in maintaining the delicate balance of hormones necessary to support pregnancy. If thyroid hormone levels are insufficient, implantation and early fetal development can be disrupted, increasing the risk of early pregnancy loss."* (California Center for Reproductive Health)

While the iodine-131 doses would have been reduced for the people who were evacuated from Rongelap, Ailinginae, and Utrik, the full impact of the fallout would have been felt in all other atolls throughout the Marshall Islands, the more so in the northern atolls, with corresponding potential for adverse pregnancy outcomes. The women of Utrik who returned two months after Bravo and became pregnant in the following weeks may well have experienced additional impacts of iodine-131 beyond those experienced due to the fallout in the days immediately after Bravo. For instance, iodine-131 impacts would be expected due to the two tests in May 1954 (Yankee and Nectar) whose combined explosive power was about the same as that of Bravo. Some iodine-131 due to the fallout from earlier tests, particularly the ones in April, would also remain.

Zinc-65 is an activation product created due to neutron radiation of zinc in seawater, corals, and metals in bombs. Non-radioactive zinc, being an essential element, is necessary for the fetus. The "concentrations [of zinc] in human embryos increased about seven-fold in the period of rapid growth from 31 to 36 days, during which mass doubled." (Sikov and Hui 1996, pdf p. 71). Since radioactive zinc is indistinguishable biologically from the stable isotope (zinc-64), it will cross the placenta similarly. Zinc-65 is intensely radioactive and has a relatively long half-life –244 days.

Even though Rongelap and Utrik evacuees were medically followed, zinc-65 was not measured "in 1954 and 1955, which represent the years of peak exposure." (Franke 2002.) Based on available data, Franke (2002) estimated the average dose to Utrik residents in those two years to be 42 mSv and 64 mSv respectively; the maximum individual doses were estimated at 170and 240 mSv.

The point in the context of pregnancy outcomes is that highly radioactive zinc-65 would have crossed into the embryo and the fetus. The build-up would have been rapid in the fifth week of pregnancy. Damage to the embryo in the early periods increases miscarriage risks.

Rainwater would have been contaminated with tritium in the aftermath of the tests, potentially contaminating water collected from roofs in cisterns and precious groundwater resources. Since tritium has a half-life of 12.3 years, significant amounts of tritium may have persisted for several decades, once it entered in the local environment. A fraction of it would become organically bound in plants, crabs, and fish.

Health risk estimates also need to take into account differences in food consumption between men and women, as Johnston and Barker (2008) have noted:

> *"Women tended to suck on the bones and eat the organs of the fish, while men ate more of the flesh. Surveys of radiation levels in fish found high levels of radioactivity in the liver and viscera of fish – parts often consumed by women – which could lead to greater consumption of organ- and bone-seeking radionuclides in women."*

Dietary differences between atolls would also need to be taken into account.

In sum, there is sufficient scientific basis to conclude that radioactivity due to nuclear weapons testing in the Marshall Islands would potentially have entered embryos and fetuses in variable amounts throughout the country – iodine-131 for up to three months after each test, zinc-65 for some years, and tritium on a more enduring basis due to its longer half-life. There is enough scientific basis to take seriously the testimonies of the women of the Marshall Islands and the evidence in the Alcalay survey. While more definitive work is done, local testimonies should be given the benefit of the doubt. Dismissing local experience and concerns because scientists presumed they were expressed by people who "understandably did not understand" radiation (Cronkite et al. 1997) was not scientifically justifiable.

No scientific study has as yet seriously examined the widespread testimony of adverse pregnancy outcomes in the Marshall Islands. This gap is especially notable in light of the following facts:

- Official U.S. government maps and other data show significant fallout throughout the country.
- U.S. government studies have estimated that elevated exposures occurred throughout the country. Average thyroid doses in most of the country were far greater than the average estimated for the most exposed counties in the United States due to testing in Nevada.
- The problem of hot spots due to rainout of radioactivity (especially iodine-131) hundreds or even thousands of kilometers from atmospheric test locations has been well-understood for decades (see NCI 1997 for instance).
- The problem of increased risks of major birth defects occurring worldwide due to testing fallout was noted at least as far back as 1960.
- There is evidence from Hiroshima/Nagasaki survivors of teratogenic impacts.
- There is extensive medical literature, some cited above, that indicates that, at the levels of exposure experienced, that teratogenic impacts would be expected.

Displacement, loss of traditional occupations, loss of traditional diet, unemployment, and stress have all been attendant upon nuclear weapons testing, resulting in adverse impacts on health. The people of Rongelap and Bikini still live in exile. The places to which people have moved have also been impacted. The people of Enewetak who returned live in an atoll that has radioactive contamination from testing and a huge, deteriorating nuclear waste disposal site.

Kwajalein island has become a major U.S. military base for the long-term; its lagoon is used for testing the accuracy of strategic missiles, a single one of which can carry multiple nuclear weapons, each one of which can destroy a city. The Marshallese of the atoll have been largely displaced from their home islands and concentrated on a single island, Ebeye, which is the closest to the U.S. base.

This section is a very brief exploration of some non-radiation harms.

6. Other damages

a. The people of Bikini, Enewetak, and Rongelap

The 167 people of Bikini Atoll were evacuated to Rongerik Atoll, about 200 km to the east starting in March 1946. Their homes were burned to make way for U. S. personnel and equipment. Some of their outriggers were also burned (Stone 1988); some were loaded onto ships as part of the evacuation (Niedenthal 1988). Rongerik was uninhabited at the time. It was far smaller with far fewer resources. It was a strong traditional belief that Rongerik "was inhabited by evil spirits." As things turned out, it might as well have been:

> *"The Administration left the Bikinians with food supplies for only a few weeks. The islanders soon discovered that the coconut trees and other local food crops produced very few fruits when compared to the yields of the trees on Bikini. As the food supply on Rongerik quickly ran out, the Bikinians began to suffer from starvation and fish poisoning due to lack of edible fish in the lagoon. Within two months after their arrival they began to beg U. S. officials to move them back to Bikini."* (Niedenthal 2013, p. 2)

The starvation worsened in 1947 when coconut trees caught fire. Relocation to Ujelang atoll was decided. Bikinian men built homes there – but the United States decided to move people from Enewetak there, stranding the Bikinians once more. They were moved to Kwajalein in March 1948 and moved again in June 1948 to Kili, in the very southern part of the Marshall Islands (see the Marshall Islands map, Figure 1-1 above).

For some Bikinians, there was a return to their home atoll in the 1970s. It followed an Atomic Energy Commission investigation into Bikini resettlement that included radiological surveys. Radiation levels varied widely from near background to many times that. Strontium-90 and cesium-137 were elevated in many places but unevenly. Coconut crabs were found to concentrate strontium-90 (AEC 1971). Overall, the ad hoc committee found that "exposures to radiation exposures that would result from repatriation of the Bikini people do not offer a significant threat to their health and safety" (AEC 1969). It did not turn out that way. The water exceeded drinking water standards. Cesium-137 built up in the bodies of those who returned. Bikinians were advised to restrict themselves to a single coconut a day; imported food became essential. Bikinians left for Kili and also to Ejit, a small island in Majuro atoll. There is now a Bikinian diaspora (Niedenthal 2013, pp. 9-11). Bikinians, once *"known throughout the Marshall Islands as some of the most skilled canoe builders and sailors, were now on an island without a lagoon, suffering economic, social, and cultural deprivation that has persisted for generations."* (Niedenthal 2013).

Like the Bikinians, the people of Enewetak Atoll were also force to leave their homes prior to the start of testing there in 1948. They were moved to a much smaller atoll, Ujelang, with one-fourth the land area of Enewetak. The protected lagoon of Ujelang atoll was just six percent of the size of Enewetak's lagoon. There were, therefore, far fewer resources for the displaced people; food was soon in short supply. Resupply ships came only once in six months and the people came "close to starving", according to an Enewetakese administrator of the trust territory of the time (Wilford 1977). About two decades after the end of testing, the United States initiated partial clean-up efforts, enabling resettlement on two islands for part of the population, but also creating a massive radioactive waste dump in the process (Section 7.a below).

Barker 2013 has described the fate that befell the people of Rongelap, who suffered high radiation doses after Bravo before they were evacuated. They were taken to Ejit, on Majuro Atoll. They were returned to Rongelap in 1957; but the land and food were contaminated. People who were not on Rongelap during the Bravo fallout but returned there in 1957 also experienced health problems, including adverse pregnancy outcomes; an example is in Section 5.a above. Unwilling to take continued risks of exposure, they chose exile in 1985. They requested

Greenpeace to evacuate them; the evacuation occurred "without the assistance or approval of the U.S. Government." (Johnston and Barker 2008,p.26). They went to Mejatto, an island in Kwajalein atoll.

The Rongelap community has grown more urban over the decades; there are jobs on Ebeye, which is next to Kwajalein Island, a U.S. military base, with housing for Americans. But Ebeye is 60 kilometers from Mejatto, across the lagoon. Some Rongelapese now live on Ebeye, which has serious housing problems and a population density of 150,000 per square mile (Barker2013, p. 68), about five times that of New York City.

Ebeye testimonies (quotes are in Barker 2013, Chapter 5):

> No. 1: *"On Ebeye…we buy things. We don't have pandanus leaves to make sleeping mats. I lie on a tile. We need money for everything. When it runs out there is no food.…There's no vehicle to go and get birds to eat [25].…My children grow up on Ebeye. They just hang around."*

> No. 2: *"What is life now? It is filled with sickness. It was better on the island [Rongelap]. I came to Ebeye because my kids have to go to school. Food is hard when you don't live on your own land."*

> No.3: *"There are thirty-some people in three rooms. You would laugh if you see us sleeping -- everyone together.…My husband is retired, but he still works because no one else has jobs."*

iii. A perspective on loss

The losses are varied and profound, across all areas of social and personal life. Traditional Marshallese society was organized around scarce land resources, where rights and obligations were linked to the food and other resources that everyone needed to live. Nuclear weapons testing has meant the "loss of the means to maintain a healthy sustainable life" (Johnston and Barker 2008, p. 57).

A great loss that has occurred over the decades of some of the finest mariner skills the world has known – a grievous loss not only for the Marshallese, but also for global society. The people of Rongelap were also known as the best sailors; they literally read the waves and navigated without instruments across hundreds of kilometers of open ocean, unerringly arriving at their destinations. It is among the most amazing feats of human ingenuity and inventiveness, passed down in the Marshallese oral tradition by elder ri-meto, "persons of the sea", to younger ones. Reading the waves was "indispensable as the sole means of collecting food, trading goods, waging war and locating unrelated sexual partners." Those traditions are being lost. But, as in other areas, there are valiant efforts to revive them (Tingley 2016).

b. Cancer care

As discussed above, nuclear testing increased cancer risks – more in the northern atolls than in the southern ones – but nonetheless throughout the Marshall Islands. Both governmental and non-government literature are clear on that. Yet, only a very small fraction (about two percent) of the population have received U.S. medical attention, which has come with its own downsides, including being treated as experimental subjects.

Care for most has been provided by family members:

> *"Virtually every family in the Marshall Islands knows the first hand struggle to find care for family members with cancer and the grief and loss that occur when loved ones succumb to the illness.…In the 1970s, Manuwe (a Mili resident) moved to Bikini where she ate and drank from a contaminated environment. Manuwe's husband is plagued by illnesses and is confined to a wheelchair. Because his exposure occurred while working on remediation projects, rather than the 1954 Bravo event, he is not eligible to participate in medical monitoring or treatment programs."* (Johnson and Barker 2008, p. 238).

There is no oncology center in the Marshall Islands. Patients must travel to Hawai'i or other distant centers at great expense. Together, both the time of family members and the cost of treatment are part of what Johnston and Barker have called the "consequential damages of nuclear war" – the nuclear war that came to the Marshall Islands in the form of 108.5 megatons of nuclear weapons testing – equivalent to a Hiroshima-size bomb, it is worth noting again in this specific context, every day for 20 years.

The National Nuclear Commission of the Marshall Islands has pointed out that

> *"The absence of cancer care facilities and its link to forced migration are deplorable, and it means that the violence of the testing program continues despite the cessation of weapons testing; the violence now comes in the form of inadequate healthcare that means people die from treatable illnesses and endure suffering that they would not if they had adequate healthcare."* (National Nuclear Commission 2020)

In that context, the Commission noted that the Marshall Islands has petitioned the

> *"U.S. Government to fund a robust medical infrastructure in the RMI [Republic of the Marshall Islands] to support primary and secondary health care, and to provide annual funding enough to maintain quality health care well into the future. U. S. acceptance of these requests would have created the infrastructure for all Marshallese to access cancer care in the RMI, and not just those that are legislated by the U.S. Congress to receive care. Furthermore, creating a cancer care facility in the RMI means that cancer patients, especially our elders, would not have to leave the country to seek life-saving treatment in locations that are unfamiliar and foreign for family members."* (National Nuclear Commission 2020)

7. Scientific aspects of remediation and resettlement

> *"In the Marshall Islands there is a deep sense of distrust for DOE's scope and methods of work. That legacy of mistrust reflects that DOE's work is not seen as meeting the needs of impacted communities, but of advancing the scientific and political interests of the US. The roots of this distrust are deep because we have been damaged by actions and failures to act -- with the failure to evacuate several irradiated atolls being a prime example of the latter. The lack of health care to the people who suffered needless additional radiation doses has meant that the original damage has been compounded and the violence of the nuclear era continues when people cannot access healthcare or ancestral islands. The Runit dome provides another example."* Rhea Moss-Christian 2021, at the time Chair of the National Nuclear Commission of the Marshall Islands

The history of damage by and distrust of the United States is compounded by Marshallese dependence on the United States for funds and for scientific and medical expertise. The Marshall Islands does not at present have sufficient technical capacity in a number of relevant fields – oncology, field measurements of radioactivity, laboratory facilities for analyzing soil, water, and food samples, and radioecology. As a result, the Marshall Islands has little recourse but to commission independent work by non-resident experts or to rely on the United States. Franke 2002 is an example of independent work; it was commissioned by Utrik Atoll to study the impacts of various diets.

Complete remediation of contaminated areas is generally impossible; radionuclides are far too dispersed in the Marshallese environment for complete cleanup. For instance, gathering up all the contaminated soil would turn much of the scarce land resource into a barren wasteland. Some cleanup of hot spots by gathering up the soil is possible.

But what should be done with the waste, given the fact that some of the radionuclides in it have very long half-lives? Much of the radioactivity resides in lagoon sediments. Some coral reefs, well known as resource and biodiversity rich ecosystems, have been destroyed.

Many displaced Marshallese also long to go home. Staying has the stresses and difficulties that come from being refugees – the Marshallese are in their own country, but given the specificity of the traditional land attachments they are not "home." It was the sentiment of Bikinian elder Kilon Bauno when he said of his place in exile

> *"There is nothing in my life I want more than to go home to Bikini. The reason I can't go back is because the Americans tell me there is "poison" there. I don't understand this but that is what the Americans say. This is not my island. I want to go back to my paradise where God intended us to be. I am asking America to take us home. I want to go back to my island to live out my final days."* (Stone 1988, 49:40)

He had been told there was "poison" there. But he did not seem to know what to make of it. The reality was that Bikinians had experienced poison in the form of poisonous fish after they were displaced to Rongerik – as well as starvation.

Yet, the contamination is undeniable. There is risk in moving back, and loss in not moving back. No one can decide but the displaced Marshallese themselves. If the experience of other nuclear disasters – Chernobyl, Fukushima, and indeed, the Marshall Islands – is any guide, some may move back and some may not. In any case, a systematic approach to remediation is needed to minimize risks for those who may move.

Remediation requires a capacity to answer difficult questions. What is ecologically sensible that is also technically possible? What are the standards by which decisions can be made about the resources that are usable? Grappling with "acceptable risk" from pollutants – given the reality of their ubiquity – is a near-universal modern problem. It is a question that is addressed in the United States by a regulatory process that has had the merit of considerable openness – even if the results are often not warmly welcomed by those who participate in it. In the case of the Marshallese, the central difficulty is that those who have created the problem still control the technical reins and, to a large degree the financial means.

Having the means for their own health care is also critical, given the experience, well summarized in Ruff 2015:

> *"The 1955 US government assessment of "Bravo" fallout that all twenty-two populated atolls of the Marshalls received hazardous fallout was kept classified. As comprehensively documented in the Rongelap Report [Johnston and Barker 2008], medical follow-up and interventions undertaken by US government agencies (principally the Brookhaven National Laboratory, Atomic Energy Commission and then Department of Energy) were aimed not primarily at serving patient care, but at monitoring and documenting long-term movement of radioisotopes in the environment, foodstuffs, and humans, and the health effects for people deliberately returned to a contaminated environment that was known to be hazardous. Research documenting the late effects of radiation, the secret Project 4.1, involved 539 children, women and men who did not give informed consent. Some received radioisotope injections including chromium-51, radioactive iodine, iron, zinc, carbon-14 and tritiated water, and underwent experimental surgery and procedures that were not carried out for their benefit. Many regularly underwent treatment that was dehumanizing, painful and traumatic."*

A brief review of remediation on Enewetak that resulted in the creation of the "Runit dome" illustrates some of the difficulties of remediation controlled by the United States and of achieving a just outcome. That is followed by discussions of remediation standards in the United States, a few approaches to remediation as a preliminary to the technical basis on which the Marshallese may make their own remediation and resettlement decisions.

a. The Runit Dome – a case study

The U.S. government undertook a remediation effort in the 1970s to facilitate the resettlement of Enewetak Atoll. Like Bikini in 1946, Enewetak was evacuated in 1947 to make way for the Operation Sandstone fission bomb tests in April and May 1948 totaling just above 0.1 megaton. More than 31 megatons of tests were done at the atoll subsequently. Despite the vast amounts of fission and activation products created by the fission and thermonuclear bomb tests, the remediation was oriented to reducing plutonium and other transuranic radionuclides in areas that were to be resettled. Clean-up levels for plutonium were set:

- The lowest residual contamination level was 1.5 Bq/gram was for an island that would be resettled.
- The limit was up to 15 Bq/gram in other areas, depending on anticipated use.

Contaminated soil above the 15 Bq/gram limit would be removed, mixed with cement and then put "inside an unlined nuclear test crater, the Cactus Crater, on the north end of Runit Island." (DNA 1980). Since the crater had been created by an 18-kiloton nuclear bomb test (on May 5, 1958), it was highly fractured limestone, porous to water penetration from tidal fluctuations. Nonetheless, it was not lined before the plutonium waste was put in it. The bottom of the waste remained in contact with the ocean. A concrete cap was built to cover the waste; it has become known as the "Runit dome." The Cactus crater was chosen in preference to the more secure Lacrosse crater even though there were greater concerns about the durability and soundness of the containment in Cactus. It was cheaper to use the Cactus crater (DNA 1981, p. 428).

There was no cleanup of the lagoon, an important source of food. It contains an estimated 30 kilograms of plutonium. The waste put into the Runit dome is estimated to contain 0.25 kilograms.[26]

In any case, no concrete structure could endure even for a tiny fraction of the 24,110 year half-life of plutonium-239. In fact, there are already cracks in it in less than 50 years. The Department of Energy has nonetheless declared that the dome continues to be "an effective and erosion resistant seal for the encapsulated radioactive material within the containment structure" (U.S. DOE 2020, p. iii). The DOE has opined that

> *"The key pathway for exposure to radioactive materials contained in the Cactus Crater containment structure is from leakage of contaminated groundwater entering the local marine environment, and the subsequent uptake of dome derived fallout contamination into the marine food chain"*(U.S. DOE pdf p. 11)

Runit Island itself is uninhabitable.

Climate change, more intense typhoons and sea-level rise are general risks but especially for low-lying island countries like the Marshall Islands. It is worthy of note that the process of remediating just a small fraction of the plutonium was long enough that three typhoons occurred during the cleanup (DNA 1981, pdf p. 518).

The remediation at Enewetak is in contrast to two earlier efforts – in Spain and in Greenland; in both cases, the most contaminated plutonium waste was repatriated to the United States.

i. Palomares, Spain

A 1966 aircraft accident resulted in the loss of four thermonuclear bombs over Spain. Two of the bombs were recovered. The conventional explosives in the other two ignited; the result was dispersal of the plutonium in the bombs over a wide area near Palomares, a village in Mediterranean Spain. Agricultural land was contaminated (DNA 1975). The U. S. government sought and got the approval of the Spanish government. The technique was essentially the same – gathering up the contaminated soil that had plutonium above a specified threshold. But in this case, the soil was packaged and shipped to the DOE's Savannah River Site in South Carolina, which already had large amounts of radioactive waste from plutonium production and separation. Areas with contamination below the threshold were dealt with locally so that some contamination remains in Spain.

ii. Thule, Greenland

An even more cooperative approach was taken when a crash near Thule in Greenland dispersed plutonium from nuclear bombs onto ice and snow. The U. S. commander wanted "to store the contaminated snow and ice in surplus 25,000 gallon tanks and then bury them in the permafrost" (SAC 1969). The Danes did not agree; they wanted the contamination to be removed from the country; in addition, ecosystem protection was an issue. The ice and snow were not to be allowed to melt, which would wash plutonium into the ocean. The United States and Denmark agreed that most of the contaminated snow and ice would be gathered up. The tanks with the contaminated melt were taken to the Savannah River Site to be "buried beside the barrels of contaminated soil collected at Palomares, Spain" (SAC 1969). There was also contaminated debris. It was taken to Hanford, Washington, the other site of military plutonium production in the United States, and to the Pantex plant in Texas, where nuclear weapons are assembled and disassembled (Taschner 2005). Some contamination remains in Greenland.[27]

The contrast is rendered even more poignant by two things: the scarcity of land in the Marshall Islands and its far greater vulnerability to climate change. Repatriation was considered in the Enewetak remediation; that was the preferred option not only by people in Enewetak and the DOE's own office at its continental test site in Nevada. But the authorities decided it "was uneconomical, would generate considerable political resistance, and would adversely affect the entire project." The added expense was estimated at $9 million (DNA 1981, pp. 112-114).

b. Remediation Standards

The United States uses a standard of 1 mSv/y radiation exposure to assess the effectiveness of remediation in the Marshall Islands. This is the overall limit for public exposure set by both the DOE and the Nuclear Regulatory Commission. However, that is not the standard that applies to the remediation of highly contaminated sites. That regulation is popularly known as “Superfund”. The Superfund rule limits the post-remediation lifetime cancer risk to future generations to between 1 in 10,000 and 1 in 1,000,000. The U. S. Environmental Protection Agency (EPA) has interpreted this range to mean a maximum dose of 0.15 mSv per year over a lifetime (EPA 1997).

Two other standards are also relevant. For radioactive waste disposal, the appropriate standard (assuming equivalence with the United States) would be the Nuclear Regulatory Commission’s rule for low-level waste. The rule sets a post-disposal limit of 0.25 mSv/year to the whole body or the most exposed organ, except for the thyroid, for which the limit is 0.75 mSv/year (NRC 2006). The EPA drinking water standard is also relevant. It limits doses from most man-made gamma and beta-emitting radionuclides, like cesium-137, by the drinking water pathway alone to 0.04 mSv/year. Numerical concentration limits are set for strontium-90, plutonium, uranium, and tritium (EPA 2000).

The Marshallese, being aware that the Superfund limit is far stricter than the limit used at Enewetak, tried in 2020 to get the U. S. government to adopt the 0.15 mSv/y limit (Nemra and Note 2020). The DOE rejected the request in 2021 (U.S. DOE 2021).

Radiation protection generally goes beyond the limits set in standards, which are maximum values that should not be exceeded for anyone. Keeping radiation exposure below the maximum limits is highly desirable since all exposure causes some increment of risk. This is part of radiation protection is known as keeping radiation exposure “as low as reasonably achievable” below set standards. It is known by its acronym as “the ALARA principle.” The ability to sample and screen foodstuffs and water, to investigate suspected hot spots, and experiment with bioremediation are essential for ensuring standards are met and that the ALARA principle is respected. Activities related to such regulatory performance require considerable scientific, analytical, and laboratory capacity.

Apart from well-established activities for which capacity is needed, newer molecular-level investigative tools and technologies could also be applied. They would enable measurement of cellular-level effects in people and indicator organisms in real time, including DNA and RNA damage and repair, oxidative stress, metabolic changes, and immune suppression.

8. Capacity

a. A general perspective on capacity

From capacity for health care to capacity for assessing and monitoring the radiological aspects of the legacy of nuclear testing, the needs are large, both from a financial and technical point of view. Apart from the expedient of retaining external independent scientists, as they have done from time to time, the real need is for culturally-connected resident scientists, radioecologists, medical experts, and laboratory technicians to staff infrastructure that needs to be built. Such capacity would be important in any circumstance; it seems to be essential given that (i) testing was continued, despite significant U.S. government evidence available then (1947-1948), it was contrary to key purposes of the U.N. trusteeship, (ii) the vast majority of Marshallese were excluded from medical monitoring and treatment even though the entire country suffered fallout; for example, the "low" exposed southern atolls had average thyroid doses approximately double those of the U.S. counties most affected by iodine-131, and (iii) the small minority who were provided medical monitoring were treated as experimental subjects, as is clear from the minutes of the 1956 meeting of the Advisory Committee on Biology and Medicine of Atomic Energy Commission, quoted above in detail.

Indigenous Marshallese capacity may benefit the whole world. There has in recent decades been an increasing realization in scientific circles that indigenous knowledge of nature is profound and complements contemporary science. All of the world's people are living in more or less contaminated environments with variations that tend to reflect larger inequities. Marrying a holistic and very local understanding of the land and lagoons and ocean with detailed scientific data and understanding could reduce risk in new ways, for instance, through creation of new bioremediation techniques and through new understandings of how radioactive ecosystems work.

For instance, two Aotearoa (New Zealand) scientists, have argued for a complementary scientist-indigenous approach:

> *"The current state of global systems in an uncertain risk landscape creates an urgent need for many knowledges and approaches to build resilience and prosperity of communities ...*
>
> *"Indigenous knowledge can and has contributed empirically generated, intergenerational knowledge, making it an increasingly valuable tool in environmental management, particularly around rare but increasingly frequent natural events such as large-scale deadly bush fires that plague Australia and parts of North America. For at least 40,000 years, Indigenous Australians have been managing the landscape, leaving a deep human imprint, one that has been nearly erased from living memory. However, in parts of Australia, local authorities, scientists, and Indigenous communities are now coming together to revisit Indigenous fire management and reframing science through Indigenous knowledge to better understand these modern environmental dilemmas."* (Black and Tylianakis 2024)

Similar examples can be found in other areas, from farming clams to the importance of indigenous languages, because such efforts can "convey unique knowledge of medicinal plants. Researchers analyzed ethnobotanical datasets for North America, northwest Amazonia and New Guinea, which link more than 3,500 medicinal-plant species with 236 Indigenous languages. They found that 75 % of the medicinal uses for these species are known in only one language." (Graham 2021)

The Marshallese are making efforts in many areas, from the Marshallese language to the cultivation of traditional navigators' mariner knowledge of sailing the open ocean by reading the waves and observing birds in flight and reflections from clouds. Designing recovery from the range of damage, from radiological contamination to loss of home atolls to loss of traditional ways of sustainable living, could provide an opportunity for the Marshall Islands, possibly in collaboration with other similarly affected parts of the Pacific Region, to become a center for scientific-indigenous collaboration. Collaboration may make the development of capacity more feasible for several reasons: (i) The range and depth of capacity needed is considerable; (ii) the cost and time needed to achieve that will be substantial; and (iii) the Marshall Islands, like some other impacted places, have limited population and resources. Combining them increases the pool of people and resources that could be devoted to common purposes.

b. Nuclear justice

The National Nuclear Commission of the Marshall Islands, after extensive consultation with "national stakeholders and external friends and partners over an 18-month period", published a "nuclear justice" strategy document. We have already quoted the petition for in-country medical facilities, including cancer-care facilities, in Section 6.b above. In concluding this review of the legacy of U. S. nuclear testing, it is important to put that request in the context of the "key pillars of nuclear justice" that are the core of the Commission's nuclear justice strategy. They are (National Nuclear Commission 2020):

- "Full payment of all past and future awards of the Nuclear Claims Tribunal (Compensation);
- "Quality health care for all Marshallese (Health Care);
- "Reducing the risks of exposure to radiation and other toxins in the environment (Environment);
- "Building national capacity to monitor and understand radiation impacts (National Capacity);
- "Education & awareness of our nuclear legacy (Education & Awareness)."

National scientific, technical, and analytical capacity is part of the fourth "key pillar." The National Nuclear Commission provided the following detail about it:

> *"Support to national agencies and departments to establish a capacity in radiological monitoring will lead to greater national participation and ownership in radiation-related research throughout the RMI. Decades of reliance on mostly U. S. Government-led research has resulted in a U.S. monopoly on radiation data in the RMI and in turn, a U.S.-controlled narrative about the impacts of its nuclear testing program. Capacity building efforts targeted at relevant national government agencies and departments, with the support of the international community, will ensure that the RMI leads its own national monitoring efforts, identifies its own priorities for knowledge making, and can direct external assistance in the most efficient and appropriate ways.*
>
> *The training and engagement of Marshallese in this work has to start now as we cannot afford to wait any longer to be the dominant voices and lead authors in our nuclear story. This can begin with the strict adherence to the NNC Research Protocol for nuclear-related research, which requests researchers to employ nationals to participate in the duration of the research project. This approach ensures that knowledge is transferred both ways and that local capacity for research and understanding is developed."* (National Nuclear Commission 2020)

This capacity has not yet been realized. France and Britain have also harmed the Pacific region by nuclear testing (IPPNW and IEER 1991; Ruff 2015). In all cases, indigenous people and the lands of which they have been stewards for millennia were impacted.

Nuclear testing harms and the issues of remediation and redress are gaining renewed attention in the context of the Treaty on the Prohibition of Nuclear Weapons, which came into force in January 2021. No nuclear weapons power has signed the treaty, which is based on humanitarian principles. Article 6 of the TPNW is explicitly about the parties' obligations to provide assistance to the victims of nuclear testing. Article 7 is addressed to those who have used or tested nuclear weapons:

"Without prejudice to any other duty or obligation that it may have under international law, a State Party that has used or tested nuclear weapons or any other nuclear explosive devices shall have a responsibility to provide adequate assistance to affected States Parties, for the purpose of victim assistance and environmental remediation."

Evidently assistance is necessary; given the damage, it should be obligatory, though the tools available to convert that obligation into reality on the ground have not been equal to the task. Perhaps the growing realization that science has not provided the stewardship of the planet that is the need of the hour, despite the technological possibilities that have been created, could provide the occasion for the world to support an infrastructure for survival that would centrally include indigenous leadership.

Endnotes

1 References provided in the text are not repeated in the Executive Summary.

2 The total land area of the Marshall Islands is only 181 square kilometers, less than one-fourth the area of New York City.

3 Copra is the dried meat of the coconut, rich in oil that can be used for cooking as well as making products like soap. It can also be directly eaten; it is high in calories and dietary fiber.

4 Highly enriched uranium, used in the Hiroshima bomb, was in far shorter supply than plutonium in the immediate aftermath of the war.

5 Since the memorandum is dated April 21, 1948, the data and most of the analysis likely came much before the first test at Enewetak, which was on April 14, 1948. It is therefore likely that only 0.042 megatons of tests – the ones in Operation Crossroads, had been done when the US concluded the Marshall Islands were not meteorologically suitable as a nuclear test site.

6 Ten half-lives is a common rule-of-thumb for estimating the period that it takes for the radioactivity to decline to very small levels because it declines to about 0.1 percent of the initial amount in that time.

7 Calculated from estimates in Chapter 3, IPPNW and IEER 1991 and, for tritium, UNSCEAR 2000, p. 49

8 Dates are as per the time in the Marshall Islands.

9 Data from U. S. documents has been converted to approximate values in Standard International units, using 1 roentgen ≈1 rad = 10 milligray.

10 An approximation for total radioactivity after the test is that it decays as $t^{(-1.2)}$. Thus, fallout radioactivity R(t) at t hours after the test would approximately equal $R(t) = R(1)*t\wedge^{(-1.2)}$, where R(1) is the radioactivity at time = 1 hour.

11 The fallout data do not include the "Koon" test; it was a failed design that did not produce the minimum expected thermonuclear yield. Even though classified as a failure from the design point of view, it was about five times the explosive power of the Nagasaki bomb.

12 We have used 30 nanogray/hour as the background photon radiation, though this also includes some charged particle ionization. UNSCEAR 2000, Vol. II, p. 86.

13 An approximation for total radioactivity after the test is that it decays as $t^{(-1.2)}$. This fallout radioactivity R(t) at t hours after the test would approximately equal $R(t) = R(1)*(t^{(-1.-2)})$, where R(1) is the radioactivity at time = 1 hour.

14 The U.S. Department of Energy list only two atolls, Rongelap and Utrik, as part of its "Special Medical Services" program, which provides cancer treatment and medical screening to those who were present during the 1954 Bravo fallout. Of the 253 people in the original 1954 cohort, 71 were still alive and eligible for the program in 2023 (U.S. DOE 2024, p. iii). However, three atolls were actually involved because some Rongelapese were fishing on Ailinginae atoll at the time of the Bravo fallout. They were also evacuated, though with a slightly greater delay than the people who were on Rongelap (Meade and Meade 2018, pp. 79-80). The radiation doses suffered by those who were on Ailinginae at the time of the Bravo fallout were officially estimated to be about the same as Rongelap doses (NCI 2004, Table 1). The United States also provides some funds for healthcare for the people of Bikini and Enewetak. These funds are provided "to the Marshall Islands' Ministry of Health and Human Services" as part of a four-atoll healthcare program that also includes Rongelap and Utrik. The amount for fiscal year 2025 was $2.24 million (Pacific Island Times Staff 2025).

15 He was Aikichi Kuboyama. His death, caused by liver disorder, was attributed by his attending Japanese physician to blood transfusions needed because of radiation exposure, radiation exposure itself, and "degeneration of the liver, caused by the debris of other radiosensitive cells destroyed by radiation injury." In other words, all three causes identified were directly related to the radiation he suffered. Some U. S. experts disagreed, causing anger in the Japanese public; it also led the Lucky Dragon's surviving crewmen to feel "that the United States behaved in a cold-blooded way with regard to the accident of the Lucky Dragon." (Lapp 1958, pp. 175-176)

16 Official estimates of the risk of cancer per unit of radiation exposure have generally increased over time but have not changed significantly since the late 1990s.

17 Disclosure: The author of this report was an Associate of SC&A on an unrelated project from 2004 to 2018. He was not involved in SC&A's Marshall Islands research.

18 The "[l]ow exposure atolls" in the NCI 2004 report were Lae, Kwajalein, Maloelap, Namu, Arno, and Mili. The "[v]ery low exposure atolls" were Lib, Aur, Ailinglaplap, Majuro, Ujae, Kili, Jaluit, Namorik, and Ebon. NCI 2004, Table 1.

19 The hypothesis that there is no threshold of dose below which cancer risk is zero was used to make this calculations. It generally accepted by regulatory bodies.

20 Thrombopenia is the medical term for when platelets, responsible for blood clotting to stop bleeding, are abnormally low.

21 It should be noted that this was also the period when the radiation exposure experiments were done on people in the United Statesfrom1944 to 1974. Examples of experiments and their purposes can be found in SDA 1994. Many experiments had similar purposes to the medical plans for the Marshallese.

22 The University of California ran both Los Alamos and Livermore nuclear weapons laboratories exclusively for decades, after which time it has continued to do so but in partnership with others, including corporations.

23 Calculated by the author from data in UNSCEAR 2000, Vol. II, pp. 86-87

24 A survey of the literature on tritium is in Mousseau and Todd 2023. The conclusion of the authors, having done this extensive survey, was "that tritium is a highly underrated 90 environmental toxin that deserves much greater scrutiny."

25 Birds are a part of the traditional diet.

26 Calculated from radioactivity data in U.S. Department of Energy 2020, p. 6.

27 A 2002 doctoral dissertation estimated the marine inventory to be 3.8 kilograms of plutonium-239/240. Ericsson 2002, p. 31. This can be compared to the estimated 30 kilograms in Enewetak lagoon.

28 The date provided is that in Washington, D.C. at the time of test. It was July 26 in the Marshall Islands.

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