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CASTLE BRAVO: FIFTY YEARS OF LEGEND AND LORE

A Guide to Off-Site Radiation Exposures

January 2013

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CASTLE BRAVO: Fifty Years of Legend and Lore

A Guide to Off-Site Radiation Exposures



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Figure 0–1. Utirik Island village seen from a raft bringing radiation safety monitors to shore,
3 March 1954

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The location of the Marshall Islands is illustrated in Figure 0–2.

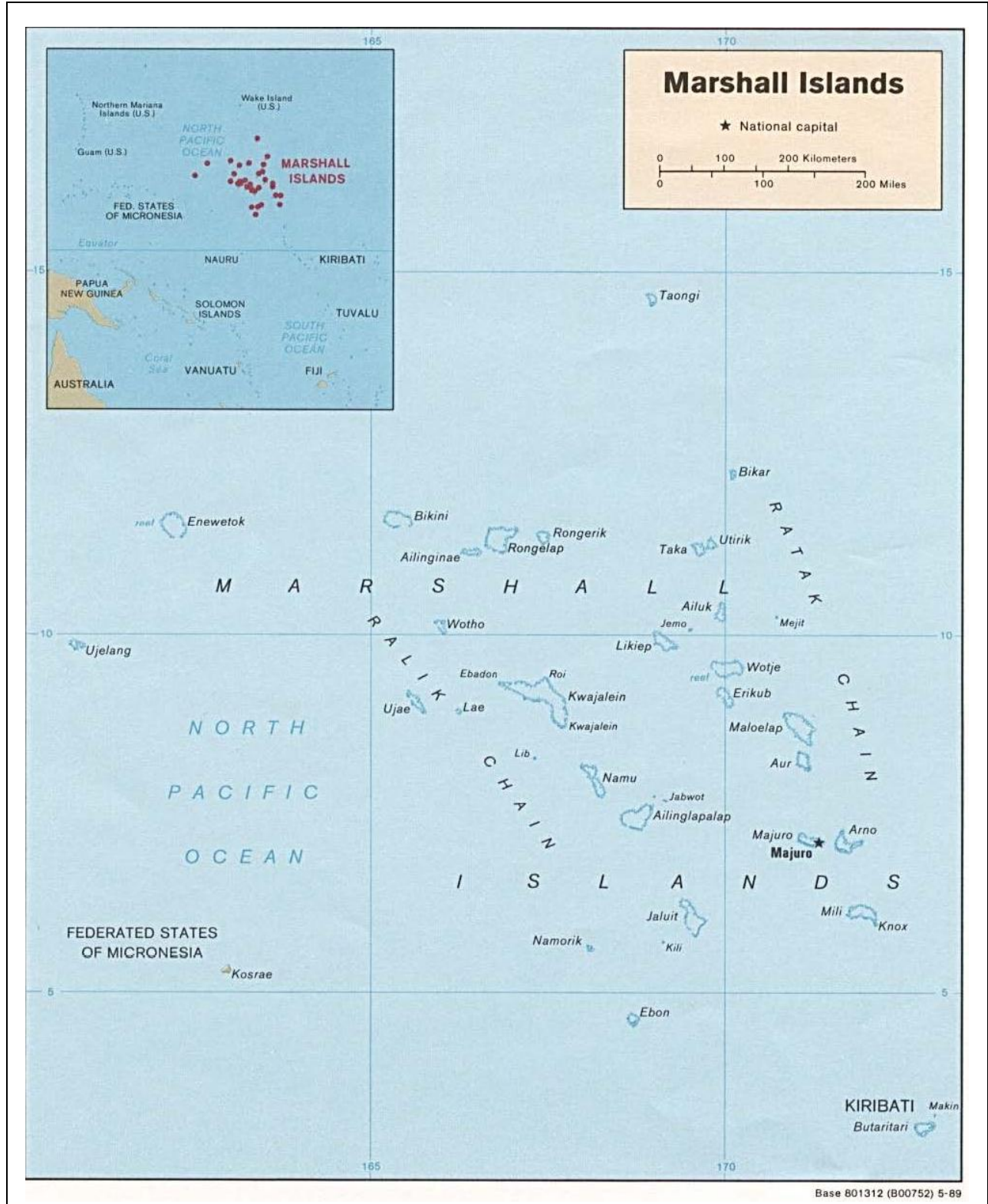


Figure 0-2. The Republic of the Marshall Islands. (US Government, 1989)

1.0 Introduction

I anticipate being pressed by higher authority for an explanation regarding the circumstances that led to the exposure of the natives.

—Brigadier General Kenneth Fields, 12 March 1954

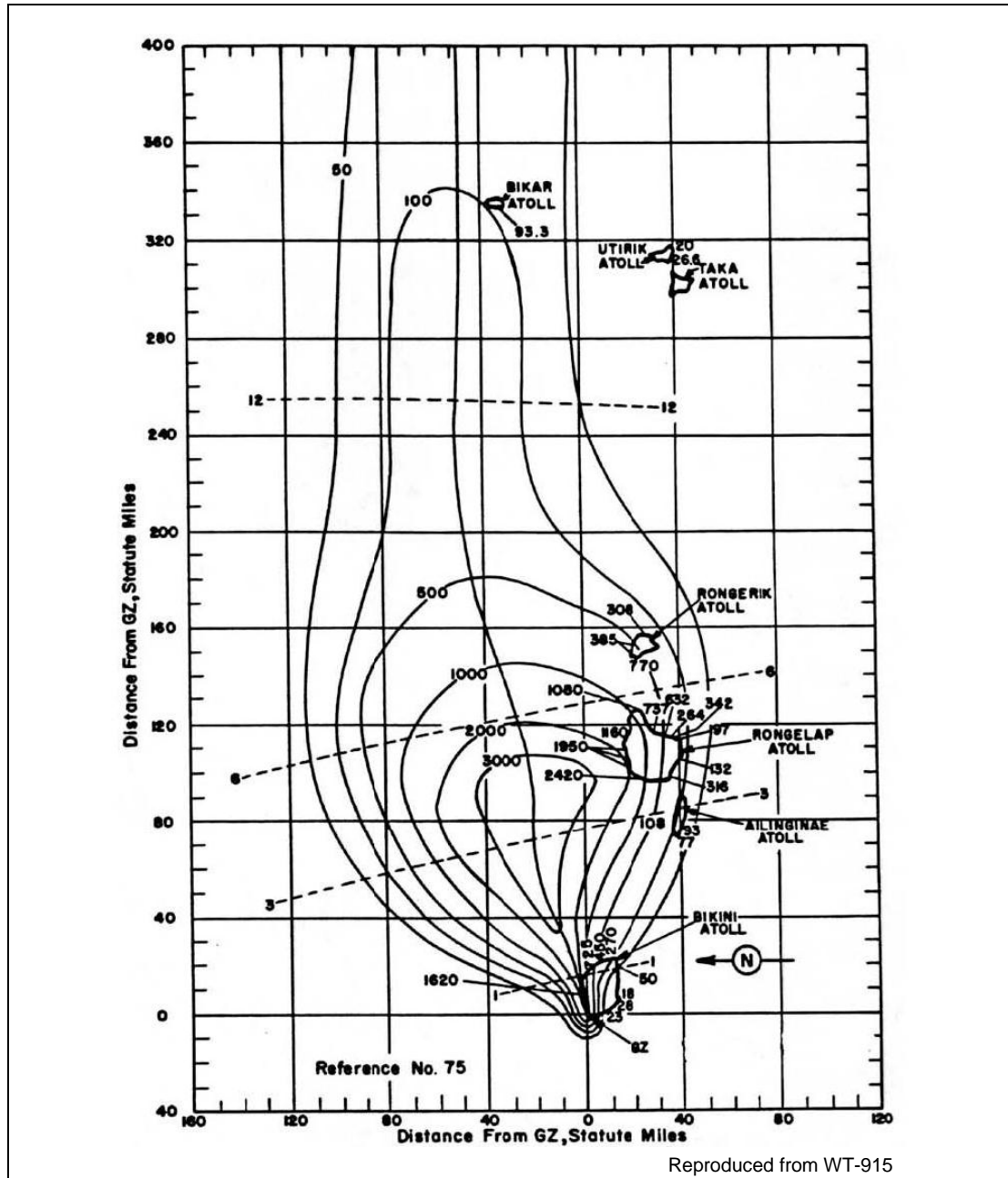


Figure 1-1. Radioactive fallout from the CASTLE BRAVO nuclear detonation

This report is a narrative history and guide to primary historical references concerning the CASTLE BRAVO nuclear test of 1 March 1954. Detonated at Bikini Atoll in the Marshall Islands, BRAVO was the largest-yield American nuclear explosion. Also, it was the only American nuclear test to result in prompt harm to civilian populations.¹ Radioactive fallout arrived within hours on several nearby populated islands, necessitating emergency evacuations of Rongerik, Rongelap, and Utirik atolls, and resulting in radiation overexposures to approximately 665 island residents. This report focuses on the circumstances that resulted in radioactive contamination of the inhabited atolls. No attempt is made to address, in any detail, the larger issue of the effects of BRAVO on and around the shot site at Bikini Atoll.

Because of the logistic and security problems presented by the remote location in the central Pacific Ocean, joint military and civilian task forces were established to conduct nuclear tests at the Pacific Proving Ground (PPG) in the Marshall Islands. Joint Task Force Seven (JTF-7) was responsible for the CASTLE test series of 1954. The task force chain of command involved a military commander assisted by a civilian scientific director. The commander was Major General Percy W. Clarkson, USA, Deputy Commander of US Army Forces in the Pacific, who, in turn, reported to the US Army Chief of Staff, Executive Agent for Operation CASTLE. Dr. Alvin C. Graves, Field Test Division (J-Division) Leader at Los Alamos Scientific Laboratory, was scientific director.² The task force was divided into five task groups (TGs). TG 7.1, led by Dr. William Ogle of Los Alamos, was responsible for all scientific operations. The military services were represented by TG7.2, the Army contingent commanded by Colonel Edward H. Lahti; the TG7.3 Navy task group commanded by Rear Admiral Henry C. Brunton; and the TG7.4 Air Force element commanded by Brigadier General Howell M. Estes, Jr. Mr. James E. Reeves, of the US Atomic Energy Commission's (AEC) Santa Fe office, was in charge of TG7.5, the civilian contractor group.

The JTF took care to thoroughly document its activities and operations, with the twin goals of providing a complete historical record, and of protecting the US Government from unwarranted legal claims and actions. The numerous formal and informal reports, memoranda, movies, press releases, letters, notes, communication messages, artwork, and personnel records collected and archived by the task force allow many decisions and activities to be thoroughly investigated and assessed. This report is primarily limited in scope to the intentions and operations of the JTF as disclosed through official records and documents.

¹ The atomic bombs dropped at Hiroshima and Nagasaki were combat strikes, not test detonations.

² The fact that Dr. Graves was a Los Alamos employee had no bearing on his JTF responsibilities and authorities, a fact he made scrupulously clear to other laboratory staff members (Campbell 1985).

Soon after the BRAVO test, Brigadier General Kenneth Fields, the AEC director of military application, sent a message to General Clarkson and Dr. Graves apprising them of current developments in Washington. He anticipated “being pressed by higher authority for an explanation regarding the circumstances that led to the exposure of the natives.” The overall intent of this document is to provide such explanation. General Clarkson is shown speaking with Utirik and Rongelap natives in Figure 1-2.



Figure 1-2. General Clarkson (left) visits with Kabdo of Utirik and John, the magistrate of Rongelap. Admiral Clarke, commander of Naval Station Kwajalein, is on the right. Naval Station Kwajalein, 5 March 1954.

1.1 The Marshall Islands and the Pacific Proving Ground

During the 12 years from July 1946 to August 1958, the United States conducted 67 nuclear tests in the Marshall Islands area of the central Pacific Ocean (DOE/NV-209 [2000]). The PPG was established in 1947 at Eniwetok Atoll³ as the site for nuclear weapons development tests to be conducted by the newly established AEC. The US Navy had previously conducted the two Operation CROSSROADS nuclear weapon effects tests in the lagoon at neighboring Bikini Atoll. The more isolated Eniwetok location was selected as the AEC proving ground because the available land area on the Bikini Atoll islands was too small to support the testing operations envisioned. In the spring of 1953, the PPG was expanded to include Bikini, and both locations were thereafter used for nuclear testing.

The Marshall Islands are geographically composed of two island chains, each extending nearly 600 mi from north–northwest to south–southeast. The eastern Sunrise, or Ratak, and the western Sunset, or Ralik, chains are separated by roughly 120 mi.

The PPG encompassed the northern end of the Ralik island chain. All of the five single islands and 29 atolls in the Marshall Islands group are low islands, or coral atolls, rising only a meter or two above high-tide levels; the highest natural elevation in the Marshall Islands is but 23 ft. An aerial view of Rongelap Atoll is shown in Figure 1-3.

The atolls were formed by the sustained growth of coral reefs atop slowly subsiding submarine volcanic platforms, in the manner first described by Charles Darwin (1842). Atoll islands are normally situated on the fringes of shallow lagoons, and are composed mostly of coral sands and shell fragments. The atolls and their islands are affected greatly by changes in ocean level as global ice ages wax and wane. During the long glacial periods, the ocean level drops so much that current-day lagoons may become dry land, while during the short episodes of globally warm, interglacial climate, rising seas often engulf the islands (Ristvet 1987). The current-day total land surface of all 1150 individual islands and islets in the Marshall Islands amounts to only 70 mi² (45,000 acres) of dry land.

³. Morison (1951) believed “Eniwetok” to mean “Land between East and West” in reference to the geographical location at the extreme end of the Ralik island chain. Hines (1962) reported that linguistic experts at the Bishop Museum in Honolulu felt that the meaning of the name was not really known. Subsequent research resulted in the place name being changed to “Enewetak.” To avoid confusion with historical records, the version in common usage during the period of nuclear testing is used throughout this document.

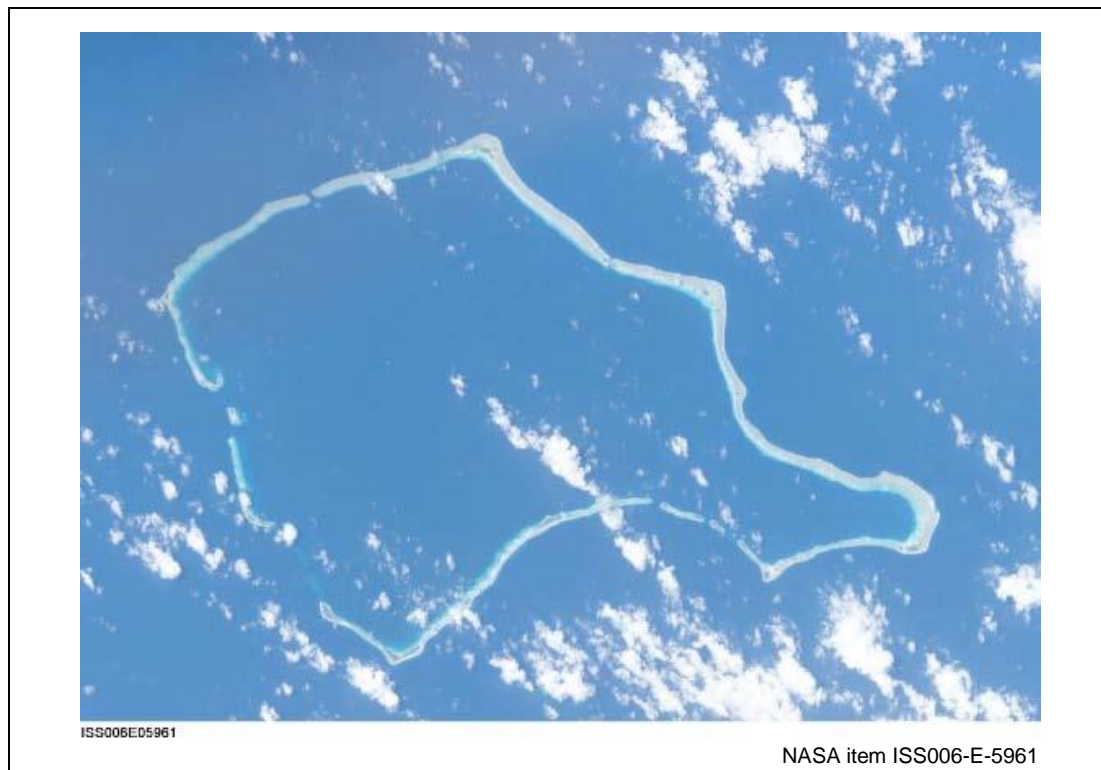


Figure 1-3. Rongelap Atoll photographed from the International Space Station

Located between 4° and 13° north of the equator, the climate of the Marshall Islands is tropical. The monthly mean temperature varies from 80 to 83 °F, with a diurnal range of less than 10 °F, with high humidity. The surface weather most often involves brisk northeast trade winds. Rainfall is generally plentiful, with frequent rainsqualls and thunderstorms during the summer months. The southern islands are wetter than those in the north, where there is a pronounced dry winter season, during which, water scarcity is a problem. Typhoons can cause great surface damage and beach erosion to the sandy islands, especially if they strike at high tide. While they may develop at any time, typhoons are most frequent in the late summer and early fall. Seismic sea waves (tsunamis)—induced by distant volcanic eruptions, earthquakes, or submarine landslides—can potentially cause catastrophic damage. However, the beach run-up conditions needed to turn sea waves into massive shore breakers are, fortunately, rare in the Marshall Islands.⁴

⁴. See Barney (1952) for a colorful and educational account of the “great tsunami” of 5 November 1952.

The normally abundant rainfall allows tropical vegetation to flourish even in the poor island soils. In their natural state, many islands are covered with coconut, breadfruit, and pandanus trees, as well as halophytic (“salt loving”) stranded plants, such as sea lavender (Sachet and Fosberg 1955). In response to the rainfall pattern, the southern islands are generally more verdant (Figure 1-4). The lagoons and other shallows are home to marine plant life typical of the tropical Pacific, and the waters abound in tropical marine fauna. Marine and shore birds are numerous, but land birds are rare. Various insects were established on the islands, but no mammals or large land animals were living ashore prior to the arrival of the Polynesian settlers.



Figure 1-4. Windswept trees on Majuro Island

Armed with the then-new technology of outrigger-stabilized canoes, ancestral Austronesian settlers first pushed out of the South China region about 5600 years ago. Island-hopping south through the Philippines to Borneo and then eastward through Java and the Bismarck Archipelago, the advancing wave of new settlers honed the technology of long-distance voyaging, and developed expert skills in open-ocean navigation. Leaving the Solomon Islands, the Polynesian migration swept eastward across the previously uninhabited island groups of the mid-Pacific, reaching the Santa Cruz Islands and Fiji, south of the Marshall Islands, approximately 3200 years ago. Around 1500 years ago, the first of successive waves of settlers and then invaders ventured north from the Marquesas to reach Hawaii. Nearly every inhabitable island in the tropical and subtropical Pacific had been colonized by the time Europeans first reached the area.⁵

⁵ The dates in this historical sketch are drawn from the information presented in *Speedboat to Polynesia* by Jared Diamond (1997).

The exact date when humans first arrived in the Marshall Islands is not well established. If the interglacial sea level was sufficiently low to allow dry land and if Polynesian navigational practices had been fully developed by such an early date, then the islands might have been first settled two to three thousand years ago. Although the history is still somewhat a matter of conjecture, it is certain that Polynesian settlers had made the islands and atolls their home for many hundreds of years before the first European ventures into the area. The meager natural resources allowed the existence of only subsistence economies. Communities of perhaps a few dozen inhabited many of the more isolated islands and atolls, and many more were entirely uninhabited. Roughly 70% of the dry land was suitable for cultivation using traditional methods. The average population density seems to have been roughly 185/mi² (OPNAV P22-100-M [1951]), suggesting a total population of perhaps 10,000 throughout the two chains of islands.

Spanish sailors first chanced upon the Marshall Islands in 1529. Although Spain claimed sovereignty, no concerted effort was made to include the remote and economically profitless islands into the colonial regime. The next centuries brought little contact with the European world, and the tiny island groups were effectively lost to Western history until discovered once again in 1788 by Captain William (or John) Marshall, commanding the English merchant vessel *Scarborough* in the employment of the East India Company. Explorers, traders, whalers, pirates, and missionaries gradually arrived, bringing with them diseases to which the indigenous inhabitants had little immunity or protection. The people were stricken by the medical scourges that killed many of the original inhabitants of the Pacific islands (Diamond 1997). Several previously populated atolls may have become entirely uninhabited.

European colonial powers contested sovereignty during the nineteenth century. Because German traders were active in the area, Germany proclaimed a protectorate in 1885. Counterclaims by England and Spain were addressed by negotiation, and in 1886, the Marshall Islands were formally ceded to Germany by the European powers. The German government had, by then, negotiated the Treaty of Friendship between the Marshallese chiefs and the German Empire (Spennemann 2000b). Subsequent German administration, although autocratic, was moderate and efficient. "Every encouragement was given to the development of trade and the expansion of production. Emphasis was placed on economic exploitation for the benefit of Germany, but it was tempered by a policy of enlightened self-interest," (OPNAV P22-100-M [1951]). The principal economic product was copra, or sun-dried coconut meat, which was commercially valuable first as the source of coconut oil, and then as raw cellulose for products ranging from animal feed to plastics and gun propellants.

At the onset of the First World War, German Vice-Admiral Graf von Spee, in command of the East Asiatic Squadron, assembled his ships and fled the China coast for the vastness of Micronesia. The small German fleet coaled and provisioned at Eniwetok from 19 to 22 August 1914. From here, von Spee sent his auxiliary merchant cruisers to raid in Australian waters, while taking his heavy warships to Majuro, where the squadron lay at anchor in the lagoon when Japan declared war on 27 August. The German force quit its base and moved eastward across the tropical Pacific, raiding ports and cutting submarine communication cables along the way. By early October, von Spee was operating in the busy sea lanes off western South America, where, on 1 November, he annihilated a British cruiser force at the battle of Coronel. His luck drew to an end on 7 December when a raid on the British coaling station at the Falkland Islands turned up not what the merchantmen had anticipated, but, rather, Admiral Doveton Sturdee and battle cruisers from the British Grand Fleet sent to hunt him down. Sturdee had the great ships make ready for sea, sat his men to a good breakfast, and then chased down von Spee and destroyed the German squadron.

To prevent their further use by the German cruisers and commerce raiders still operating in the Pacific,⁶ the Japanese Navy took military possession of the Marshall Islands. Japanese military control and administration continued throughout the war years. Following the negation of German claims by the Treaty of Versailles, the Japanese requested authority under the Mandates System of the League of Nations. On 17 December 1920, the Council of the League of Nations granted a Class “C” mandate, and Japanese military administration was replaced by Japanese civil administration through the South Seas Islands government (*Nanyo-Cho*).

The early years of the Japanese mandate saw unprecedented productivity from the island economies. As had the Germans before them, the Japanese continued to set aside certain atolls, usually in the rainier southern portion of the archipelago, for use as copra plantations, and copra production soon reached an all-time high. There were no handicraft or tourist industries. Increased economic productivity was made possible partially by the Japanese policy of complete and direct rule, with no participation by the native people in their own government or civil administration. Japanese law was enforced. Yet by all accounts, the people were well treated by the South Sea Islands government. A particular benefit provided under the mandate was medical care. A program was established whereby promising young men from each inhabited atoll were sent to Japan for education and medical training. The corps of Indigenous Medical Practitioners and Dental Practitioners provided primary care throughout the area, with the assistance of Japanese medical personnel.

⁶ Commerce raiders produced disruptions in commercial sea traffic entirely disproportionate to any actual threat. The auxiliary merchant cruisers *Wolf* and *Seeadler* were particularly effective in the Pacific in 1916–1917. Lowell Thomas’s 1927 action-adventure classic *The Devil of the Sea* recounts the exploits of Count Felix von Luckner commanding the old sailing sloop *Seeadler*.

Article 22 of the League of Nations covenant forbade any military use of the mandated islands or their inhabitants. In 1933, Japan gave two years' Notice of Withdrawal, and on 27 March 1935 seceded from the League. Questions as to the fate of the mandated islands were answered by Japanese declaration that "... under no circumstance would any other nation be allowed to control the islands." In early 1937, Japan placed the South Seas Islands under administrative control of the Imperial Navy, and then prepared a last annual report to the League of Nations. The Marshall Islands area became a military exclusion zone. No foreigners were permitted to visit, no vessels were allowed to call at the ports, and no courtesy visits by military forces were received. The civilian economy ground to a halt, and preparations began for use of the islands in the coming war.

The Marshall Islands presented a military frontier to be breached before hostile forces traveling west across the Pacific could engage the Japanese Imperial Army in Asia or move against the Japanese home islands. Military construction began in earnest in November 1940. During the following 3 years, airfields were built on Engebi Island, Eniwetok Atoll; Roi-Namur Islands and Kwajalein Island, Kwajalein Atoll; Otdia Island, Wotje Atoll; Taroa Island, Maloelap Atoll; and Mili Island. These are about the only natural landmasses in the Marshall Islands of sufficient size (at least 6000 yd in length), and of proper orientation with respect to the prevailing surface winds, to support heavy air operations. Japan responded to prewar rumors by claiming these airfields were for "cultural purposes" to benefit the civilian population. Korean and Okinawan laborers and other noncombatant personnel were transported to support the Japanese military garrisons. Additional labor was provided by local people who were "[forced] to labor on 'cultural' runways for a very low wage, and kept at work under pain of severe beatings" (Morison 1951).⁷

Kwajalein was particularly well fortified and defended, and by 1943 had become one of the major Japanese bases in Micronesia. Nearly 9000 imperial troops were deployed in an extensive network of bunkers and fighting positions on the major islands in the northern and southern portions of the atoll. Another 11,000 men were stationed in the three garrisons at Wotje, Maloelap, and Mili airfields. Eniwetok, which until late 1943 was used only as a base for refueling transient aircraft, was at first only lightly defended. Anticipating attack, on 4 January 1944 the 2600 men of the 1st Amphibious Brigade of the Imperial Japanese Army were deployed to Eniwetok. The remaining atolls were fortified much less extensively.

⁷ The propriety of these labor conscripts was considered at the Tokyo War Crimes trials. The Tribunal was not convinced by Japanese claims that forced labor on the airstrips and military bases "enhanced Micronesian culture."

In late January 1944, the Allied Forces invaded the Marshall Islands. The amphibious landing operations were preceded by air and naval bombardment of the six airfields, eliminating the aircraft, destroying the runways and support facilities, and giving the Allies complete control of the air. Majuro was the first atoll to be taken. It was assaulted not because it was a military stronghold, but because the US Navy required a fleet base and anchorage in the Marshall Islands, and, as it had for the Germans, this placid deep-water lagoon fit the bill. A small amphibious unit, designated the Majuro Attack Group, secured the atoll without loss of life on 31 January 1944. Preinvasion intelligence had indicated that the atoll was only lightly defended, and upon landing, it was discovered that the Japanese military contingent had withdrawn entirely in order to concentrate forces at Kwajalein.

Kwajalein Atoll also was invaded on 31 January, in an ambitious two-pronged amphibious assault known as Operation FLINTLOCK. Here, however, fierce military resistance was encountered. The Northern Attack Force took on the islands of Roi-Namur, where Imperial Navy Captain Seiho Arima had been ordered to instruct the 3563 island defenders to fight to the last man. The Southern Attack Force was directed at the naval facilities at Kwajalein Island and the seaplane base at nearby Ebeye Island. Over 5000 (5112) defenders manned an array of fortifications. Following intense bombardment at close range by 5th Fleet battleships, most of the defenders and fortifications of the northern islands were eliminated, and the US 4th Marine Division took only 26 hours to secure Roi-Namur. The Japanese did, in fact, fight to nearly the last man; there were but 51 taken prisoner. An equally impressive display of naval firepower took place in the south, where seven US Navy battleships shelled the islands for 2 full days, denuding the landscape,⁸ but neither killing nor demoralizing the majority of the defenders. The US Army 7th Infantry Division fought in intense combat for 6 days to seize and secure the two islands. “The extreme toughness of the struggle again proved the amazing survival power of Japanese troops and installations under naval gunfire and air bombardment” (Morison 1951, 272). The Japanese defenders again fought to the last man, with only 49 survivors. Of the 41,000 invading American troops, 372 were killed and 1582 were wounded.

⁸. See Morison (1951, 262) for “before” and “after” aerial views of Kwajalein Island.

The Eniwetok Expeditionary Force commanded by Rear Admiral Harry Hill invaded Engebi Island on 17 February 1944. Opposing Operation CATCHPOLE was Major General Yoshima Nishida, commanding the tough veterans in the 1st Amphibious Brigade, who dug in his troops and ordered the men to die in battle. The local inhabitants, numbering fewer than a hundred throughout the atoll (Heinl and Crown 1954), took to the woods as best they could. The assault was preceded by a bombardment that started with air strikes and naval gunfire on 30 January and continued almost unabated until landing craft approached the beaches. Having just witnessed the staying power of Japanese troops and fortifications at Kwajalein, preinvasion bombardment was taken to a new level of severity; over 3000 tons (3 kt) of bombs, shells, and rockets pounded the meager terrain (Figure 1-5). The 22nd Marines took only a day to secure the remains of the island.



Figure 1-5. The effects of preinvasion bombardment on Kwajalein

Due to intelligence shortcomings, it was not until nearly invasion day that the allies realized the Japanese occupied Eniwetok Island, but it was then added to the list for destruction. Although the battleships were busy rearming, having expended all of their nearly 1 tn projectiles in the bombardment of Engebi, Navy heavy cruisers and Army artillery emplaced on the neighboring islets blasted Eniwetok Island for two full days before landing on 19 February. It took an entire day and a hellish night of fighting for the Marines to overcome the 808 island defenders. By 20 February, the three battleships of the Fire Support Group were back in action, and they spent the next days firing boatloads of shells into Parry Island, while Army heavy artillery and Navy bombers also pounded the target. The tiny island and its 1347 defenders were hit with roughly 5 kt of explosives. “After the final bombardment, at daybreak 22 February, the entire island appeared to be blowing up; eyewitnesses wondered whether there would be anything left” (Morison 1951). Even with this ferocious preliminary, a full day of intense fighting was required for the attacking Marines to overrun the Japanese defenders.

During the fight for Eniwetok, the 8000 American officers and men of the expeditionary force lost 195 (killed or missing in action) and 521 were wounded. The total cost to the Japanese defenders was 2677 killed and 64 taken prisoner. Refer to Crow and Love (1955) and Heinl and Crown (1954) for a complete description of the seizure of Eniwetok.

The Japanese airfields and garrisons at Wotje, Maloelap, and Mili, and the seaplane base at Jaluit were not invaded. Because these locations could be effectively controlled by air strikes and naval bombardment, the four remaining Japanese bases were “leapfrogged.” “The only interest that the Pacific Fleet had in them was the negative one of neutralization. Not wanted for military purposes, they were not worth the American lives that would be expended in taking them” (Morison 1951). The Japanese-controlled islands effectively became little more than live-fire targets; during the remainder of the war, 10.4 kt of bombs and 1.9 kt of shells were lobbed their way (Spennemann 2000a). “[The Japanese] worked hard on building defenses until mid-1944, after which they were mainly concerned with fishing, growing gardens, and hunting rats for food” (Morison 1951). The four Imperial garrisons had no intent of surrendering, and remained in their positions “ever fewer and more feeble, their ranks thinned by disease, starvation, and the eating of poisonous fish” until the end of the war. By the September 1945 surrender, only 4785 survivors remained of the original 11,495 men. A US Navy photograph portrays the gaunt images of Japanese Naval personnel at a Marshallese hospital in Figure 1-6.



US Navy Photograph 80-G-347131

Figure 1-6. Emaciated Japanese Naval personnel
Photographed at a Japanese hospital in the Marshall Islands,
15 September 1945. Location unknown, but probably Wotje or Maloelap atoll.

The local populations of the leapfrogged atolls were not entirely happy with sharing their homelands with the starving Japanese. In September 1944, the Navy learned that the situation on Wotje had reached the point where the native islanders wished to leave. Two small craft were dispatched to neighboring Erikub Atoll, and, under cover of darkness, native scouts led the evacuation of over 700 men, women, and children from the Japanese-occupied atoll. In March 1945, an additional 452 people were evacuated.

The small Japanese military contingents on the remaining islands and atolls were “mopped up” during March and April by the 22nd Marine Regimental Combat Team, with a slight assist from the 111th Infantry Regiment. Civil affairs officers, medical personnel, interpreters, and native scouts from Kwajalein augmented the combat forces. The officers were ordered to “instruct the natives in the war situation and their changed sovereignty” and to “assist them in any way practicable economically, and establish relations of friendliness and good will.” With the exception of short, but sharp engagements with remnant forces at Ailinglapalap, Utirik and Ujelang, these forays to enemy territory were of little military concern, and soon became a combination of fleet amphibious operations training and recreation activity. After rounding up or accounting for whatever Japanese defenders there may have been, the junior naval officer in charge of the expeditionary force would read a greeting and proclamation from Admiral of the Fleet Chester Nimitz, while the Marines would picnic and trade for souvenirs. With the exception of Lae Atoll, where a child had recently been killed by the explosion of a hand grenade washed ashore in a wooden box, “[t]he natives were uniformly friendly, joyfully assisting the Marines in hunting down stray Japanese.” “The flag was duly raised, and the naval force departed, [returning to base] gorged with glory, good spirits and souvenirs” (Morison 1951). Refer to Crow and Love (1955) and Heinl and Crown (1954) for a detailed account of the military occupation of the lesser Marshall Islands.

The Allies made prompt use of their new territories in the central Pacific. Kwajalein Island was rebuilt and greatly enlarged, and became the center of US Army air power in Micronesia. Majuro remained in use as a fleet base and anchorage in which the fast carrier groups of the Pacific Fleet would rest and refuel between combat sorties. A short airstrip was constructed on Dalap Island, and nearly 5000 men were soon based at Majuro. The principal islands of Eniwetok Atoll had been essentially wiped clean in the fighting. “Engebi was more nearly pulverized before the landing than any object taken by an amphibious force in 1944.” “The once-verdant coconut grove [at Parry Island] was a scorched-earth of ruins and blasted tree trunks with a few dying palm fronds clacking miserably in the tradewind” (Morison 1951). Having been largely stripped of natural landscape by warfare, Navy construction battalions moved in and completed the job with bulldozers. By the end of March, Eniwetok Island was so covered with new buildings that all traces of battle had been obliterated. By the end of February 1944, the airbase at Engebi was rebuilt and an additional bomber runway was soon added. Eniwetok was used extensively as a staging area during the military campaigns in the Marianas and Philippines in middle and late 1944. Over 100 warships and support vessels were known to lie at anchor in the lagoon. During the final months of the war, construction projects were begun to expand the carrier-aircraft service-unit facilities at Parry Island and to build a fleet recreation area for 35,000 men.

After the defeat of the Imperial military forces and the collapse of the Japanese naval government, the US Department of War administered the Marshall Islands as Occupied Enemy Territory. In accordance with prevailing international law, all non-Allied personnel were initially considered “captured Japanese subject” prisoners of war. Legal review soon permitted indigenous civilians to be reclassified as “liberated persons,” and in April 1944, a US Navy military government was established to provide for their care. The situation for some was dire. “The condition of the people of the few islands where landings had been made indicated the magnitude of the problem awaiting military administration. The natives were in a state of mental shock. Most of them had been in the midst of the fighting or had experienced its repercussions. Their industry and trade was gone and they were forced to return to a subsistence economy. They had been displaced from their homes and gardens and fishing grounds. Their food had been confiscated. They had had little medical care for years. Schools had been non-existent since the war began. Everywhere there were dislocations and deprivations.”

“[US Navy] military government policies and activities were based on the assumption that the indigenous inhabitants should be treated as liberated people. The immediate problem was to furnish the people with food, water, clothing, shelter, and medical attention” (OPNAV P22-100-M [1951]). The liberated population greeted the change of regime with enthusiasm. The people were allowed to return to civilian life, and were no longer pressed into “menial service on distant atolls.” Navy construction and engineering battalions erected shelter, as necessary, and refurbished or installed basic sanitation facilities. Food and water were provided from naval stores. By April 1944, welfare inspections were being routinely conducted throughout the islands. Special Navy units comprised of marines, civil affairs officers, and medical doctors visited each populated atoll every 2 weeks.

Following the conclusion of hostilities in September 1945, the US Navy continued to administer the Marshall Islands under the Terms of Surrender. Most of the resident Japanese citizens, and the Korean and Okinawan laborers were repatriated. To provide a corps of knowledgeable personnel with which to staff the Navy military government, Stanford University established a special school to train serving officers in civilian administration of the former mandated islands, graduating the first class in August 1946.

The end of the war was accompanied by dramatic interest in the military potential of atomic weapons. While the combat strikes at Hiroshima and Nagasaki had clearly demonstrated the capabilities of low-yield nuclear weapons⁹ against urban-industrial targets, their effectiveness in other military applications was a matter of conjecture. “On 25 August 1945, Senator Brian McMahon, latter chairman of the Senate Special Committee on Atomic Energy, suggested that the new weapon be tested against naval vessels. On 14 September, an Army spokesman in Tokyo proposed that atomic bombs be used to destroy the Japanese fleet” (Hines 1962). By November, the Joint Chiefs of Staff had established a special committee to investigate the potential usefulness of atomic bombs for engagement of naval forces. Only 2 months later, on 10 January 1946, President Truman approved the creation of Joint Task Force One with the mission of conducting such tests at the earliest possible date.

The search for a suitable nuclear test site was underway even before the president had approved the concept. A protected anchorage with a reach of at least 6 mi, and within 1000 mi of a heavy bomber base, was required, and a location with mild and reliable weather was desired. It was necessary that the site be extremely remote and only sparsely populated, or, more preferably, uninhabited. After review of potential locations in the Atlantic, Caribbean, and Pacific, Bikini Atoll¹⁰ was selected as the most feasible site for the Navy nuclear tests. While Eniwetok was perhaps a better location, being somewhat more isolated and already possessing several airfields, it was still in use by the Navy.

Unlike so many of the islands of the central Pacific, Bikini had been largely untouched by the war.¹¹ The only military installation had been a small Japanese weather observation station, and the five-man garrison committed suicide as the atoll was liberated on 30 March 1944, thus obviating combat operations. In addition to being a nearly pristine environment, another significant disadvantage with Bikini as a nuclear test site was private ownership by the 162 people living there. The landowners would need to acquiesce to Navy use, and then be compensated and relocated. Discussions with the traditional and administrative island leaders took place, and it was only after their consideration and approval that the decision to relocate was reached.

⁹. Atomic weapons are generally grouped into four yield classes. From 1 to 20 kt is “low yield,” 20 to 150 kt is “intermediate yield,” and above 150 kt is “high yield.” Battlefield weapons with yields of less than 1 kt are generally referred to as “subkiloton.”

¹⁰. Morison (1951) states that the name *Bikini* means “fanned by palms.” The swimsuit was named for the nuclear tests conducted at the atoll.

¹¹. Although the island environment was little changed, the behavior of the Japanese occupation garrison had a profound effect on the island inhabitants.

Although Navy personnel exercised what they believed to be great care and consideration in arranging for use of the atoll as the site for American nuclear tests, the ensuing discussions were essentially those of a powerful nation asking a favor from a small, nonnational group recently liberated from a cruel and hated mandate. What might not have been adequately considered, or even known by the Americans, is that in traditional Marshallese culture, there is no way to turn down such a request (Brownlee 1994). “In traditional fashion, [the people of Bikini] did not make their feelings plain in a situation where they lacked power” (Firth 1987).

Being offered a choice of several possible “temporary” homelands, the Bikinians chose Rongerik Atoll. Although uninhabited, this atoll was owned and visited occasionally by the people of Rongelap. Nevertheless, Navy construction battalions built an island village, and on 6 March 1946, the exodus to Rongerik was undertaken amidst international press coverage. Although billed by the Navy as “a model village . . . that anyone would be proud to live in,” it was a village on a small island of a remote and unprosperous atoll. The new colony did not thrive. Castaway in a location of marginal agricultural and marine value, and in a setting believed to be imbued with supernatural bad spirits, the people were unhappy and malnourished. In May 1947, a fire destroyed the major portion of the coconut trees, and by early 1948, the people were “actually and literally starving to death.” It was soon necessary to relocate the Bikinian community to Kwajalein Island on 14 March 1948, where they endured life in a tent city near the edge of a busy runway. In June, the group held an election to decide their future. On 2 November 1948, the now 184-person colony moved to Kili, a small, isolated island in the southern portion of the Ralik island chain lacking both a lagoon and docking facilities.¹²

While the Bikinians were attempting to settle into their new living situation on Rongerik, preparations for the Navy nuclear tests proceeded. By July 1946, some seventy-odd target ships had been moored in the lagoon, and the principal islands of the atoll, including the village on Bikini Island, had been bulldozed flat and covered with support facilities. Because the long-range pattern of radioactive contamination resulting from nuclear detonations in oceanic settings was totally unknown, the populations of Eniwetok, Rongelap, and Wotho atolls were relocated for the duration of the operation. More than 42,000 military, technical, and scientific personnel and observers assembled to witness what “unquestionably was the most thoroughly documented, reported, and publicized peacetime military exercise in history” (Hines 1962). “Eighteen tons of cinematography equipment and more than half of the world’s supply of motion picture film were on hand to record the [atomic] detonations, and also the movement of the Bikinians from their atoll” (Niedenthal 2003). Anonymous among the assembled throng was Soviet Commissar of Internal Affairs Lavrenti Pavlovich Beria, sent by Stalin to see if America really did possess atomic weapons.

¹² The website <http://www.bikiniatoll.com/interviews.html#anchor1266109> is recommended to the interested reader. This set of oral history interviews with Bikinian elders provides source accounts of many significant events in atoll history.

Events at Bikini culminated with the Operation CROSSROADS ABLE and BAKER atomic detonations. Dropped from a Boeing B-29 heavy bomber on 1 July 1946 (local time), the ABLE device detonated in the air 518 ft above the target fleet. Uncertainty in the aerodynamics of the bomb resulted in the intended target being missed by a distance of 1500 ft. The BAKER device was exploded underwater on 25 July (Figure 1-7). The resulting column of water dwarfed even the nearby aircraft carrier and battleships. Glasstone and Dolan (1977) provide a technical description of this shallow underwater burst. Perhaps overawed by the results of BAKER, a planned third test was cancelled. By August 1946, the Navy activities were largely completed. Bikini was placed in “interim” status, and a program of radiological observations was begun (Hines 1962).



Figure 1-7. CROSSROADS BAKER nuclear test

Atomic bombs withdrawn from the small US nuclear stockpile were used for the two CROSSROADS detonations. The purpose of the tests was not to evaluate or improve the atomic devices themselves, but, rather, to study the effects of the explosions on the Navy target ships. Because of the small amount of weapon data to be gleaned from the tests, interest was limited within the weapon design community at Los Alamos, where the expedition to Bikini was referred to somewhat disparagingly as “those Navy tests.” But by early 1947, the original wartime pace of nuclear weapon development was returning to Los Alamos, and it was apparent to laboratory scientists and management that additional nuclear tests would soon be necessary for the specific purpose of evaluating improved weapon designs.

Recognizing the need for civilian government in the Occupied Enemy Territories, on 6 November 1946 President Truman proposed to the newly formed United Nations that the former mandated islands be placed under United Nations Trusteeship, with the United States as the Administering Authority. After comment, review, and modification by the Member States, with a self-determination clause being added by the Soviet Union, the Security Council approved the agreement unanimously on 2 April 1947. On 18 July 1947, President Truman signed the Trusteeship Agreement and issued Executive Order 9875, delegating responsibility to the US Navy Commander in Chief, Pacific (CINCPAC), as High Commissioner of the Trust Territory. On this same day, the Secretary of the Navy formally disestablished the naval military government and passed administrative control to the high commissioner.

The AEC was established by the Atomic Energy Act of 1946 “subject at all times to the paramount objective of assuring the common defense and security.” Five commissioners were appointed by the president and reported directly to the Joint Congressional Committee on Atomic Energy. Scientific advice was provided by a nine-member General Advisory Committee (GAC) composed of distinguished American scientists, and several Nobel Laureates, while five general officers, appointed by the Secretary of War and the Secretary of Navy, staffed the Military Liaison Committee (MLC). The joint civilian-military Division of Military Application (DMA) provided liaison between the military services, the advisory committees, and the commissioners. On 1 January 1947, the civilian commission assumed control of the United States nuclear weapon research, development, and production program from the military Manhattan Engineering District.

Similarly, the secretaries of War and Navy established the Armed Forces Special Weapons Project (AFSWP), with Major General Leslie Groves as its first director. AFSWP was responsible for the military use of “atomic” weapons.

In the summer of 1947, Los Alamos Scientific Laboratory notified the commission that certain notional improvements in nuclear weapon design could be verified only by full-scale experimentation, and recommended a series of nuclear weapon development tests be scheduled in 1948. The general purpose of the proposed tests was to develop atomic weapons using smaller amounts of fissile special nuclear materials than previously used. In the spring of 1947, the number of weapons in the nuclear arsenal was limited by the availability of fissile material to 13 bombs. To expand the arsenal, it was necessary to make more efficient use of the material available, and this required testing. The commission, with the advice of the GAC and concurrence of the MLC, reviewed and endorsed the Los Alamos recommendations, and submitted the proposed test program to the president for approval.

Following presidential endorsement, the AEC began looking for a suitable test site. The initial thought, at least at Los Alamos, seems to have been a return to Bikini. The possibility of continued nuclear testing, and of other military operations, in the Marshall Islands area was allowed under the terms of the newly enacted United Nations Trusteeship. Whereas the League of Nations Mandate had forbidden all military activity and utilization, Article 5 of the Trusteeship stated that the “trust territory shall play its part . . . in the maintenance of international peace and security” and authorized the Administering Authority “to establish naval, military, and air bases and to erect fortifications” and “to station and employ armed forces in the territory.” Because the nuclear tests were said to be for “the good of mankind and to end all world wars,” the use of Trust Territory domain as a nuclear test site was viewed as allowable within the bounds of the Trusteeship. It seems always to have been envisioned by the US Government that these would be “islands with a military future” (Firth 1987). Representative Mike Mansfield is said to have remarked during the Congressional debate concerning the Trusteeship agreement that “We have no concealed motives because we want these islands for one purpose only, and that is national security.”

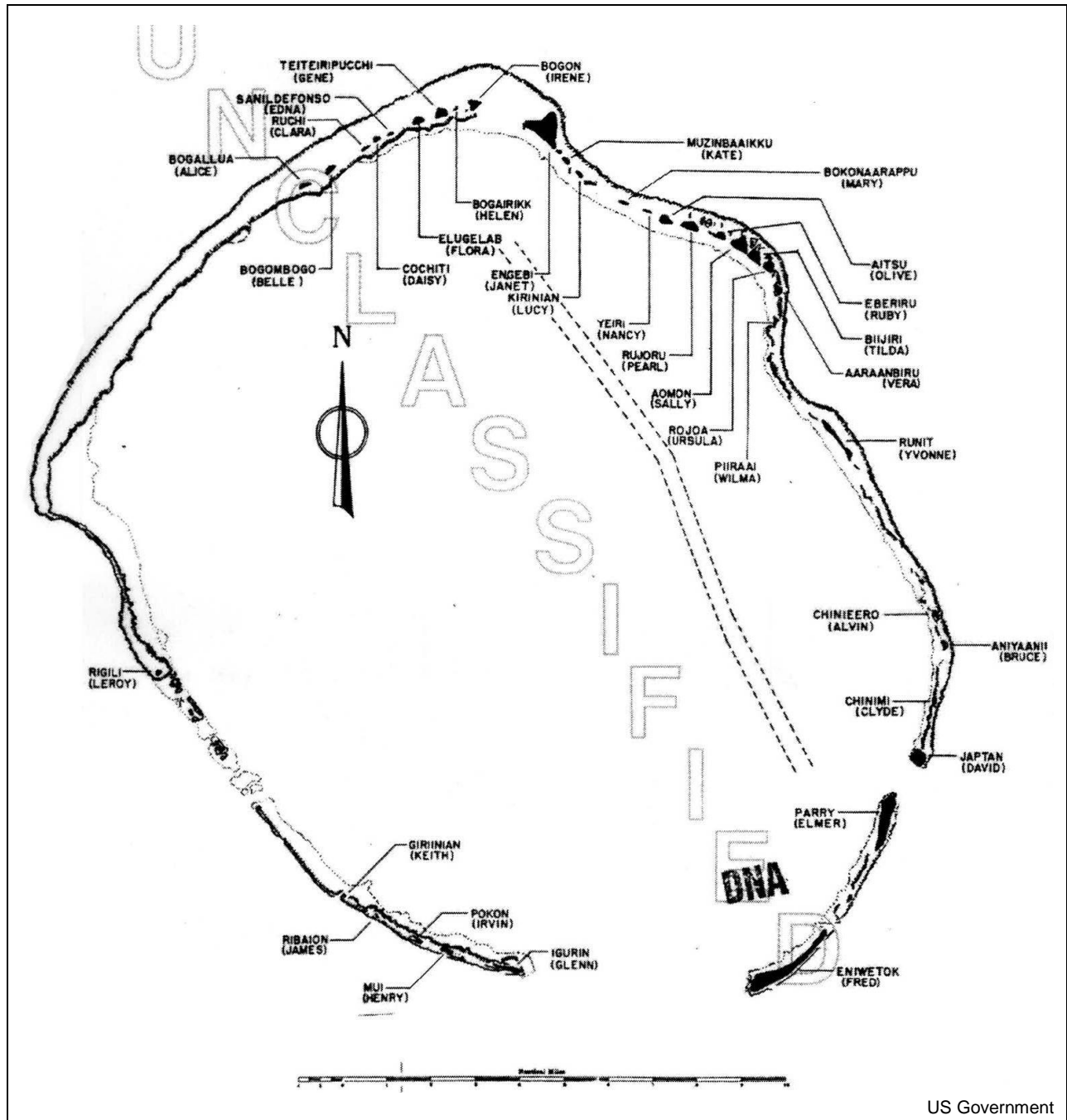
The available land area at Bikini, only 2 mi² spread over 26 separate islands and islets, was, however, too small to support the type of testing operations envisioned by Los Alamos, and the search began for a new location.

The AEC initially considered sites in the continental United States as well as locations in the Indian Ocean, the Aleutian Islands, and the Trust Territory of the Pacific Islands. Because President Truman opposed continental testing,¹³ the search rapidly narrowed to the islands of the mid-Pacific. Considering the available land and existing facilities, the best candidate locations were Kwajalein and Eniwetok. Further review convinced DMA Deputy Director Captain James S. Russell, US Navy, and Los Alamos Field Test Division Leader Dr. Darrol K. Froman that Eniwetok was the best choice. It was among the most remote locations anywhere on Earth (Figure 1-8). The Navy had largely abandoned the atoll, and the task force could have exclusive use of the already existing airfields and support facilities. The native people, long since relocated by the US Navy to alternate locales,¹⁴ would now need to be permanently relocated.¹⁵ However, the number of people affected would be far smaller than at Kwajalein, where several thousand people lived. Froman and Russell, who had wartime experience on Eniwetok, also may have believed that the islands and islets of this atoll, first ravished by combat and then engineered to meet the needs of the military, would be a more suitable nuclear test site than some less devastated location, such as Bikini. Their recommendation was accepted by the AEC Commissioners, and approved by President Truman on 2 December 1947.

¹³. Truman opposed continental testing not out of any health or safety concern, but, rather, for the political aim of adding to the awe and mystique surrounding nuclear energy by giving the impression to an international audience that atomic bombs were such potent weapons that they could not be safely tested in the “zone of the interior.” This is one time when government propaganda concerning atomic weapons intended to scare and mislead the Soviets proved more effective at scaring and misleading the American people.

¹⁴. “Secretary of Defense Robert S. Lovett recommends that the forthcoming news release on the selection of a proving ground at Enewetak ought to mention that the natives are not now living in any historic home but instead on islands to which US forces moved them during World War II” (Deines et al. 1990).

¹⁵. Los Alamos J-Division records indicate that by 1956, the task force believed reoccupation of Eniwetok would never be feasible following its use as a nuclear test site, and that Los Alamos scientists viewed the removal of the native people as a permanent separation and not a temporary relocation.



US Government

Figure 1-8. Eniwetok Atoll

In the fall of 1947, the leaders of Eniwetok were taken to inspect Ujelang Atoll as a possible relocation site. After being ravished by a typhoon that killed all but a few of the inhabitants, Ujelang had been purchased in 1880 by the private concern Jaluit Gesellschaft, and had thereafter been used by both the Germans and Japanese as a copra plantation. It was therefore uninhabited and held as public domain under control of the Trust Territory Alien Property Custodian. Ujelang also was being considered as a possible relocation site for the Bikinians, then languishing on Rongerik. On 21 December 1947, the 145-person Eniwetok contingent was moved to Ujelang, which proved to be a more practicable home than was Rongerik for the Bikinians. Despite the fact that the usable land area at Ujelang was only 274 acres, much smaller than the 1761 acres at Eniwetok, the Trust Territory Report to the United Nations for 1951 stated that “no difficulties have arisen in the adjustment of the Eniwetok people to life on Ujelang.” “The economic possibilities of Ujelang are similar to those of Eniwetok and the people are well content with the island” (OPNAV P22-100-M [1951]).

JTF-7 was established on 18 October 1947 with the mission to plan and conduct the 1948 Operation SANDSTONE nuclear test series. Construction of scientific and support facilities at Eniwetok began in December, and in only 4 months, preparations were completed for the three-shot campaign. The test devices were placed atop 200 ft towers, each on a separate atoll island. The 37 kt yield X RAY device was detonated at Engebi on 15 April 1948, followed by the 49 kt YOKE test at Bijiri on 2 May and the 18 kt ZEBRA shot at Runit on 16 May. In a harbinger of events to follow, traces of radioactive contamination from ZEBRA were detected at the Naval Station Kwajalein, 423 mi distant from the explosion site. The nuclear cloud evidently mixed with upwelling surface moisture, and a “rainout” of radioactive contamination was deposited by a passing squall. And for the first time, the term “fallout” was used in reference to radioactive particles from a nuclear cloud drifting downward to the Earth’s surface (Malik 1977).

Unlike the media circus surrounding CROSSROADS, Operation SANDSTONE was conducted entirely out of public view. Judging that the success or failure of the experimental atomic devices would markedly affect the international balance of military power, every effort was made to limit any knowledge of the technical objectives and results of the tests to those with an established “need to know.” While the security cocoon surrounding SANDSTONE may have achieved the intended objective of denying information to enemy nations, the restrictions in openness set a precedent that would adversely affect all subsequent test operations at the PPG.

Completion of the technical work at Eniwetok was followed by preparations to mothball the test site. Temporary buildings were burned, and artifacts or other physical evidence that might disclose the yields of the test devices were obliterated as best as possible. A 50-person military guard force was left to garrison the atoll.

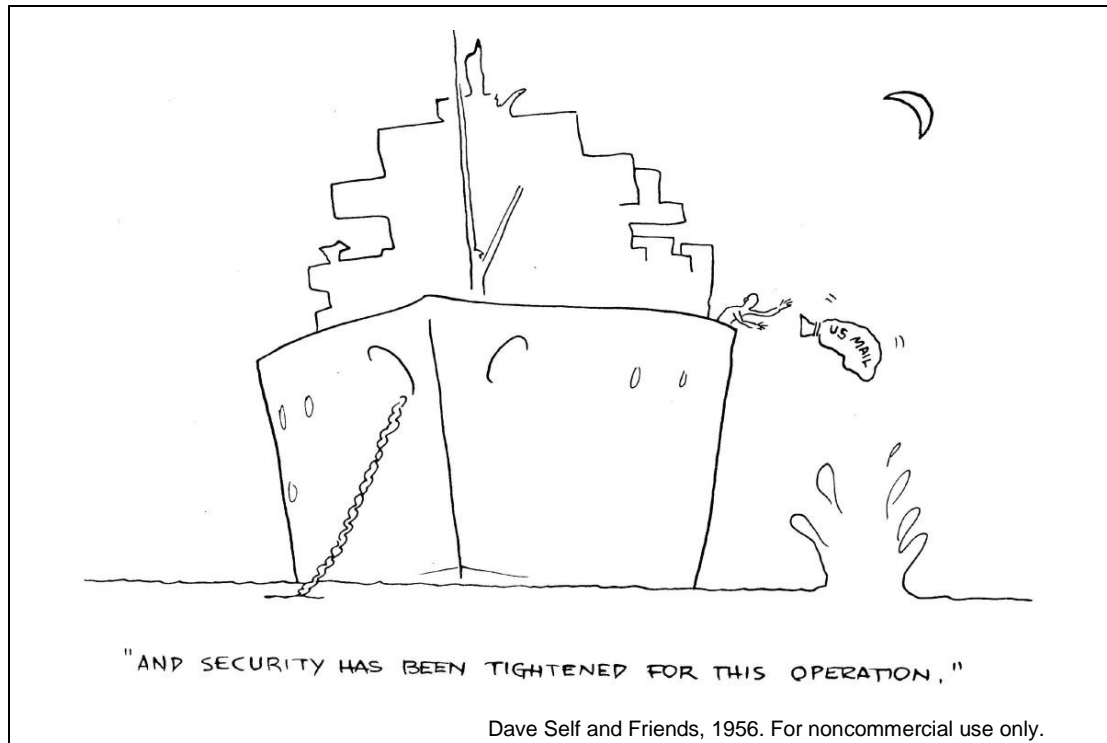


Figure 1-9. Cartoon from *More Minus than Plus*

Both Los Alamos and the AEC were interested in establishing a continental test site to be used for any further weapon development testing. “As successful as SANDSTONE was, logistics, weather, and security and safety concerns during the operation revived thinking about a continental test site. The logistical problems associated with transporting, supplying, and housing a nuclear testing task force in the middle of the Pacific were self-evident” (Fehner and Gosling 2000). Although Project NUTMEG, a scientific study of the necessary attributes for a continental nuclear test site, indicated that continental testing of nuclear devices with yields of less than 50 kt was technically possible, the AEC concluded in March 1949 that a continental test site was not desirable excepting in the case of “a national emergency.” The combination of the first atomic test by the Soviet Union on 29 August 1949 and the outbreak of the Korean War on 25 June 1950 constituted just the type of national emergency perhaps envisioned. Interest was renewed in a nuclear test site within the national boundaries of the United States. By December 1950, a portion of the Air Force Las Vegas Bombing and Gunnery Range north of Las Vegas, Nevada, had been selected by the AEC as its new test site. On 18 December 1950, presidential approval was obtained, and only 5 weeks later, the first nuclear tests were underway at the newly established Nevada Proving Ground (NPG).

The Soviet nuclear test of August 1949 had a profound effect on American thinking. Before this date, the United States had a qualitative military advantage in possessing a type of weapon not available to other world powers; afterward, the advantage was reduced to one of unknown and, therefore, doubtful numerical superiority. To counter the perceived threat, the president authorized programs to both increase the number of weapons in the US nuclear stockpile and investigate the possibility of developing a new type of nuclear device—a superweapon using thermonuclear fusion reactions to produce yields far larger than standard atomic bombs. The decision to develop thermonuclear weapons¹⁶ was extremely controversial, and it split the AEC into what can only be described as warring camps. The GAC, led by former Los Alamos Director Dr. Robert Oppenheimer, believed there was no valid military mission for superweapons. AEC Chairman Louis Strauss and key members of Congress argued that thermonuclear technology would be vital to maintaining the military balance, and feared the possible consequences should the Soviet Union unilaterally develop and deploy superweapons.¹⁷ On 29 January 1950, President Truman approved accelerated development of thermonuclear technology, and the Soviet-American “Race for the Superbomb” was on (Ott and Rhodes 1999).

Los Alamos and the “thermonuclear” group at Princeton University already had been conducting theoretical research into possible uses of thermonuclear technology in atomic weapons of all types and in the notional design of thermonuclear superweapons. By January 1950, the research was sufficiently advanced for Los Alamos to propose a set of tests to be conducted at Eniwetok in the spring of 1951. These tests would be directed not toward demonstrating any actual weapon, but rather at exploring some of the fundamental physics of thermonuclear processes and investigating needed improvements in fission weapon technology. Planning for the four-shot Operation GREENHOUSE test series was well underway when the Korean War erupted in the summer of 1950. Military planners were reluctant to commit resources to the JTF during wartime, and for a while it seemed that the series might be postponed. The AEC reevaluated the test objectives, but came to the conclusion that the shots were absolutely necessary to support the thermonuclear program. In mid-September, the Joint Chiefs of Staff, swayed by the AEC arguments and the Joint Committee recommendations, approved the required military resources, and test preparations commenced.

¹⁶ United States terminology is that a “thermonuclear weapon” produces more than half of its yield from fusion of light elements. The now-obsolete terms “superbomb” and “superweapon” were used to refer to very high-yield nuclear devices of all types. The technical terms are not interchangeable; thermonuclear weapons can be smaller in yield than superweapons, and superweapons do not have to be thermonuclear weapons.

¹⁷ The GAC and the chairman really were arguing about two different technical subjects, and both turned out to be correct. Superweapons with yields of tens of megatons, for which the GAC could envision no practical or valid military use, were a passing fad in nuclear weaponry, while the thermonuclear technology desired by the chairman is implicit in enduring weapon designs.

The GREENHOUSE tests were detonated atop towers at Eniwetok. The DOG shot of 7 April 1951 produced a yield of 81 kt, the largest atomic detonation yet. The record was, however, soon eclipsed. Following the 47 kt EASY test on 20 April, the GEORGE shot of 8 May gave 225 kt in the first experiment to explore the physics of thermonuclear reactions. The series ended on 24 May with the 46 kt ITEM test. The scientific results obtained from GREENHOUSE permitted rapid advancement of device concepts, and by the winter of 1951–52, Los Alamos had finalized plans for an experimental thermonuclear gadget. Should it function as envisioned, the yield would be 10,000 kt, or 10 Mt, with an outside possibility of 50 Mt. At design yield, the energy release would be 500 times larger than the atomic bombs then in stockpile. The test was assigned the shot-name MIKE. JTF-132 was established to conduct the Operation IVY test at Eniwetok in the fall of 1952, and preparations were soon underway to build and assemble the gadget, and then transport it and the necessary support, scientific equipment, and personnel to the PPG.

The vast energy release of the proposed thermonuclear detonation caused much concern about possible consequences. It was believed from the results of GREENHOUSE GEORGE that the blast and shock of the MIKE detonation could be satisfactorily mitigated into the vastness of the central Pacific. The potential for radioactive contamination would be proportionally large, and contract arrangements were therefore made with the AEC Health and Safety Laboratory in New York City to monitor and document the amounts of fallout radiation on islands and atolls throughout the central Pacific. Because the fallout characteristics of multimegaton bursts were entirely unknown, extreme caution was taken in radiological safety planning. All task force personnel were removed from Eniwetok Atoll before the shot, and the civilian population of Ujelang, the nearest inhabited locale, was evacuated to a landing ship transport.

But, in addition to the problems of heat, blast, radioactive contamination, and fallout on a scale never before encountered, MIKE would be sufficiently powerful to produce entirely new classes of potential problems never before considered. “The largest man-made geophysical event naturally created considerable curiosity and generated much speculation as to both immediate and ultimate effects. Chief among these was what seemed a remote, but real possibility that the explosion would trigger a submarine landslide at the edge of the atoll, and create a true tsunami (seismic sea wave)” (Bascom, Munk, and Van Dorn 1953). “Once such a wave is started it passes across thousands of miles of ocean basin with almost no loss of energy. The fact that there is a finite possibility of generating such a wave should make us exceedingly careful in our final planning for the IVY test” (Stephenson 1952).

The threat of explosion-induced tsunamis was considered at a special meeting held in Chicago on 9–10 September 1952, which involved, among others, Al Graves and Bill Ogle, the scientific leaders of the task force, along with R. R. Revelle, J. D. Isaacs and W. H. Munk of the Scripps Institute of Oceanography, Karl Terzaghi and Arthur Casagrande of Harvard University, and Juul Hvorslev of the Army Engineers Experimental Station. In the letter report from the Scripps scientists (JOL-7925 [1952]), they concluded, on the basis of the size of natural submarine slides then observed to have occurred at Bikini and other atolls, “that if a landslide should occur, the possibility of a destructive tsunami, although far from certain, can by no means be ruled out.” The consensus of the meeting was, however, that “the possibility of a shot-induced submarine landslide was too small to advise any major modification in the proposed test,” but that precautions should be taken to mitigate the effects of a possible tsunami, and to issue a warning in populated areas, if necessary.

A second “geophysical concern” was that small particles lofted by the heat of the detonation and suspended high in the atmosphere might reflect enough sunlight to cause cooling of the entire Earth. Major Norair Lulejian, USAF, and Hale Observatory astronomer Natarajan Visvanathan, studied this possibility in the fall of 1952 and reported their findings in two documents titled *Effects of Superweapons Upon the Climate of the World* (Lulejian 1952a, 1952b). These reports are the initial description of the “nuclear winter” theory that first received wide notice in the outside scientific community and the popular press nearly 30 years later. These studies indicated no appreciable chance of explosion-induced climate change.

The IVY MIKE test was conducted on 1 November 1952. The device functioned about as envisioned, producing a yield of 10.4 Mt. The explosion partially vaporized Elugelab Island and left a mile-wide crater in the reef. Measured amounts of radioactive contamination were puzzlingly small; most of the radioactive debris seemed to have disappeared from the face of the Earth, apparently dispersed into the uppermost reaches of the atmosphere. There were no adverse “geophysical consequences,” such as tsunamis or perceptible effects, on the weather or climate of the Earth; no nuclear test at a Pacific atoll would ever produce damaging seismic sea waves.¹⁸ To evaluate an alternative technical path to superweapons, a second detonation was added to the Operation IVY test series. The 500 kt KING test, 15 November 1952, demonstrated that high-yield devices could be manufactured using existing weapon technology. The test involved a militarily useful weapon and not just a notional design. The KING device was dropped as a bomb from an Air Force B-36D heavy bomber and exploded over Runit Island as an airburst detonation.

¹⁸ The French TYDEE test of 25 July 1979 at Mururoa Atoll in the Marquesas Islands caused a water wave (tidal wave) in the lagoon, which partially inundated the French support base and killed a worker. The wave occurred several hours after the detonation, and, evidently, resulted from the formation and flooding of a subsidence crater in the lagoon floor following collapse of the shot-induced cavity. The 8.3 Mt American HOUSATONIC airdrop test of 30 October 1962 detonated sufficiently close to the ocean surface in the broad-ocean area near Johnston Island to raise a true seismic sea wave, which produced damage in the Hawaiian Islands.

The successful test of the IVY MIKE device confirmed the scientific feasibility of superweapons. Weighing 80,000 lb, requiring cryogenic cooling, and occupying a three-story building, the MIKE device was not, however, a practicable weapon (Figure 1-10). On 12 August 1953, the Soviet Union successfully tested a half-megaton RDS-6s thermonuclear device, which “unlike the Americans . . . could be made in the form of a bomb, transported by a heavy bomber, and after finalization, could easily be put into series production” (Negin et al. 1995). In response to this advance, the pace of American research and development quickened. The Emergency Capability Program was established with the mission and presidential charter to produce a deliverable superweapon at the earliest possible date. Operation CASTLE, already envisioned as a Pacific test series in which experimental very-high-yield devices would be evaluated, was redirected toward establishing whether any of the notional designs could be made into an actual weapon and rushed into production.

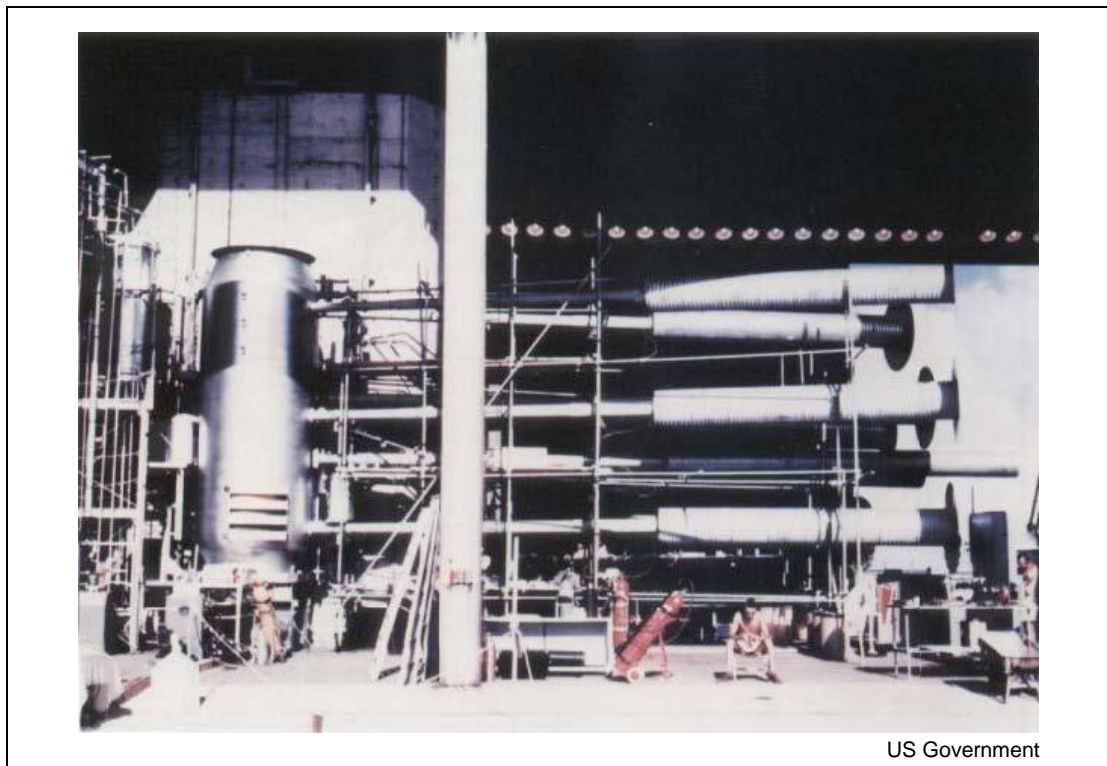


Figure 1-10. The IVY MIKE device

Because of the very high yields envisioned, it was evident from the start that CASTLE would take place at the PPG and not at the smaller confines of the NPG. Preliminary planning soon indicated that even the PPG was not big enough for CASTLE. The amount and extent of airblast damage and radioactive contamination resulting from the five or six multi-megaton explosions envisioned for CASTLE could not all be accommodated at Eniwetok. The atoll was just too small, and the atoll islands too close together and covered with too many support installations. Even before the MIKE test, the task force and AEC realized the need to expand the land area in the PPG in support of Operation CASTLE. In the summer of 1952, the Holmes and Narver Engineering and Construction Corporation (H&N) was contracted to survey Bikini Atoll for possible use as “an auxiliary proving ground.” In September, the AEC reviewed the H&N findings and recommendations, and concluded that it would be feasible for Bikini to be removed from “provisional” status and made part of the proving ground (Figure 1-11). On 2 April 1953, the AEC publicly announced that the PPG was being enlarged “to accommodate the rapidly expanding program of developing and testing new and improved nuclear weapons” and that “the United Nations is being notified by the Department of State that Bikini Atoll and its territorial waters have been closed for security reasons in accordance with the provisions of the Trusteeship Agreement.”

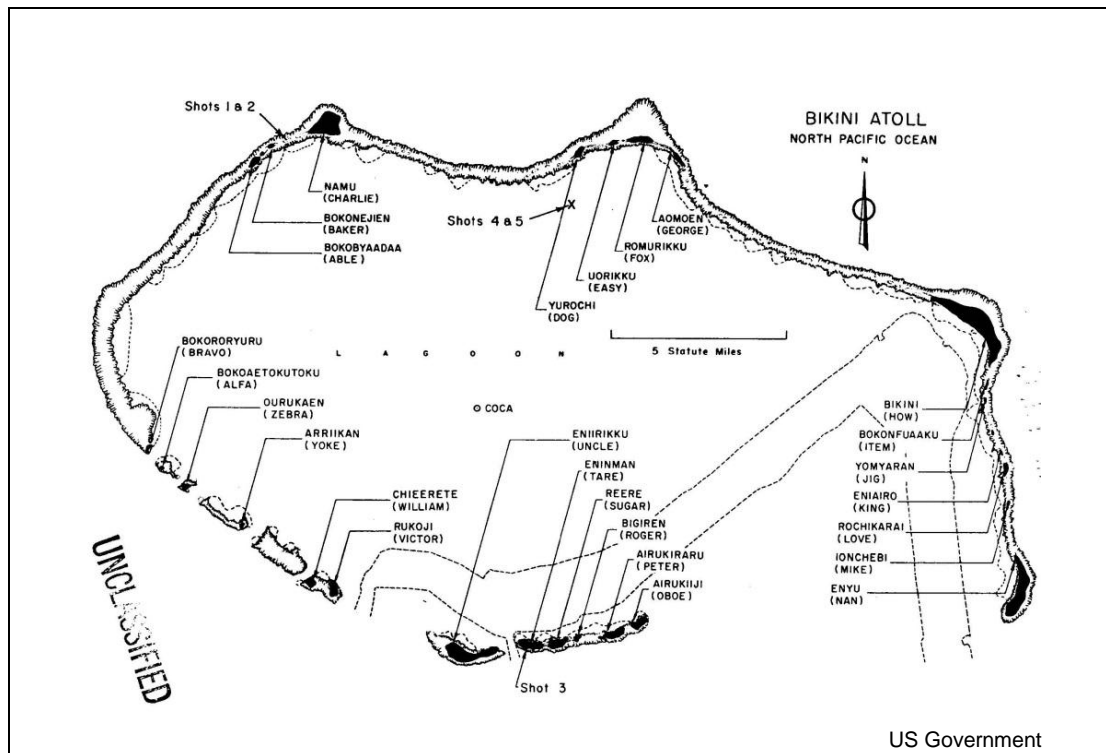


Figure 1-11. Bikini Atoll with the locations of the five nuclear tests conducted during Operation CASTLE. BRAVO was “Shot 1.”

Construction of task force facilities at Bikini Atoll began in the late fall, and by January 1953, a base camp on Eninman Island was well underway. During the following months, an airfield was built on which fully loaded four-engine propeller transport aircraft could land, and housing was built for 2000 construction and scientific personnel. The locations and configurations of the five tests then being considered were, however, still being discussed. Two of the tests required large concrete structures and weapon diagnostic vacuum line-of-site pipes the best part of a mile in length. These two experiments could be done only from land surfaces. The somewhat simpler scientific measurements needed for the remaining tests suggested a new technique, in which the nuclear device could be placed on a barge moored in the lagoon. This would limit the amount of land destroyed in the detonations, and perhaps reduce the amount of local fallout.

Based partially on the “misleading lessons from MIKE” (Hacker 2004), task force planners felt that it would be possible to safely conduct the CASTLE tests without evacuating the nearby atolls. The “apparent unrealism in the assumption of off-site health hazards of the magnitude conjectured for IVY,” combined with austerity in all phases of the operation dictated by reduction in fiscal year 1954 service budgets, resulted in policy decisions that “...in the formulation of [radiation safety] measures for CASTLE, every effort should be made to eliminate the necessity for evacuation of native populations,” but that “...the decision to shoot should be reached with the understanding that no health hazard to [task force] Units and populated islands of the Pacific or [radiation safety] conditions conducive to possible adverse criticism will ensue” (Hopwood 1953).

By late 1953, it was evident that the first test of Operation CASTLE would be both the most scientifically complicated nuclear detonation yet undertaken and the most crucial milestone to the success of the Emergency Capability Program. The shot was nicknamed BRAVO. Some in Washington—including scientists, senators, and generals—believed that the very future of the Free World might hinge upon the test results.

A spot on the reef midway between Bokonejien Islet and Namu Island on the northwest rim of Bikini Atoll was chosen as the BRAVO shot site (Figure 1-12). An artificial islet was dredged, and a 3600 ft causeway was built to Namu Island. The islet was known as Site 20. Vacuum line-of-sight pipes were installed to link the scientific detection and recording laboratories on Namu with the two-story concrete cab in which the nuclear device would be placed. A set of towers erected in the shallows near the shot islet held mirrors used to image the early stages of the fireball. The components of the nuclear device were moved from Los Alamos to Los Angeles, and hence carried to the PPG in a naval convoy guarded by warships and obeying wartime navigational practices. In the middle of February, while the scientific and support dry runs were underway, the BRAVO device was assembled in the scientific laboratory on Eninman Island. On 20 February, the experimental superweapon was moved to the shot islet, and then installed and aligned within the cab. By 27 February 1954, all necessary technical preparations had been completed, and BRAVO was ready to be fired. All that remained was to wait for a day of suitable weather.



Figure 1-12. BRAVO shot site showing the causeway with vacuum line-of-sight pipes connected to the shot cab

Images of JTF-7 Scientific Director Alvin C. Graves and Los Alamos scientists Harold Agnew, Marshall Holloway, and Wallace Leland are shown in Figure 1-13 and Figure 1-14). As the leader of the thermonuclear design staff and head of the Emergency Capability Program at Los Alamos, it is Marshall Holloway, more than any other single person, who might be considered the father of the hydrogen bomb. Harold Agnew, who flew as scientific advisor with the 509th Bombardment Group on the Hiroshima combat strike, went on to become Director of Los Alamos from 1970 to 1979. Test preparations for the BRAVO event are shown in Figure 1-15. The device installed in the shot cab is shown in Figure 1-16. A satellite view of the BRAVO crater is shown in Figure 1-17.



Photograph taken during Operation CASTLE

Figure 1-13. Alvin C. Graves, scientific director, JTF-7



(DTRIAC item 22-76)

Figure 1-14. Los Alamos scientists Harold Agnew, Marshall Holloway, and Wallace Leland.
Photograph taken at Parry Island, 10 February, 1954.



DTRIAC item 22-C50



DTRIAC item 22-C51

Figure 1-15. Construction of the vacuum line-of-sight pipes for the weapon diagnostic experiments, top view. Arrival of the BRAVO device on the shot islet on 20 February 1954, bottom.

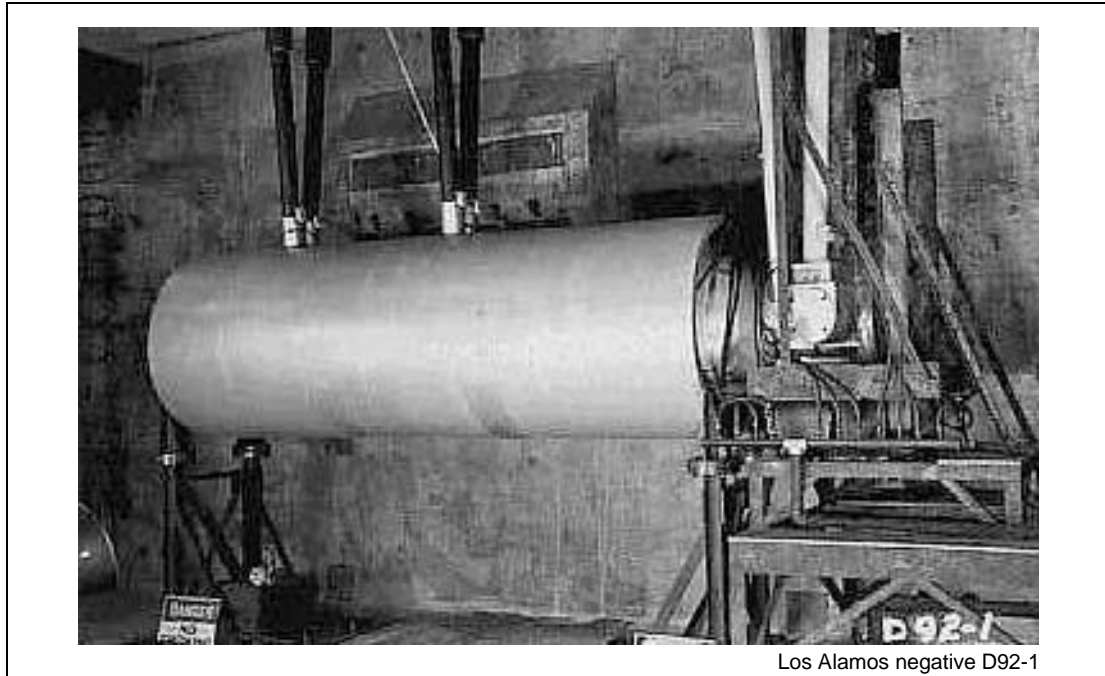


Figure 1-16. The BRAVO device installed in the shot cab



Figure 1-17. The BRAVO crater as seen from space
The mile-wide crater produced by the detonation is the prominent hole in the Bikini Atoll reef at the top left.

2.0 Weather

The weather was the final consideration in each decision to conduct a test. Never were weather data and forecasts more critically checked and screened by weathermen and non-weathermen alike. For periods of time approaching the length of Noah's cruise several thousand men waited—some with patience, some without—for a change in the upper winds.

—Lt. Col. Slater, 1 June 1954



Figure 2-1. Launching a weather balloon

Beginning with Operation CROSSROADS in 1946, the joint task forces supported basic research in tropical meteorology and weather forecasting. The extensive weather measurements made in support of PPG operations were reported in both the scientific literature (refer to, for example, Palmer 1949) and in JTF reports (refer to, for example, Pate and Taylor 1951). These weather measurements permitted some of the first well-founded interpretations of tropical weather patterns in both the tropospheric (Palmer, Miller, and Stopinski 1951) and stratospheric (Palmer 1954) regimes. Because these two atmospheric regimes play an important role in the dispersal of radioactive debris from high-yield nuclear detonations, it is perhaps useful to briefly recount the differences between the troposphere and the stratosphere.

The troposphere is the layer of Earth's atmosphere closest to the surface. Extending upward in the tropics to about 60,000 ft altitude, the defining attribute of the troposphere is that the ambient temperature decreases with increasing altitude. It gets colder as you go up. This "negative temperature gradient" leads to the phenomenon known as convection. Just as a hot air balloon rises in the cool morning air, a volume of sunlight-heated air will rise in the troposphere. As the warm air rises, the temperature contrast with the surrounding atmosphere tends to increase, and its buoyancy thus increases. Conversely, a pocket of cooler air will fall downward through the warmer air at lower elevations. Small variations can thus be amplified, and the troposphere is, therefore, said to be "unstable against convection." Perhaps the most visible manifestation of unstable convection is the summer thunderstorm. Convection causes much of our normal weather, and keeps the contents of the troposphere well mixed.

Above the troposphere is the stratosphere, a region of the atmosphere where temperature increases with increasing altitude. It gets warmer as you go up. This "temperature inversion" results from the absorption of solar ultraviolet radiation by ozone; the stratosphere is where the ozone is. Because of the temperature inversion, convection does not readily occur in the stratosphere. Pockets of relatively warm air have only warmer air above them; pockets of relatively cool air have only cooler air below them. Compared with the troposphere, the stratosphere is quiescent. In the absence of unstable convection, the contents of the stratosphere tend to become stratified. The boundary between the troposphere and the stratosphere is known as the tropopause. This boundary is important because, as a general rule, material from the troposphere that is injected into the stratosphere tends to remain in the stratosphere. This phenomenon is known as "stratospheric trapping," and it is the reason that fluorine and bromine compounds can remain in the stratosphere long enough to catalyze the destruction of ozone. The time required for material to settle from the stratosphere into the troposphere is known as the "stratospheric residence time."

Stratospheric trapping is a well-known phenomenon. Perhaps the best example “began on 27 August 1883, when the great volcanic eruption of Krakatoa blew a cloud of fine dust through the tropopause. The main body of the cloud lay initially at about 105,000 feet. By the early part of September it had descended to about 75,000 feet, and it remained near that level until late November” (Palmer 1949). “The cloud moved from east to west at an average speed of 73 miles per hour, and completed at least two circuits of the earth in equatorial latitudes” (Wexler 1951). Sunlight scattered from the high-altitude volcanic dust produced “magnificent fiery sunsets and sunrises, first in the Southern Hemisphere, then near the equator, and eventually in northern latitudes, as the cloud of aerosols spread worldwide” (Olson, Doescher, and Olson 2004); the spectacular twilight effects seen that fall and winter were widely reported in both the popular press and scientific journals, and inspired scientists, painters, and poets alike.

More recent examples of stratospheric trapping were provided by the volcanic eruptions of El Chichon in 1982 and the Pinatubo in 1991. Particulate debris from El Chichon reduced the transparency of the sky in the southwestern United States by almost half, enough so that the solar intensity was noticeably weakened even to the casual observer (Livingston and Lockwood 1983). Stratospheric debris from Pinatubo affected the color and daytime brightness of the sky for more than 2 years, and may have resulted in global cooling. The burden of stratospheric dust even caused lunar eclipses to go dark.

Similar to these volcanic eruptions, the CASTLE BRAVO detonation injected a great mass of debris into the stratosphere. As will be seen in Chapter 3, the unexpectedly short stratospheric residence time for this radioactive debris is the key to understanding the CASTLE BRAVO fallout contamination.

2.1 Winds and Fallout

The weather was the final consideration in each decision to conduct a test, and the most critical aspect of the weather was the wind (Figure 2-1). Before each shot, the winds aloft were carefully measured, reviewed, and analyzed, and estimates of the air and surface areas that would be contaminated were then developed (Figure 2-2 and Figure 2-3). Weather conditions suitable to permit the detonation of high-yield nuclear devices existed only a few days each month.



Figure 2-2. Command briefing in the weather and radiation briefing room aboard the USS *Estes*. Gen. Clarkson (left, seated) and Dr. Graves (back to camera) receive the daily weather briefing from Lt. Col. Carlos D. Bonnot (left) and Lt Col. Robert A. House (right), 16 March 1954.



Figure 2-3. Task Force Command ship USS *Estes* [CG-12], 16 February 1954

There is, in general, no simple, unified pattern to the winds aloft; winds at various altitudes tend to blow in different directions. Three types of basic weather situations commonly occur in the northern Marshall Islands (Pate and Palmer 1953). During the greater part of the period of Operation CASTLE, “normal trade flow” weather was expected. In this weather situation, the surface winds are east–northeast to northeast trade winds with speeds of 5 to 15 kn. For this reason, the atolls of Rongelap and Rongerik are commonly said to be upwind of Bikini, and Eniwetok is said to be downwind of Bikini. The trade flow generally extends upward to about 8000 ft. Above the trades, the winds turn westerly with increasing elevation, until at about 20,000 ft they lie between northwest and southwest. The “midlevel westerlies” then extend upward to the tropopause, increasing in speed to about 35 kn at 45,000 ft. Above the tropopause, the stratospheric winds tend to blow from the east and are sometimes referred to as the “Krakatoa easterlies.”

The velocity profile of the winds aloft is often displayed in hodographs, which are plots of the path a weather balloon would take following its release. A hodograph of the winds above Bikini on BRAVO day is shown in Figure 2-4. Rising at a uniform standard rate of 5000 ft/hr, the balloon first would be carried to the west in the trade flow. While rising above the trades, it would drift back toward the east. Three hours after release, the balloon would be about 10 mi south of the island at an altitude of 15,000 ft. Climbing into the midlevel westerlies, the balloon would move off to the northeast. Finally reaching the tropopause at about 60,000 ft, it would move into the Krakatoa winds and once again reverse direction to drift toward the west.

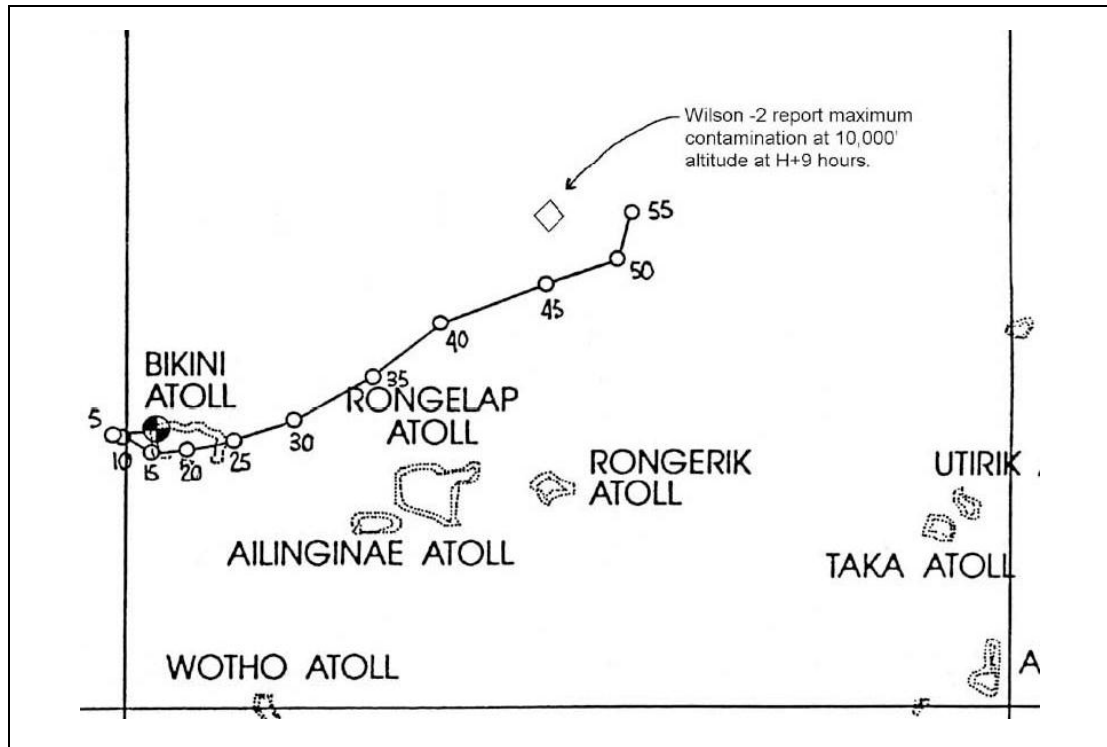


Figure 2-4. Hodograph of the winds aloft for the BRAVO event

The measurements shown in Figure 2-4 were made from the USS *Curtiss* at 01-06:00M, 45 min before the BRAVO detonation. The numbers along the hotline indicated the altitudes from which the fallout originated; for example, “45” indicates the landing point of material initially at 45,000 ft directly over the burst point. Falling at a rate of 5000 ft/hr, this material would have reached the ocean surface about 9 hours after detonation. The diamond-shaped point shows the location of maximum contamination reported by the WILSON-2 cloud tracking aircraft 9 hours after the detonation (Chapter 5.0). The position of maximum contamination was in good agreement with the preshot predictions. Refer to NV0104797 for the original hodographs for BRAVO; these were not reproduced for Figure 2-4 because the surrounding atolls are not shown.

The concern following the BRAVO detonation was, of course, not weather balloons floating upward, but small radioactive particles falling downward. Descending at a typical rate of 5000 ft/hr, fallout particles follow a reverse path on the hodogram. For example, a particle initially located 50,000 ft above the shot site would fall to the ocean surface directly under the position that a weather balloon would reach after ascending to this same altitude. The hodogram, thus, shows the surface trace of fallout from locations directly above the shot site. Because the maximum amounts of fallout contamination are expected to arise from radioactive debris initially above the shot site, the hodograph path is often referred to as the “hotline.” As shown in Figure 2-4, the closest approach of the BRAVO hotline to any inhabited location was a 45 mi distance to Rongelap Atoll. At this position along the hotline, particles falling from an initial altitude of 35,000 ft would reach the ocean surface about 7 hours postshot.

Particles initially located 20,000 ft above the shot site would drift to the east for approximately 2 hours in the midlevel westerlies as they sank to 10,000 ft altitude, and then reverse direction and move to the west as they fell through the trades. They would finally fall to the ocean surface within the Bikini lagoon. This “circulation” of material was very pronounced after the BRAVO detonation, and it played a major role in the contamination of Bikini Atoll and the task force vessels located to the east and southeast of Bikini.

2.2 The Pate-Palmer Report

An enduring element of the BRAVO legend is that the detonation produced widespread weather changes and that the resulting “nuclear typhoon” played an important role in blowing radiation to the islands surrounding the PPG (Weiman 1994). Lore also has it that this effect was predicted in the “Pate-Palmer report,” which warned that typhoons might be produced by nuclear detonations and that the task force both ignored and suppressed the warnings in this report.

In the spring of 1953, Commander Elbert W. Pate, US Navy, and Professor Clarence E. Palmer of UCLA prepared a report entitled *A Study of Certain Operational Weather Considerations Involving the Test and Delivery of High Yield Weapons* (Pate and Palmer 1953). The finished report was dated 30 June 1953. It was originally issued as a Secret Restricted Data (SRD) classified document. On 27 August 1954, the classification was cancelled, and it became an “Official Use Only” document. It was released to the public through the Department of Energy Coordination and Information Center (DOE/CIC) in 1983.

The DOE/CIC in Las Vegas, Nevada (now referred to as the DOE/Nuclear Testing Archive (NTA) [<http://www.nv.doe.gov/library/testingarchive.aspx>]) is specifically chartered with archiving and managing unclassified records pertaining to the United States atmospheric nuclear test program.¹⁹

¹⁹ The bibliographic information for the collection at the Nuclear Testing Archive can be accessed through OpenNet, <https://www.osti.gov/opennet/>. OpenNet is DOE’s bibliographic database containing declassified and publicly available documents.

As evidenced by the aforementioned references, both Commander Pate and Dr. Palmer were experienced with weather forecasting and analysis, acquired during previous testing operations, and had published their findings in both military reports and in scientific literature. Commander Pate was the Staff Weather Officer, and Dr. Palmer had been the Weather Advisor to the Deputy for Scientific Matters (Dr. Graves) during Operation IVY (J-15205 [1952]). The Pate-Palmer report contains a comprehensive discussion, written by Dr. Palmer, of the three classes of weather situations that commonly occur in the Marshall Island area. In his sections of the report, Commander Pate discussed the possibility that high-yield detonations might cause large-scale weather disturbances, including self-sustaining circulation patterns. This speculation is the source of the lore concerning “nuclear typhoons,” and has long been a subject of contention.

Among the points made to support his speculations, Commander Pate claimed that IVY MIKE and KING, the two high-yield detonations conducted at the PPG in November 1952, “induced spectacular and widespread weather changes which persisted for several hours.” This claim had been voiced soon after the IVY detonations and was not unknown to the task force. Commander Pate’s principal conclusions concerning weather phenomena resulting from high-yield detonations were reported to Command in a memo from 4 March 1953 (J-18651A [1953]). In a letter dated 27 March 1953 to JTF-7 Headquarters (J-16661 [1953]), Dr. Graves requested that he be sent the report as soon as it was available. “His conclusions are quite interesting and will receive careful consideration when we have his data available to us.” Dr. Graves received his copy of the Pate-Palmer report on 3 July 1953.

Criticism of Commander Pate’s portion of the Pate-Palmer report was quickly forthcoming. In a letter sent to Dr. Graves on 17 July 1953 (Plank 1953) Dr. Harold Plank, Director of Airborne Sampling during Operation IVY, pointed out several errors in Commander Pate’s theoretical model of plume formation. He also reported his personal observation that neither KING nor MIKE had any perceptible effect on the weather. Dr. Plank had witnessed both detonations from the B-36 Airborne Command aircraft, from where he monitored the development and motions of the mushroom clouds and directed the sampling aircraft. His was the best seat in the house for observing weather effects. He noted that Commander Pate’s description of the preshot weather was at odds with the official weather observations, and that the “weather changes” reported by Commander Pate were entirely consistent with the more-or-less normal situation of there being fewer clouds in the morning than at noon. Dr. Plank concluded by remarking laconically that “the [mere] proposal to detonate KING on the original K-day also produced widespread and unpredicted weather changes” (NV0120580).

Another description of the effect of the IVY detonations upon the weather is given in a narrative report by Lt. Col. William S. Barney, the Commander of Weather Reporting Element (Barney 1952). “I cannot state that the [MIKE] detonation . . . changed the weather over a wide area. There are many conflicting reports and I was not a witness. I can state that there were many radical changes. That the 20,000 ft towering cumulus disappeared instantaneously and that others to 50,000 ft appeared in a radius of 35 mi. Reliable observers and radar pictures proved this.” For the KING detonation, Colonel Barney flew on a C-54 photographic aircraft that orbited 12 mi away from the burst point at 12,000 ft altitude. “I had a ringside seat and the show was the best I have ever seen. We could see aircraft at 42,000 ft and could see everything within 60 mi.” No weather effects caused by the KING detonation were noted.

The best record of potential weather changes resulting from the IVY MIKE and KING detonations is the time-lapse photography obtained in support of Program 3.2, *Cloud Photography* (Edgerton, Germeshausen, and Grier 1953). This series of pictures shows three separate views of the MIKE and KING clouds over a period of 1 hour after the detonations. The “20,000 ft towering cumulus” are clearly seen both before and after the MIKE event, and the higher altitude clouds show no change in type or aerial coverage. The KING mushroom cloud erupts into an otherwise almost clear sky (Figure 2-5). It is evident from these sequences of photographs that neither detonation had any significant effect upon the weather.



Figure 2-5. The IVY KING detonation

It has long been generally understood and appreciated that “many of the forces of nature are more powerful than hydrogen bombs. The ordinary thunderstorm has many times the potential of the ordinary hydrogen bomb” (Pickering 1958, 93). As put by Dr. Graves in a broadcast interview conducted on 9 July 1953 by Radio Station KOB, Albuquerque, New Mexico, “about 1000 atomic bombs a minute would have to be exploded to equal the kinetic energy of a moderate-sized hurricane,” and “a mere rainstorm of moderate intensity releases energy equivalent to the rate of three atomic bombs *every second*” [original emphasis]. In view of their insignificance in comparison with natural weather phenomena, the general consensus was, and is, that isolated high-yield detonations can have no possible effect on the weather.

The notion that explosive detonations might affect the weather is rooted in an earlier period of American history. At the turn of the nineteenth century, large dynamite explosions were commonly conducted in the southwestern United States in attempts to coax water from passing clouds. Charges were detonated both on the surface and in the air, the latter suspended from balloons and kites. These proved of no value. In 1906, the Secretary of the Interior attended such an event in Texas, and he reported that the only evident result “was . . . a large explosion.” The notion that nuclear detonations might result in weather disturbances seems to stem from this earlier period of American history, and is an interesting example of the enduring power of legend and lore in popular society.

Commander Pate’s speculation that nuclear detonations might trigger weather disturbances seems to have originated from Dr. Palmer’s own observation that typhoons often originate in the general area of the Marshall Islands (Palmer 1949). Apparently building on this idea, Commander Pate suggested that a high-yield detonation might serve as the “seed” for an incipient typhoon. In September, Dr. Palmer wrote to General Clarkson to distance himself from Commander Pate’s portion of the report (NV0404590 [1953]). On 25 November 1953, Dr. Graves wrote to General Clarkson (Graves 1953) to give his opinion that while Dr. Palmer’s portions of the report “are excellent and should be accepted as authoritative,” the portions written by Commander Pate “must be heavily discounted.” Guided by this criticism, on 21 December 1953, General Clarkson ordered the report withdrawn (Clarkson 1953b); his reasons were given in a message sent the next day to Task Force Headquarters (RJ-68583 [1953]).

Although the Pate-Palmer weather report was withdrawn, it was not forgotten. Dr. Graves thought that the withdrawal action “appears somewhat more drastic than required,” that “consideration should be given to preparation of a task force report at the end of CASTLE,” and that “a critique by other competent meteorologists [should] be sent to recipients of the report” (J-22486 [1953]). On 27 January 1954, Dr. Graves requested that the United States Weather Bureau review the Pate-Palmer report and that a responsible scientist from the Weather Bureau confer with Dr. Palmer in Honolulu, and he ordered that a study of weather changes induced by Operation CASTLE detonations be undertaken (JF-8508 [1954]). These steps had been presented in a letter sent 18 January 1954 to James Reeves at the Santa Fe Operations Office (Graves, Reeves, and Machta 1954). In response to a request from the Joint Committee on Atomic Energy for information about possible weather effects (Allardice 1954), on 12 February 1954 the commander sent a message to the Director of Military Application at AEC Headquarters, stating that the task force was planning to investigate and prepare a report on the effects of detonations upon the weather (NV0102129 [1954]).

The study of the effects of CASTLE detonations upon the weather was conducted and reported by Lt. Col. Carlos D. Bonnot, USAF, and Lt. Col. Hershel H. Slater, USAF, in JTF-7 report SRD-180-55W issued in October 1954. The introduction summarizes the Pate-Palmer controversy:

The detonation of the most powerful explosive device produced by man—a thermonuclear bomb—rightly concerns many as to the effects produced on the Earth and its atmosphere. Detonation of atomic devices has led to conjecture that all manner of weather phenomena have resulted—droughts, floods, tornadoes, and typhoons. Operation CASTLE offered an opportunity to observe qualitatively, at least, some of the effects, if any, of high yield explosions upon the weather.

After this buildup, the results of the study are almost disappointing. Considerable amounts of high cloud at cirrus levels were formed and limited amounts of middle-altitude clouds were produced near the rising fireballs. There was little, if any, increase of low clouds. No significant changes in shower activity were documented, and self-perpetuating circulations were not produced.

The Pate-Palmer controversy spilled over into the academic community. The last of it to which reference has been found is an article in the journal *Weather* from May 1955. Professor B. J. Mason, Imperial College, London, wrote that “the fact that large weather systems, such as depressions, may grow rapidly from small beginnings—from small perturbations in a broad, unstable air stream—has led to the suggestion that the detonation of a hydrogen bomb may supply the trigger necessary to release the potential instability and initiate a sequence of weather disturbances. This arises from a misconception that large regions of the atmosphere are often so delicately balanced that a slight disturbance, applied almost anywhere, would grow rapidly. It is inconceivable that a few isolated explosions could affect the weather . . . arguments to the contrary have been merely intuitive or based on misleading analogies.” This is, of course, the same type of scientific criticism that caused Dr. Graves to discount Commander Pate’s speculations and General Clarkson to withdraw the Pate-Palmer report.



Figure 2-6. Cartoon from *More Minus than Plus*

3.0 Fallout Predictions

The theory that a significant fallout does not come from the stratosphere is not substantiated by the facts of BRAVO.

—Al Graves, March 1954

It is to be recalled that until 1954 one school of thought held that high yield surface detonations would create intense fallout only in the immediate area of the shot, and that most of the activity would be carried into the stratosphere where it would be scattered widely around the world. March 1, 1954 saw the dismissal of that school—permanently.

—Gordon Dunning, 1968



Figure 3-1. CASTLE BRAVO detonation

Radiological safety planning for Operation CASTLE was largely a continuation of that done for the two high-yield shots detonated at Eniwetok during Operation IVY in the fall of 1952. For both MIKE and KING, only trace amounts of radioactive fallout had been detected outside of the Danger Area surrounding Eniwetok Atoll (NYO-4522 [1953]). Indeed, most of the radioactive debris from the 10.4 Mt surface burst MIKE shot seemed, quite literally, to have disappeared from the face of the Earth, apparently having been trapped in the stratosphere. “Although conscientious efforts were made to document the fallout from MIKE, only about 5 percent of the total debris could ever be accounted for” (Clarkson and Graves 1954). Given the paucity of fallout from IVY MIKE, how did CASTLE BRAVO, a detonation of similar yield in a similar setting, deliver up potentially lethal fallout radiation to islands more than 100 mi distant?

The basic tools used to evaluate radiological hazards for the CASTLE tests were Fallout Plot and RADEX (RADiological EXclusion) area. The RADEX was used to define dangerous areas and to deny entry of task force units into certain areas except under specific authorization. As a consequence, it was given wide dissemination throughout the task force for the information and compliance of all. The Fallout Plot considered the entire area of “significant” fallout, usually including infinity isodose lines of at least 50,000 mR, and in some cases down to 10,000 mR. (The milli-Roentgen or “mR” is the unit of external gamma radiation dose used throughout this report; see Appendix A for a discussion of radiation measurement units.) The techniques used in preparing the RADEX and the Fallout Plot for CASTLE BRAVO are detailed in Tab D of House (1954).

Due to the small number of surface shots detonated prior to CASTLE, only a limited amount of data was available on the long-range fallout aspects of this type of burst. Three additional safety factors not used for lower-yield tests were therefore included in the BRAVO fallout calculations:

- a. Significant fallout was expected for the first 12 hours. Past experience seemed to favor a 6-hour period; however, since the off-site fallout aspects of IVY MIKE were not known, the value of 12 hours was assumed for a margin of safety.
- b. Fallout particle sizes down to 70 μm were considered. Previous studies had indicated a 100 μm lower size limit for fallout particles. Prior to BRAVO it was assumed, in the interest of safety, that particle sizes down to 70 μm should be considered; this amounted to doubling the size of the RADEX area.
- c. Diffusion widens the width of the downwind contamination. Prior to CASTLE, the accepted factor applied to the construction of RADEXs to account for the widening of the contaminated area with distance was the addition of a 10° sector on each side of the RADEX area. For CASTLE, this factor was arbitrarily assumed to be 15°.

In constructing both the RADEX and the Fallout Plot, it was necessary to know something about the source of the radioactive materials, that is, the size, shape, and distribution of radioactivity within the initial “mushroom cloud.” Based on mathematical scaling of cloud rise heights from low-yield events at the NPG, and on the observed cloud rise heights for the GREENHOUSE GEORGE, IVY MIKE, and IVY KING high-yield detonations at the PPG, it was expected that if CASTLE BRAVO were to achieve its design yield, the resulting mushroom cloud would rise to a height of almost 100,000 ft. The head of the mushroom cloud would be above the tropopause, and much of the radioactive debris thus would be carried into the stratosphere. Like the dust from Krakatoa, the small particles of radioactive debris would be trapped above the tropopause. By the time these particles floated to earth, they would be so dispersed and have radioactively “cooled” so much that they would not be a health hazard. This seemed to be what had happened following the MIKE detonation, or at least to be a scenario consistent with the failure to locate the bulk of the MIKE fallout. With this model in mind, the initial distribution of radioactive debris for BRAVO was taken to be a cylinder 15 mi in diameter extending upward from the shot site to the base of the stratosphere. How much of the radioactive debris would be below the tropopause and how much would remain trapped in the stratosphere was, however, unknown.

The amount of particulate debris suspended in the stratosphere following high-yield detonations was known to be important for reasons besides local fallout considerations. Because the particles dispersed throughout the stratosphere before eventually settling to ground, radioactive contamination was spread over large portions of the earth. This “global fallout” was of concern because it exposed nearly the entire population of the world to relatively small, but still increased levels of radioactivity. The uptake of radioactive strontium in growing bones was of special consequence, and this aspect of global fallout was studied by the SUNSHINE project.²⁰

²⁰Project SUNSHINE was a study of the behavior and distribution of radioactive strontium 90 in the environment. In 1953, monitoring stations first began to detect this fission radionuclide, and researchers set about to determine its distribution in the atmosphere, on the surface of the earth, in food materials, and in the skeletons of animals and humans. Original participants were the University of Chicago, the US Department of Agriculture, the US Weather Bureau, and the AEC Health and Safety Laboratory; the Rand Corporation was the project sponsor. The project name came from the location of the Rand Corporation in Santa Monica, California, where East Coast participants could always expect sunshine.

One of the strongest advocates of the stratospheric trapping theory was CDR Pate, the Joint Task Force Staff Weather Officer. On 3 March 1953, in a memo to Task Force Command (J 18651A [1953]), Pate stated that “all evidence indicates that [the] MIKE cloud stem penetrated to a final altitude of about 125,000 ft and that by far the major portion of atomic debris was carried well into the stratosphere.” He recommended that to prevent the occurrence of “home-made” weather, the safety requirement for a southerly wind aloft, to blow the atomic cloud away from the inhabited islands, be “de-emphasized.” “While such a recommendation might be viewed with alarm at first glance, one important fact should be considered in weighing the recommendation:

With extremely high yields, most of the radioactive debris is carried into the stratosphere, where it is “trapped” and falls out very slowly, thus undergoing normal processes of decay, mixing and dispersal. All past sampling operations bear out this conclusion, as do the results of the world-wide fall-out program.

This extreme view was shared by Lt. Col. William S. Cowart, Jr., the J-3 chief of staff. In a note attached to CDR Pate’s memo (J-18651 [1953]), he stated, “I heartily concur in CDR Pate’s paper and believe that good clear dry weather would be a welcome asset to our operation, rather than the requirement of northerly flow dictated by radiological hazard which inevitably produces moisture and clouds.” He raised this issue directly in a letter of 20 March 1953 to Dr. Graves (J-18651B [1953]), writing that “if we can adopt [CDR Pate’s] concept, the importance of wind direction will become less critical.”

The assumption that stratospheric trapping would prevent debris in the head of the mushroom cloud from floating back to earth soon enough to avoid local fallout was not, however, taken as established fact, and the requirement for a southerly component to winds aloft was not deemphasized. “It was assumed that confidence could not reasonably be placed in significant trapping of debris by the tropopause unless definite proof of such a mechanism was available” (NV0051031, D-2). In his letter of 17 July 1953 critiquing the Pate-Palmer report (Plank 1953), Dr. Plank had reported possible fallout from the stratospheric head of the IVY MIKE cloud. If stratospheric particles were to fall unhindered from the tropopause, it would, however, take longer than 12 hours for them to reach the ground, assuming a normal rate of fall of 5000 ft/hr. Since the particles would be both much dispersed and much “cooler” by this time, they were not considered still to be dangerous. Before the BRAVO detonation, the possibility of stratospheric fallout was thus viewed as more of an academic than a safety problem.

Using the planned techniques, with their built-in factors of conservatism, the winds-aloft forecast was merged with the mathematical and empirical models of the fallout process, and the RADEX and Fallout Plots were calculated for BRAVO. Although significant fallout was expected on and around Bikini, and the shot-time positions of the smaller and slower vessels in the task force fleet were changed to compensate, the inhabited northern Marshall Islands were predicted to be safe from harmful fallout. Working from this information, Task Force Command ordered the experimental superweapon to be detonated. Within 5 hours, potentially lethal fallout was beginning to arrive on the uninhabited northern islands of Rongelap Atoll, 110 mi distant from the explosion, and dangerous amounts of radioactive debris continued to fall from the skies for the next 12 hours. How had the preshot predictions been so badly flawed?

As the BRAVO device detonated, a huge fireball formed (Figure 3-1). Composed of what had been the bomb itself and the surrounding equipment, coral, seawater, and air, the fireball grew within seconds to be more than 3 mi across. For a moment it seemed to cling to the earth, but then it sprung into the sky (Figure 3-2). Ten million tons of pulverized coral debris were coated with radioactive fission products and sucked up into the rising fireball. Surrounded by moisture condensation rings caused by the passage of the shock wave, the huge bubble of superheated gas and debris rose 45,000 ft in its first minute, leaving behind a 4 mi wide stem of radioactive debris (Figure 3-3). It continued to rocket upward, punching through the tropopause and into the stratosphere. Coasting upward through the stratosphere, the cloud was squashed by dynamic pressure. After 5 minutes, the rising cloud finally came to a stop at an altitude of over 115,000 ft. An immense trumpet-shaped cloud formed. Ten minutes after the explosion, the head of the mushroom cloud had widened into an anvil resting upon the tropopause, measuring 75 mi across and growing rapidly (Figure 3-4). And from the base of the immense anvil cloud, looking like virga from a desert shower, was debris falling toward the earth below (Clarkson and Graves 1954, 29).

It is clear that relatively large particles were swept up into the stratosphere within the rising fireball and that these particles fell rapidly back to earth. Stratospheric trapping had not kept the fallout high in the sky above the Pacific. Analysis of samples collected at Rongelap showed particles up to 500 μm in diameter,²¹ and fallout collected upon the floating platforms near the western edge of the Danger Area contained individual particles up to 1000 μm (1 mm) in diameter (Steton et al. 1956). The source of the BRAVO fallout was not the expected 15 mi wide cylinder extending upward to the stratosphere, but instead a 100 mi wide cloud resting upon the tropopause. Dr. William Ogle, commander of TG7.1, subsequently wrote that “debris was carried up and dispersed over a much larger area than was thought possible” (Ogle 1985). “The original source cannot be considered as a point or a relatively small area but must be considered to be an area of about a hundred miles diameter” (Clarkson and Graves 1954, 4).

²¹ For comparison, human hairs are roughly 70 μm in diameter.

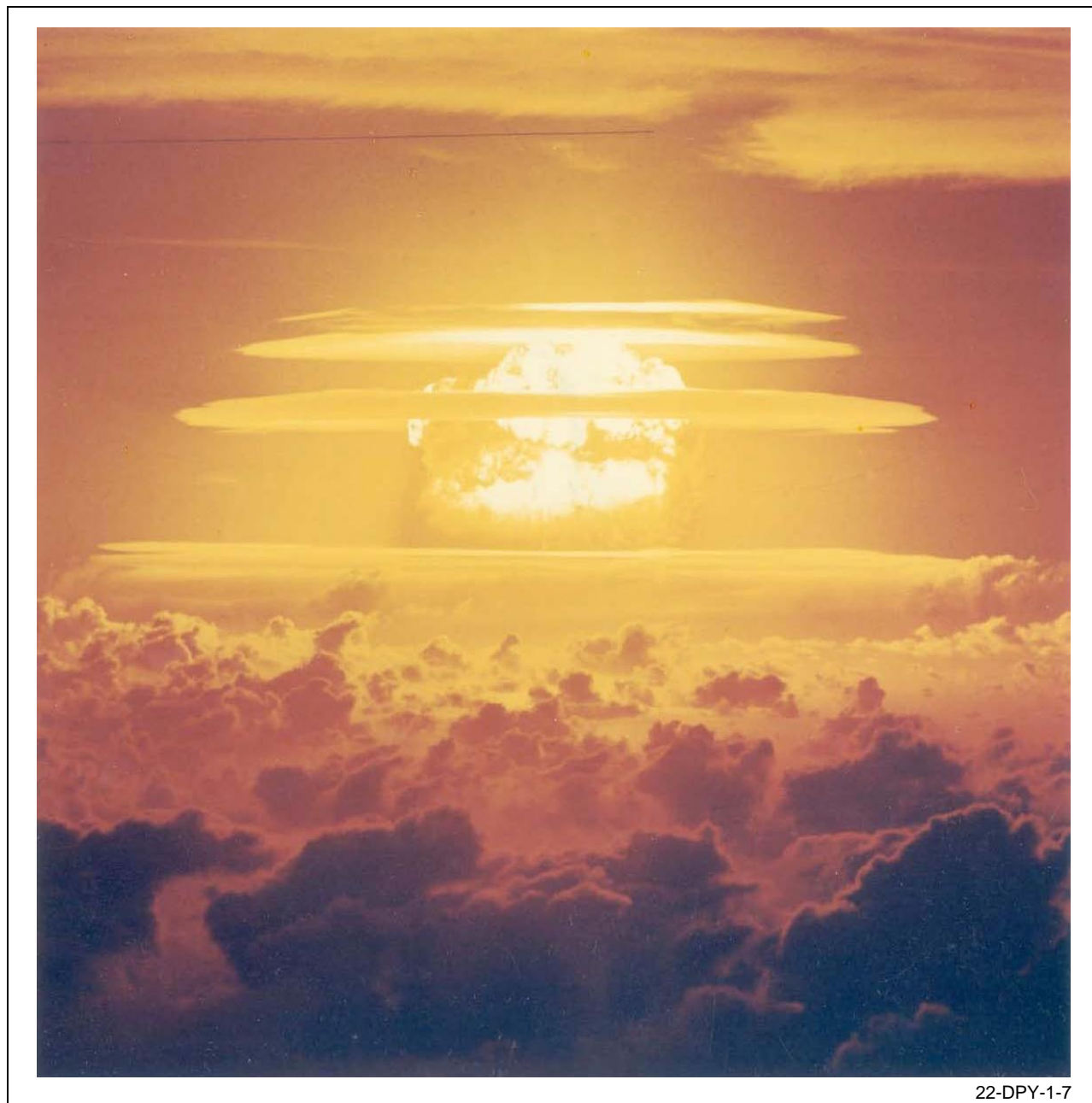


Figure 3-2. BRAVO event, 3.5 seconds after detonation
This image was taken at a distance of 75 nm east of ground zero (GZ) from an altitude of 12,500 ft.



Figure 3-3. BRAVO event, 62 seconds after detonation
This image was taken at a distance 50 nm north of GZ from an altitude of 10,000 ft. The lines running upward to the left of the stem and below the fireball are smoke trails from small rockets. At this time the cloud stem was about 4 mi in diameter.

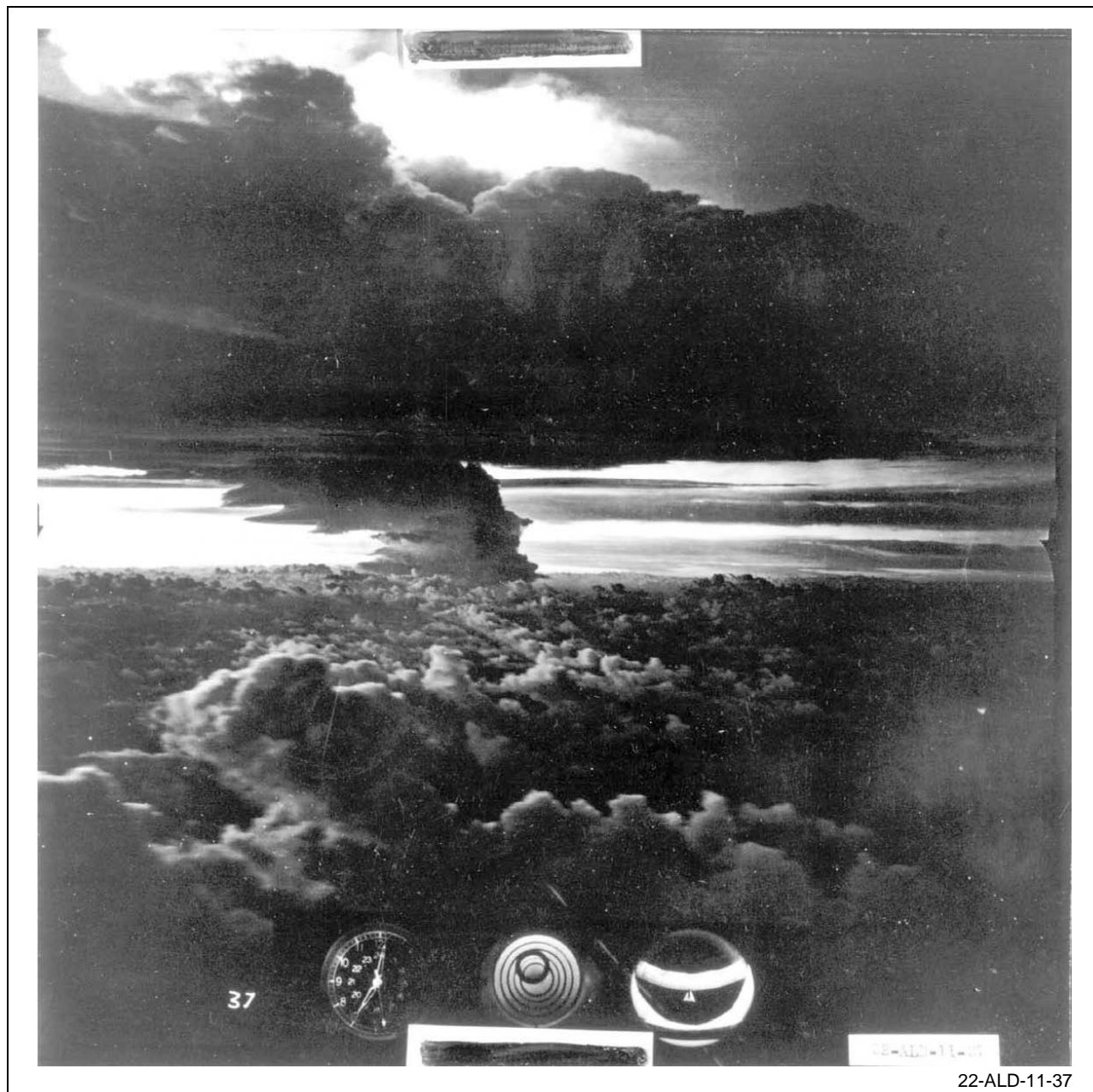


Figure 3-4. BRAVO event, 16 minutes after detonation
This image was taken at a distance of 50 nm northwest of GZ from an altitude of 10,000 ft.

The cause of off-site contamination was the unexpected rapid fallout from an unexpectedly large source: the stratospheric head of the mushroom cloud. As concisely summarized by Dr. Graves (Clarkson and Graves 1954, 5), “the theory that a significant fallout does not come from the stratosphere is not substantiated by the facts of BRAVO.” The difference between the preshot predictions and the actual BRAVO fallout pattern can be estimated roughly by taking the RADEX area, which was calculated assuming that the debris would come from a relatively small source, and expanding the borders by 40 mi, the approximate additional radius of the stratospheric cloud. This has been done in Figure 3-5. The adjusted RADEX contains both Rongelap and Rongerik atolls within the radiological exclusion area.

The conclusion that much of the unanticipated fallout had come from the stratospheric head of the mushroom cloud was reached almost immediately (NV0122517 [1954]), and within a week, the first detailed analysis of the situation had been completed (Maynard 1954). Using Lt. Col. Lulejian’s method of elliptical approximations, individual fallout envelopes were calculated for the stem and head of the mushroom cloud. The fallout pattern for the head of the cloud was developed assuming that the cloud diameter during the period in question was at least 70 to 100 mi. The resulting fallout pattern (Figure 3-6) encompassed the populated atolls. On 2 April 1954, General Fields briefed the GAC to the AEC that “heavy particles . . . falling out of the dome [of the mushroom cloud] . . . effectively enlarged the stem to a diameter of 50–75 miles” (NV0073409 [1954], 31).

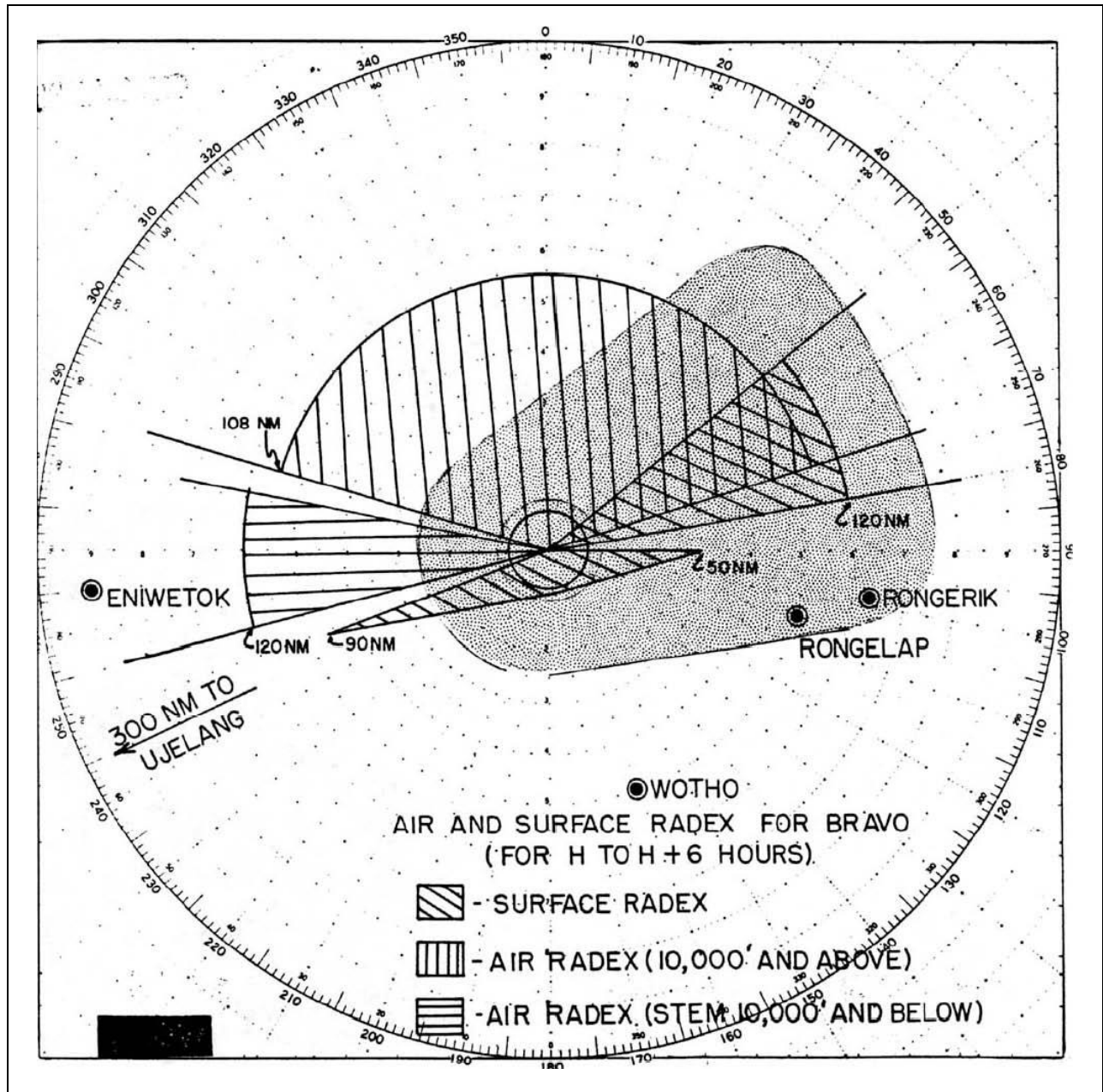


Figure 3-5. RADEX plot for the BRAVO event
To account roughly for the large size of the BRAVO cloud, the boundary of the preshot RADEX area has been expanded by 50 mi and indicated by the stippled area. Reproduced from House (1954, K30) with the stippled area added.

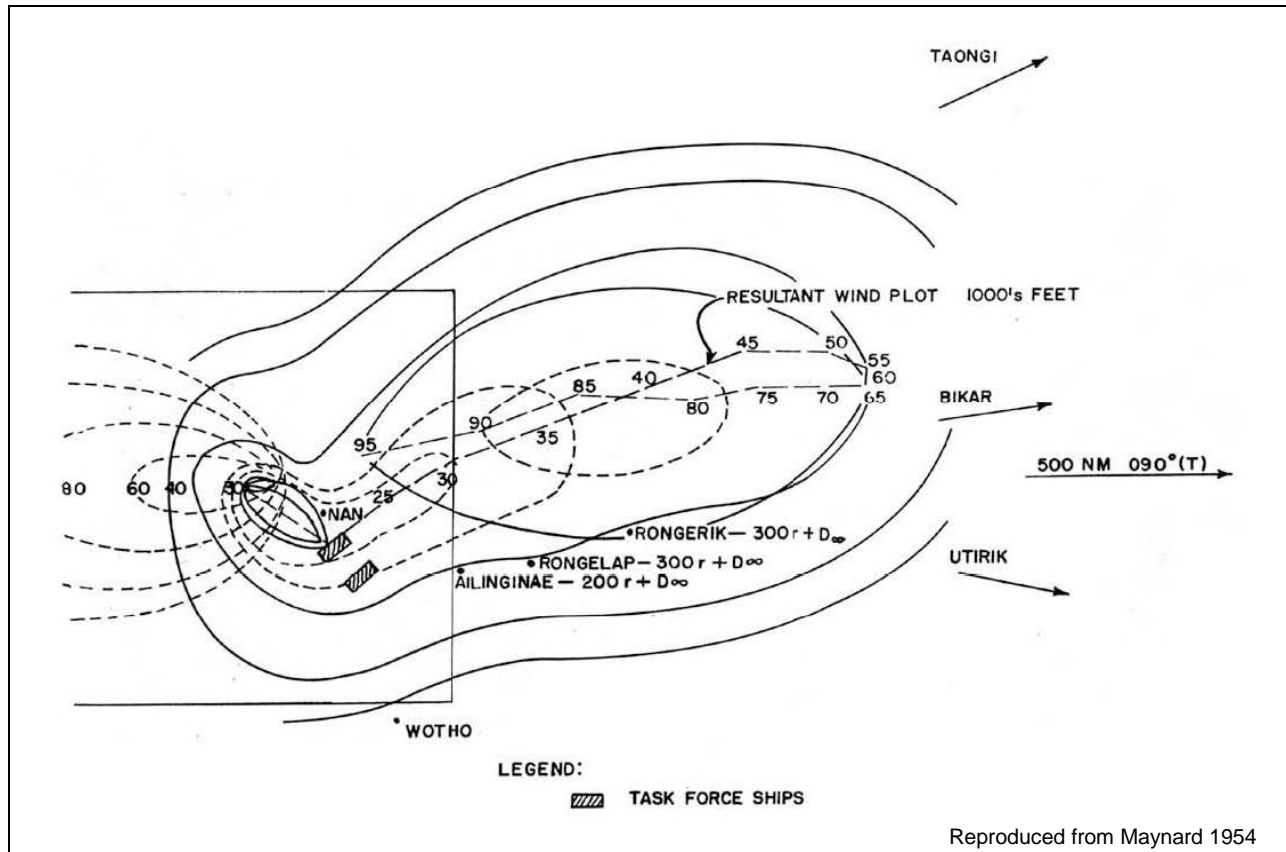


Figure 3-6. Reconstruction of the BRAVO fallout pattern made several days after the detonation
 The solid lines indicate isopleths of surface fallout exposures resulting from material falling from the stratospheric cloud head; dashed lines indicate exposures resulting from material in the cloud stem. It is interesting to compare these calculations with the observed CASTLE YANKEE fallout pattern shown in Figure 3-10.

3.1 The BRAVO Fallout Pattern

A thorough analysis and reconstruction of the primary fallout pattern for BRAVO was done by the US Naval Radiological Defense Laboratory (NRDL) as part of Operation CASTLE Project 2.5a. Final reconstruction of the BRAVO pattern is shown in WT-915 (Steton et al 1956) Figures 6.8 through 6.11 (refer to Figure 3-7). This reconstruction is based on all available radiation data, the observed sizes of the fallout particles, the actual winds aloft, and Project 9.1 Cloud Photography pictures (WT-933).

Two other representations of the BRAVO fallout pattern were developed in the year following the CASTLE test series, one by the RAND Corporation (Greenfield et al. 1954; Rapp 1955) and one by the US Air Force Air Research and Development Command (ARDC) (NV0026357 [1954]; Luedecke 1955). The ARDC pattern reconstruction has been widely disseminated. It is shown, for example, in Figure 9.105 of *The Effects of Nuclear Weapons* (Glasstone and Dolan 1977). The pattern depicts the principal fallout being constrained within a relatively narrow band, about 170 mi long and 35 mi wide, stretching to the east-southeast of Bikini. This representation also appears on the title page of the report prepared by the Congress of Micronesia concerning medical aspects of the BRAVO incident. It is unfortunate that this illustration has been so widely distributed, since it is incorrect.

The three reconstructions of the BRAVO primary fallout pattern employed radically different assumptions about the initial distribution of radioactive debris within the mushroom cloud. In the NRDL model (Schuert 1955; Steton et al. 1956), the radioactive particles were uniformly distributed, in both size and activity, throughout the visible dimensions of the entire cloud (Figure 3-7). About 90% of the fallout came from the 66 mi wide stratospheric cloud head and only 10% from the 4 mi wide cloud stem. In the RAND model, about 10% of the activity was again in the cloud stem, but most of the remainder was in the innermost section of the lower portion of the stratospheric head; the particle size changed systematically through the cloud, with smaller particles in the top and larger particles in the base (Figure 3-9). The ARDC model assumed that the distribution of particles and radioactivity within the cloud was extremely nonuniform, with 80% of the radioactivity being in the stem and only 20% in the stratospheric head (Figure 3-8). As in the RAND model, the average particle size was assumed to vary with altitude. Fully 40% of all radioactivity was thought to be carried by 70 μm diameter particles located at altitudes between 30,000 ft and 40,000 ft. Nearly half of the radiation was thus assumed to come from just 2% of the cloud, and the massive stratospheric cloud head was taken to be essentially free of radioactive debris.

In brief, ARDC argued that most of the fallout came from the cloud stem with little contribution from the stratosphere cloud head, while both NRDL and RAND assumed that the bulk of the fallout came from the stratosphere, with little contribution from the stem.

As might be expected, these three models for the initial distribution of radioactive particles within the mushroom cloud result in very different primary fallout patterns. The NRDL pattern is very wide, with the inhabited islands located at its extreme edge, as shown in Figure 3-7. The ARDC pattern is relatively narrow, with the inhabited islands located toward its center, as shown in Figure 3-8. The RAND pattern falls between these two extremes, as shown in Figure 3-9. Since all three reconstructions account reasonably well for the radiation data from the contaminated islands, additional information is needed to determine which, if any, is correct. “Because of the absence of observations from large areas of the ocean, the choice of the [BRAVO] fallout pattern . . . is largely a matter of guesswork” (Glasstone and Dolan 1977, Section 9.105).

Fallout from the subsequent 13.5 Mt CASTLE YANKEE test was observed over large areas of the open ocean (Folsom 1955); this was the first time the ocean surface was used as a “fallout trap.” Using equipment and techniques planned and implemented on short notice after the BRAVO detonation, oceanographic methods were used to collect water samples to survey a large area of open sea east of Bikini Atoll. From these measurements, it was possible to determine the fallout pattern for YANKEE, shown in Figure 3-10. Although YANKEE was detonated from a barge instead of a land surface, which tended to reduce the total amount of fallout, it was otherwise similar to BRAVO. To the extent that the YANKEE observations are representative of BRAVO, it is clear that the fallout pattern is best matched by the NRDL model. The ARDC model is not even close.

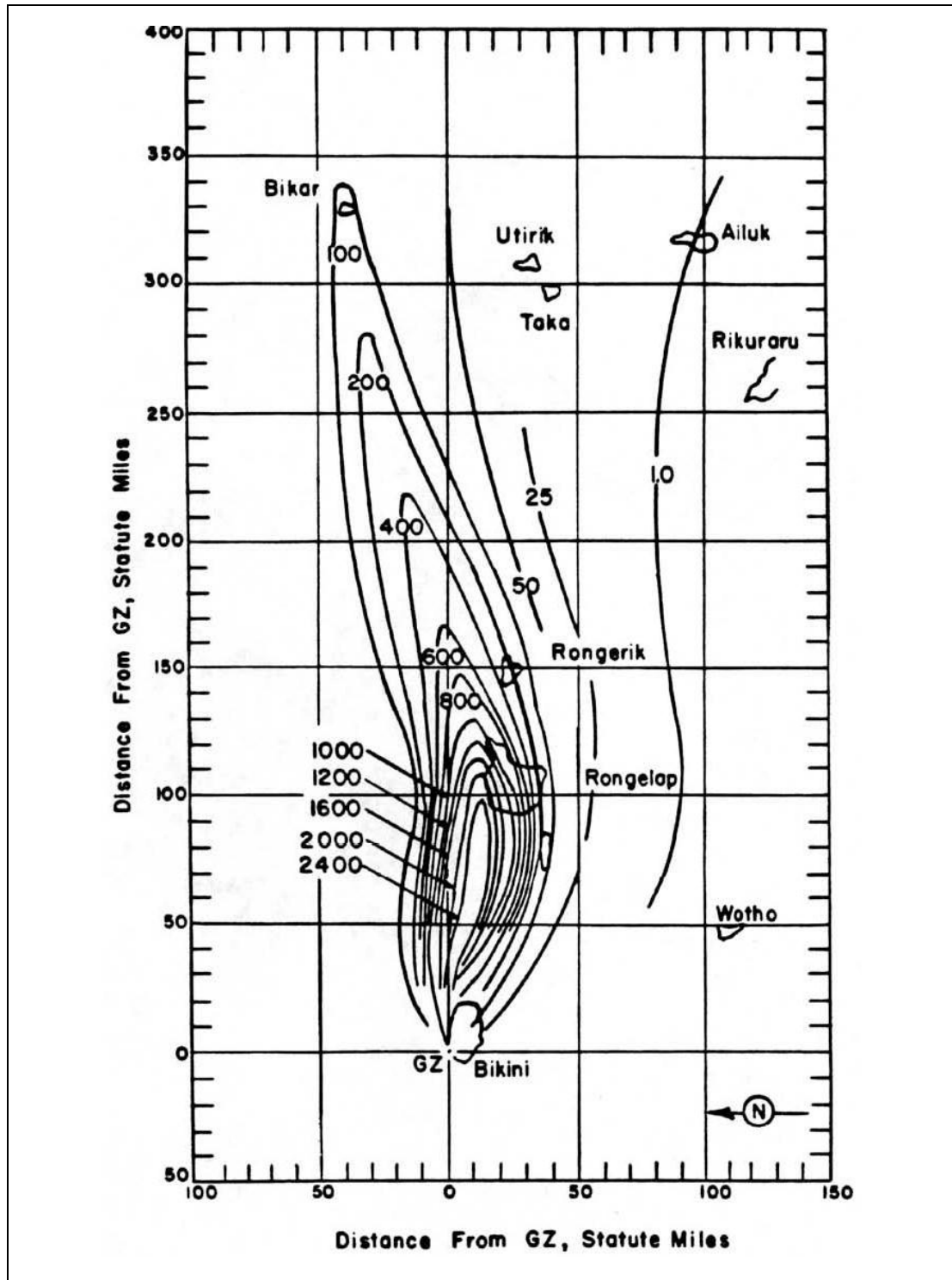


Figure 3-8. ARDC reconstruction of the BRAVO primary fallout pattern
Reproduced from Luedecke (1955); also refer to NV0410526.

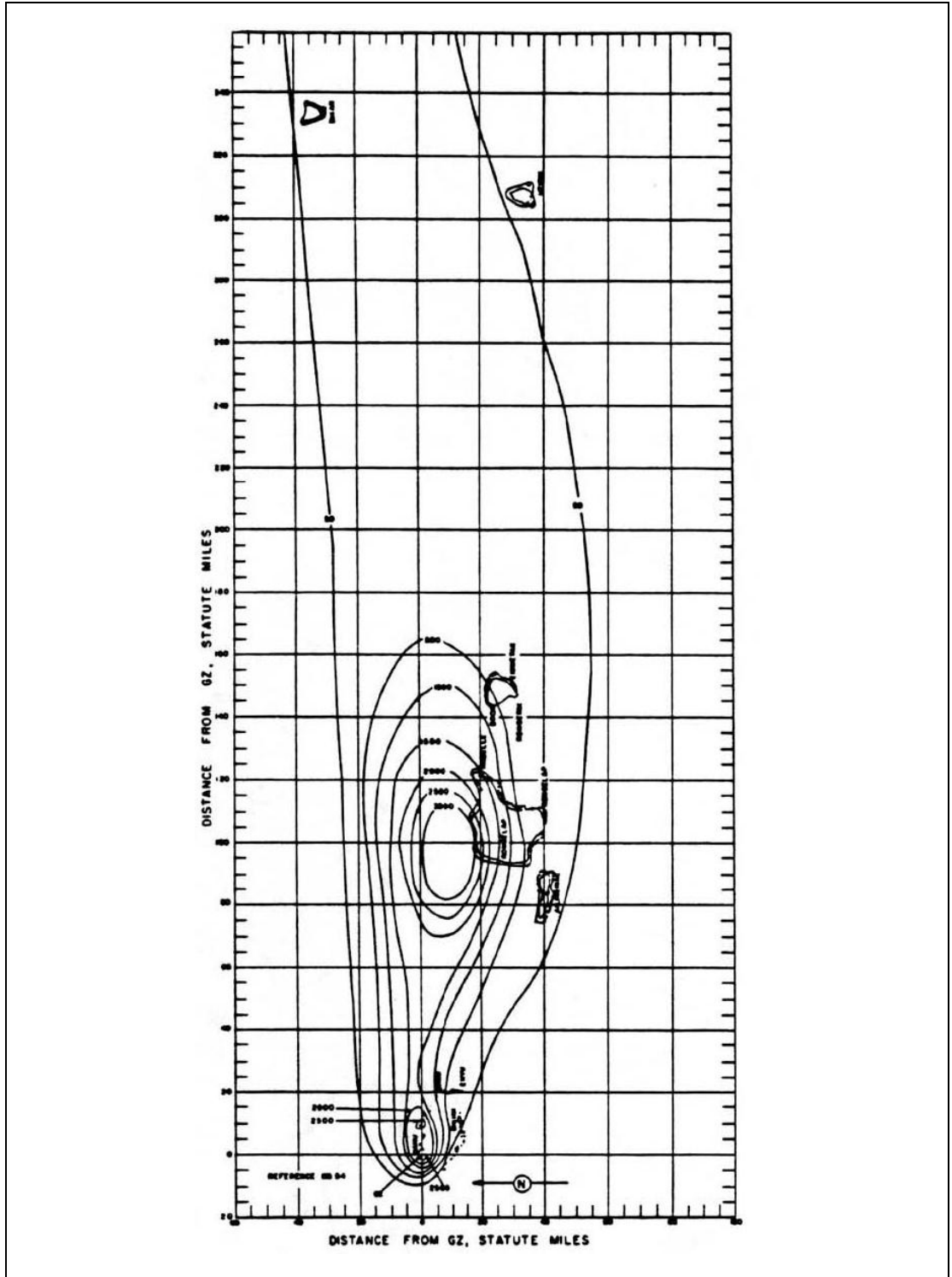


Figure 3-9. RAND Corporation reconstruction of the BRAVO primary fallout pattern
Reproduced from Greenfield et al. (1954); also refer to NV0410526.

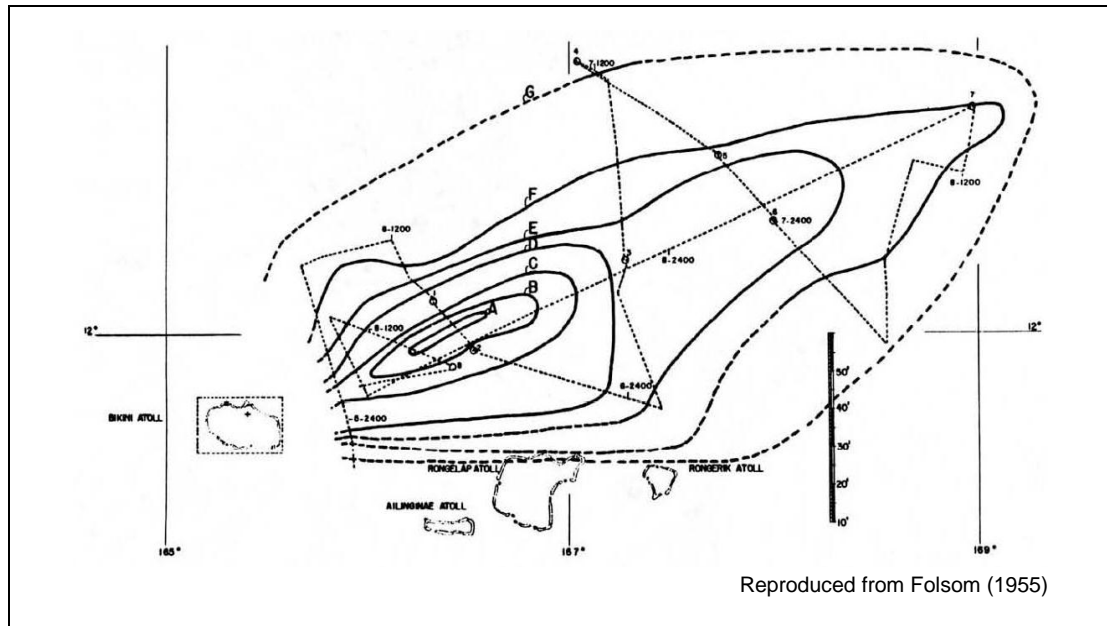


Figure 3-10. CASTLE YANKEE primary fallout pattern

The ARDC model for the distribution of radioactive debris within mushroom clouds was developed from experience with low-yield detonations in Nevada. To reduce the amount of fallout, the test devices were placed atop high towers or dropped from bombing aircraft. Lt. Col. Lulejian noticed that for a fixed height of burst, the relative amount of fallout originating from the stem of the cloud increased as the yield increased (Lulejian 1953a). He thus argued that a surface shot would contain most of the radioactive debris in the cloud stem. In fact, tower shots and airbursts are not at all like true surface bursts. The rising fireball from a tower shot sets up winds that “vacuum” surface dust into the cloud stem (Figure 3-11). In a surface burst, the underlying earth materials are vaporized, melted, and pulverized, and the resulting debris is incorporated directly into the turbulent, rapidly rising fireball. While Lulejian’s model for the initial distribution of radioactive debris was entirely adequate for tower shots, for a surface burst such as BRAVO, it was simply incorrect.



Figure 3-11. The BUSTER CHARLIE detonation was a 14 kt airdrop at the NPG on 30 October 1951. With a height of burst of 1132 ft, the fireball did not touch the ground. The dust stem vacuumed from the desert floor by the rising fireball did, however, reach and penetrate the radioactive mushroom cloud. In this picture, the lighter-toned dust can be seen rising upward through the orange-toned radioactive cloud. The dust is only weakly radioactive at this time. The material in the upper portion of the stem will, however, soon mix with the radioactive debris in the mushroom, and eventually settle back to earth as radioactive fallout.

Which of the three suggested fallout patterns for BRAVO is to be accepted? The preponderance of evidence supports the NRDL reconstruction. This model incorporates actual wind patterns, matches the fallout particle sizes and arrival times observed at the islands and upon the floating platforms (refer to Figure 3-12), accounts properly for the radiation data from the task force cloud tracker aircraft (refer to Section 4.1), and produces a fallout pattern that is in good agreement with that from the CASTLE YANKEE shot. The reconstructions given by Schuert, Steton and Evans (1954) and Steton et al. (1956) are the best estimates of the BRAVO fallout pattern. Lulejian's ARDC model employs an initial debris distribution that had no physical basis and was subsequently shown to be false,²² overestimates the radiation field on the inhabited islands, does not account properly for the observed particle size distributions and arrival times, is inconsistent with the airborne observations, and cannot match the YANKEE results. When Dr. Graves wrote that "the theory that a significant fallout does not come from the stratosphere is not substantiated by the facts of BRAVO," the theory in question was Lulejian's model for the distribution of radioactivity within the mushroom cloud.

Perhaps the single most damning comment on the BRAVO fallout pattern was provided by Lt. Col. Lulejian (NV0026357 [1954]), who wrote:

I am amazed at the similarity of this event with the fallout at Nevada. As a matter of fact, if the JANGLE Fallout Model had been simply extrapolated to the CASTLE Bravo yield . . . then I'm sure that the CASTLE Bravo shot would not have been fired. This is because all Bikini Atoll islands and the islands of Rongerik, Rongelap, and Bikar are clearly in the fallout area even when such a simple extrapolation is used.

This statement, which has become an unfortunate part of BRAVO legend, suggests that simple scaling analyses done before the BRAVO test would have indicated that the shot should not be conducted and that the task force was remiss in not accomplishing this preliminary work.

²² The actual distribution of radioactivity within the mushroom clouds from surface-burst megaton-yield detonations was measured by the Project 2.66a early cloud penetration flights conducted during Operation REDWING in 1956. The dose rate in the head of the cloud was observed to be from 5 to 10 times larger than that in the stem (WT-1320 [1960]).

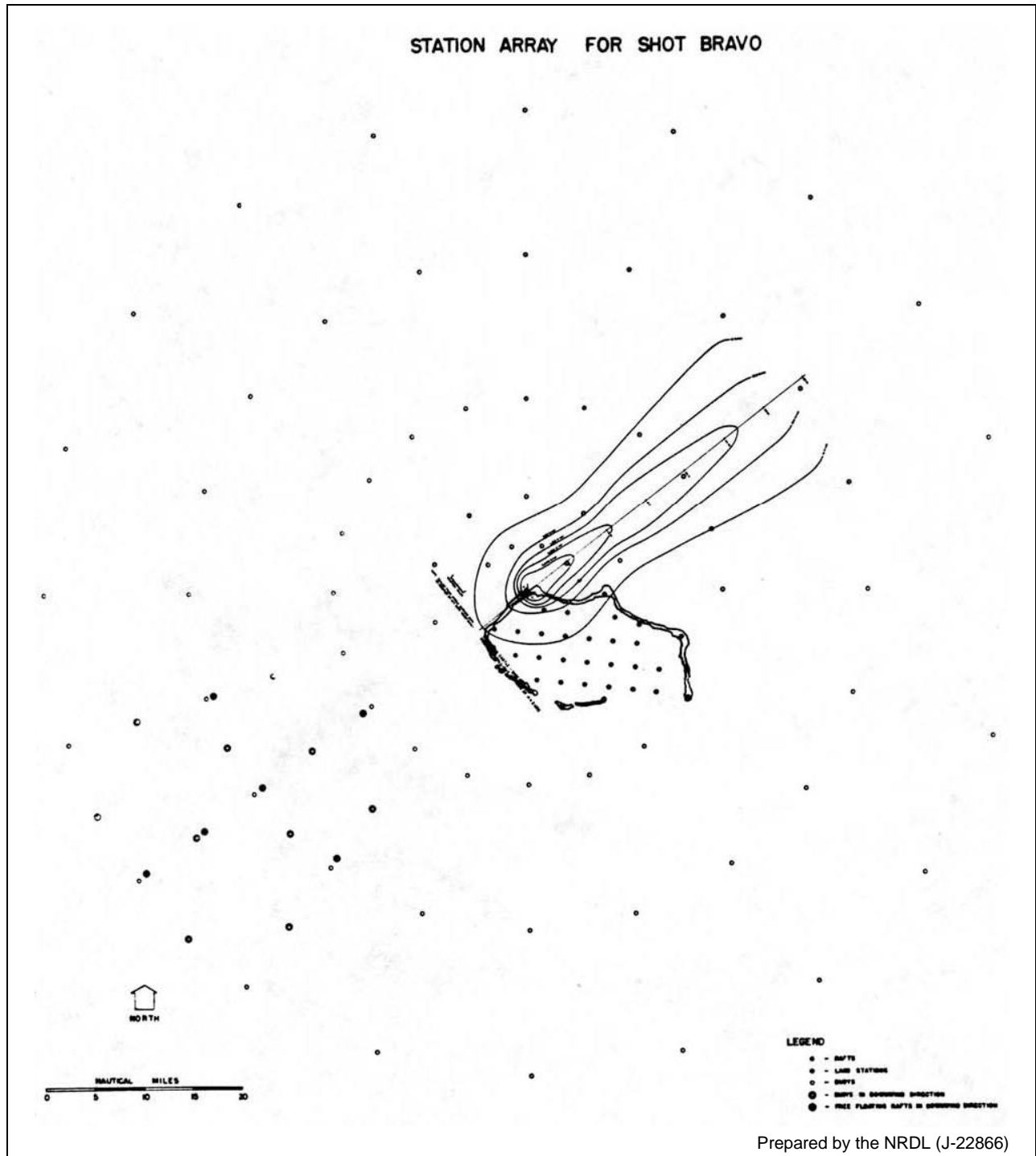
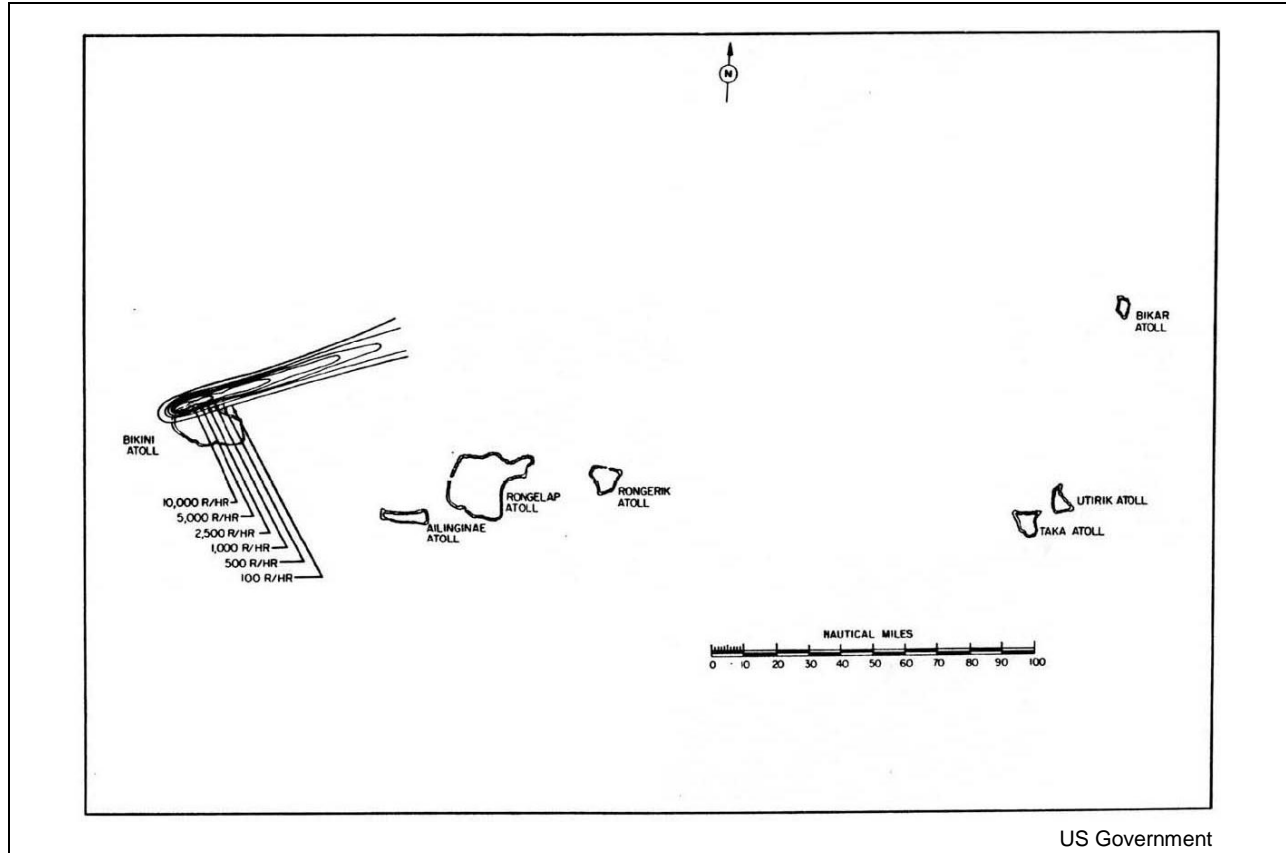


Figure 3-12. Preshot scaling of the JANGLE surface fallout data to the CASTLE BRAVO event
This figure, produced several months before the test, shows the scaled fallout pattern 3 hours after detonation. The dots on concentric circles surrounding the shot site indicate locations of the floating fallout collection platform buoys fielded by Project 2.5a.

In point of fact, “simple extrapolation” of fallout data from the 1.1 kt BUSTER JANGLE surface shot conducted at the NPG in 1951 was done many months before the 15,000 kt CASTLE BRAVO test. As part of the planning for Operation CASTLE, the NRDL scientists scaled the measured contamination from the JANGLE surface detonation in Nevada to the yields of the CASTLE devices (J-22866); the resulting primary fallout pattern is shown in Figure 3-12. After the event, the JANGLE pattern was scaled to the actual device yield by the cube-root relationship (Steton et al. 1956). The resulting primary fallout pattern is shown in Figure 3-13. These “simple extrapolations” in no way account for the actual situation; note in particular that the inhabited atolls are far removed from hazardous fallout. The inability of simple extrapolations to predict the BRAVO fallout pattern is not surprising considering the huge difference in yields between JANGLE and BRAVO, the complex nature of the winds aloft at the PPG, and the contrast between the dry desert alluvium in Nevada and the saturated coral at Bikini. During the planning for Operation CASTLE, it was for these reasons felt that little confidence could be attached to “simple extrapolations” of Nevada fallout patterns to the high-yield Pacific tests.

Lt. Col. Lulejian goes on to claim that his method of “elliptical approximation” would have “clearly indicated” that Rongerik, Rongelap, and Bikar would be in the BRAVO fallout pattern. The implication is that if the Task Force Radiation Safety Organization had done the same analysis before the shot that they did afterward, it would have been apparent that the inhabited atolls would be contaminated. In point of fact, the fallout plot prepared utilizing Lulejian’s method of elliptical approximations and using the actual winds aloft has been reproduced in Figure 3-6. This plot shows the contamination from the tropospheric stem of the BRAVO cloud together with the much larger contribution from the stratospheric head of the mushroom cloud. Hazardous contamination from the cloud stem (dashed contours) is expected only to the northwest of the inhabited atolls. The error in forecasting the BRAVO fallout was that the contribution from the stratosphere was not adequately considered. Contrary to Lt. Col. Lulejian’s widely circulated beliefs on the matter, there was, in fact, significant fallout from the stratosphere.



US Government

Figure 3-13. Postshot scaling of the JANGLE surface fallout data to the CASTLE BRAVO event. Reproduced from Steton et al. (1956).

3.2 Lower Level Wind Effects

An often-told story in the BRAVO lore is that the task force was aware that the winds were blowing toward Rongelap, and that the commander ordered the test to proceed, knowing that these winds would blow fallout to the inhabited atolls. In statements presented at the Congressional Hearing of 24 February 1994, Mr. Weisgall (1994b) noted that the “winds at 20,000 were headed toward Rongelap to the east,” while Dr. Hamilton (1994) wrote that “the wind direction was due east, toward Rongelap, prior to the detonation of BRAVO.” Firth (1987) wrote that “meteorologists at BRAVO knew that winds up to 55,000 feet were blowing in an easterly direction before the awesome device was detonated, yet, unbelievably, their superiors ordered that the explosion proceed.” The clear implication in this piece of BRAVO lore is that the fallout on the inhabited atoll was due to windblown radioactive material from the lower, tropospheric stem of the mushroom cloud. This is not what happened. In view of such claims, a discussion is warranted concerning the actual winds at the time of the detonation and the effects of these winds on the fallout at Rongelap and Rongerik.

The winds aloft forecast was developed from weather measurements made from task force vessels, from the weather island stations, and from aircraft. The forecast winds were summarized in hodographs (refer to Figure 2-4), which are plots of wind velocity as a function of altitude, and in air particle trajectory plots, which show the path a constant-altitude balloon would follow if released over GZ. The forecast air particle trajectories for BRAVO, issued 9 hours before the shot, are reproduced in Figure 3-14. The winds between 20,000 and 55,000 ft were blowing to the northeast, thus moving contamination clear of the inhabited islands to the southeast. The winds at 20,000 ft were predicted to move material slowly to the northeast. The winds at 10,000 ft, just above the trade flow, were predicted to be calm. At altitudes below 8000 ft and above 60,000 ft the trade winds and the Krakatoa easterlies blew directly away from the inhabited islands.

The actual winds aloft trajectories,²³ issued 15 hours after the shot using weather data taken 9 hours after detonation, are shown in Figure 3-15. The actual air particle trajectories for the levels from the top of the trade flow to 20,000 ft are seen to be quite different from forecast. This is the “change in the winds” that has been widely cited as the cause of the BRAVO offsite fallout. Although material from the lower portion of the cloud stem was initially blown in the direction of Rongelap, before moving far in that direction the fallout particles fell out into the trade winds, which carried them back to Bikini (refer to Figure 2-4). The fallout at Rongelap and Rongerik came from the high-altitude bulk of the cloud that was blown to the north of these atolls.

²³ The shot time winds for CASTLE BRAVO and for IVY MIKE were given in a 1956 *Science* magazine article (Machta, List, and Hubert 1956), which discussed the worldwide travel of debris from these detonations.

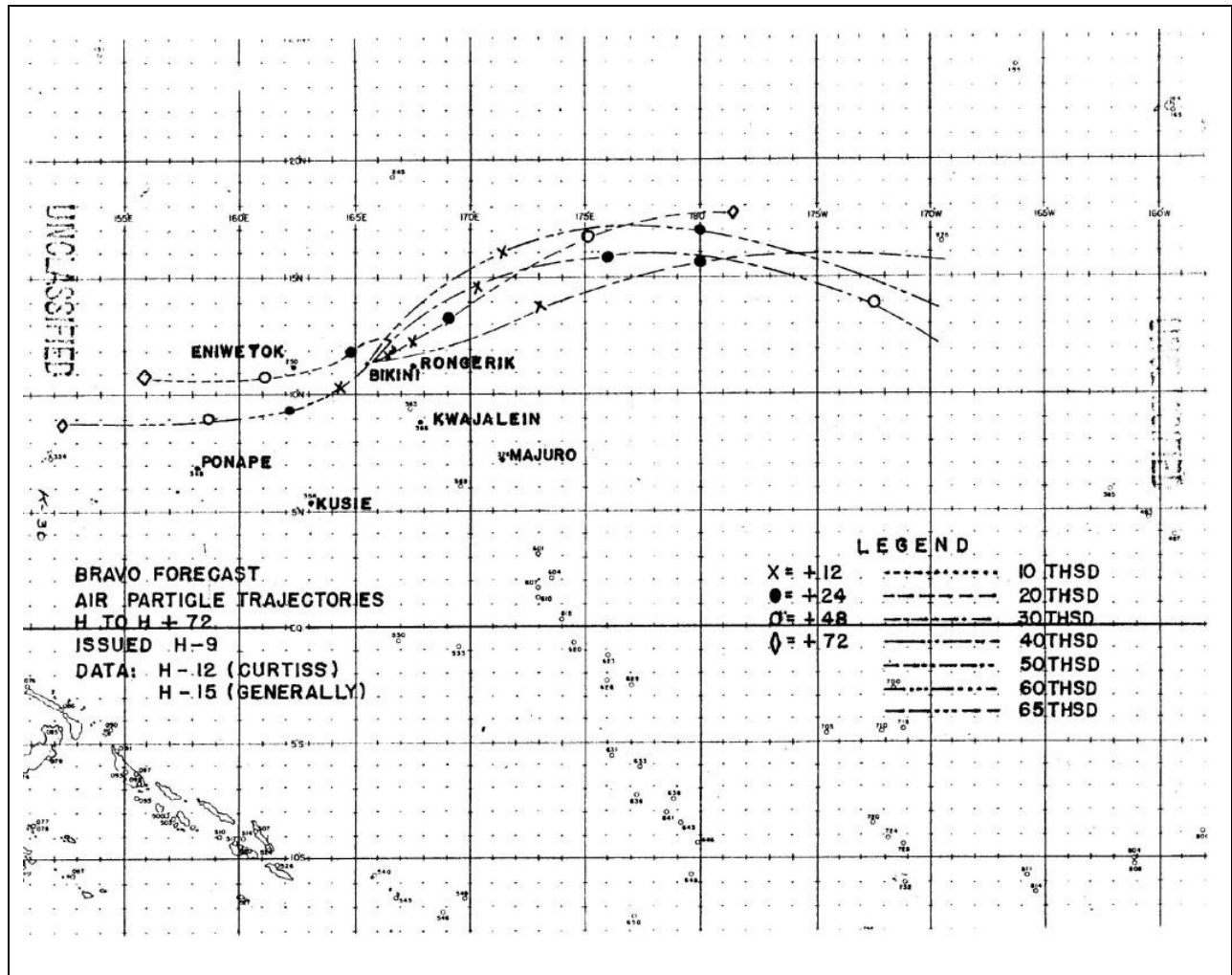


Figure 3-14. Forecast air particle trajectories issued 9 hours before the BRAVO event

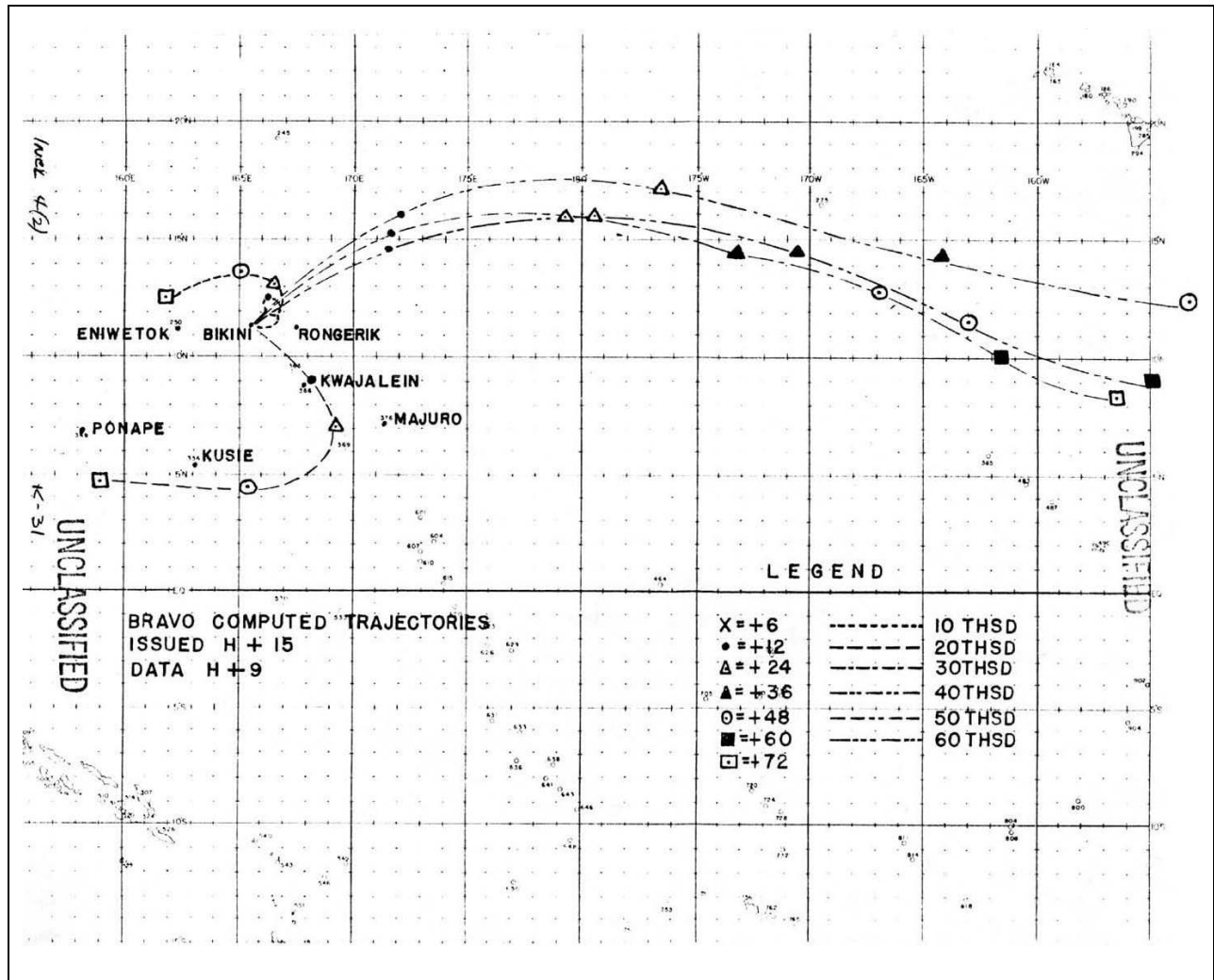


Figure 3-15. Actual air particle trajectories issued 9 hours after detonation

Because of their prominence in the BRAVO lore, the winds at 5000 to 20,000 ft, those said to be blowing “directly toward Rongelap,” deserve special reference. The following paragraph is from the Memorandum for Record of the midnight (01-00:00M)²⁴ Command Briefing (Clarkson and Graves 1954, 15):

In general, the forecast presented at the midnight briefing was confirmed, except that in the levels between 5 and 15 thousand feet the forecast was light and variable. In an attempt to delineate direction to these winds, it was determined that the best forecast that could be given was for the 10 thousand foot level. This was forecast to be westerly at 10 knots as the most pessimistic situation that could occur. Consequently, the hodograph plot was made using the 10 thousand-foot westerly wind in order to present the most pessimistic situation that would occur. This picture gave resultant winds in the direction of Rongelap and Rongerik, however, it was considered that the distance to Rongelap and Rongerik compared to the resultant wind speeds were such that no fall-out should reach those atolls. From the forecast hodograph the time of travel to Rongelap would have been about 12 to 15 hours. . . . Native atolls in the southeast quadrant were discussed at this point and elsewhere in the briefing. The net result of the forecast was that these atolls should remain favorable due to the forecast long time of travel for fall-out to these places. Specifically, Wotho and Rongelap were considered by name and position, these being the closest native populated atolls in the vicinity of ground zero.

As was made clear at the command briefings, the winds between 5000 and 15,000 ft were essentially calm, and a 10 kn speed to the east was assigned as the most pessimistic situation for shot time. It also was forecast that the winds at these altitudes would reverse within 12 hours and blow to the west, away from the inhabited atolls. Assuming the standard settling rate of 5000 ft/hr, radioactive particles would spend only an hour or two in this wind flow regime. Debris initially at 20,000 ft altitude would thus move at the most only 20 mi east before it would drop into the trade winds and be carried back to the west, away from the populated atolls. With this information in mind, the winds from 5000 to 15,000 ft were correctly seen to present no credible threat to the safety of the inhabited atolls.

²⁴ Date and time are indicated in the form “dd-hh:mm.” A following *M* indicates local time in the Marshall Islands, which is 12 hours ahead of Greenwich or “Zulu” time. The BRAVO detonation occurred at March 01-06:45M, that is, at 6:45 a.m. local time in the Marshall Islands on 1 March 1954.

The actual effects of the winds on the BRAVO cloud are shown in Figure 3-4 and in Figure 3-16. Taken from an aircraft positioned approximately 50 nm west–northwest of GZ at an altitude of 10,000 ft, these pictures show the cloud development at 16 minutes and 30 minutes after detonation. The rising sun is seen to the left of the cloud in Figure 3-16; sunrise was at 01-07:15M at an azimuth of 98° true. As anticipated, there was no organized direction of travel at altitudes below 20,000 ft. The lower portion of the radioactive cloud essentially hung above GZ, thus contributing to the heavy contamination near Bikini Atoll. Above 20,000 ft, the stem of the cloud is seen to be moving away from GZ along the forecast path. As indicated by the hodograph and the air particle trajectories, the wind speed increased with altitude up to the tropopause, causing the mid-level portion of the stem to slant toward the northeast. The bulk of the cloud, and the bulk of the residual radioactive debris, was above the tropopause. It was radioactive material from the high-altitude portion of the BRAVO cloud that fell on Rongelap and Rongerik. As is documented by the photography, the lower altitude winds played no direct role in the contamination of these atolls.



Figure 3-16. BRAVO event, 30 minutes after detonation.

This image was taken at a distance of 50 nm west–northwest of GZ from an altitude of 10,000 ft. The rising sun is seen to the left of the stem.

In the information prepared for the postoperation report, the task force weather office constructed summary charts showing wind trends at Bikini and Eniwetok from February through May 1954 (House 1954, I-2 through I-5). The wind-time charts for mid-February through March are reproduced in Figure 3-17. For each 6 hour interval, wind directions between 10,000 and 55,000 ft are indicated as being favorable (cross-hatched shading), marginal but acceptable (stippled shading), or unfavorable (unshaded). A shaded area extending from top to bottom of the chart would indicate an ideal shot day. It can be seen that BRAVO and ROMEO, the first shots in the CASTLE test series, were conducted on the two best possible days in March 1954. A somewhat better day for BRAVO would have been either 27 or 28 February local time. It is ironic to note that all technical preparations had been completed, and that the test could have been conducted on either of these dates, except that the orders to General Clarkson stated that the first detonation was not to occur before 1 March 1954 (NV0101497 [1954]). (This directive was “bent” somewhat when BRAVO was shot on 28 February, local time in Washington, D.C.) Dr. Graves expressed his frustration at the situation in a letter of 17 April 1954 to General Kenneth E. Fields, AEC/DMA (JF-7580 [1954]). “If I ever have anything to do with another operation, which is an unlikely circumstance if I ever heard one, I would propose to get shots ready as soon as possible and fire when the weather is suitable rather than schedule a shot for 1 March for instance.” Never again would Dr. Graves participate in a JTF operation.

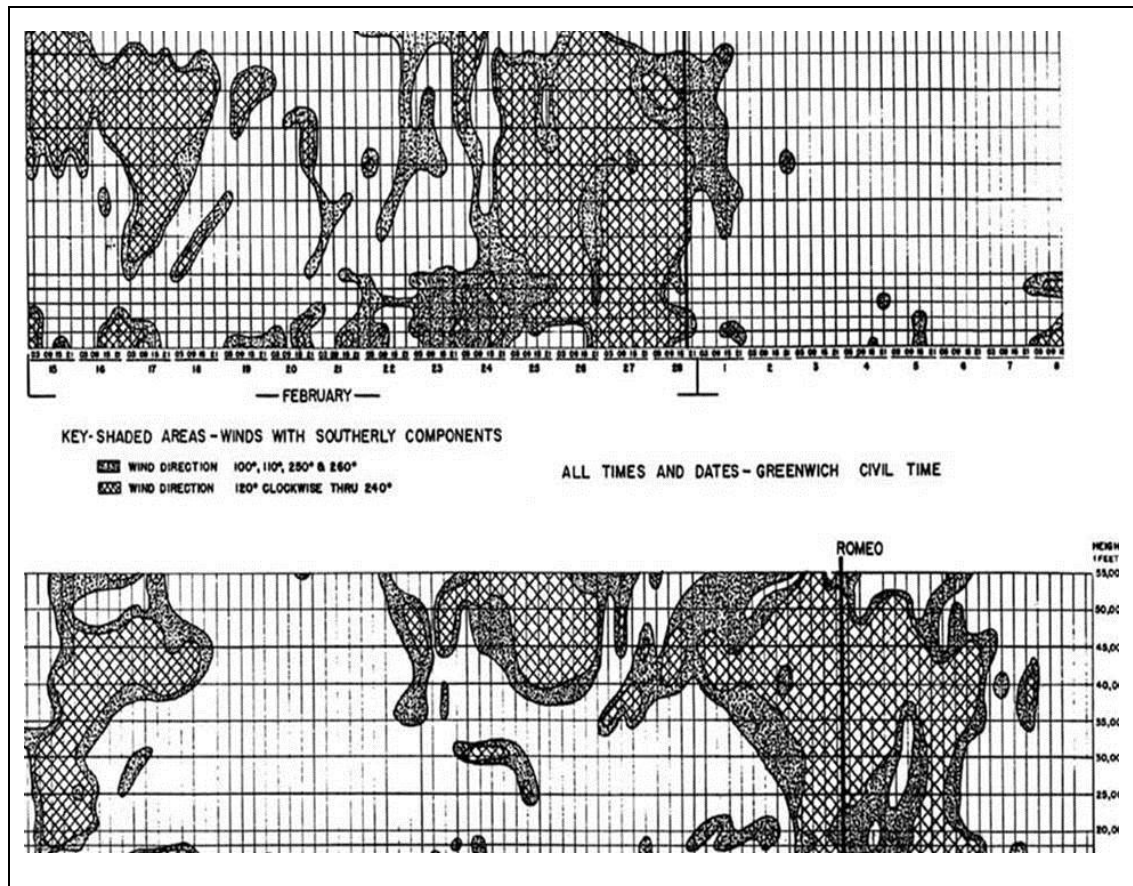


Figure 3-17. Wind-time summary charts for mid-February through March 1954

3.3 A Shift of the Winds

The story is often told that the lower-level winds shifted unexpectedly soon after the BRAVO detonation, and it was this change in the winds that caused the fallout on the inhabited atolls. The “shift of the winds” story first appeared in the press release given by AEC Chairman Lewis Strauss on 31 March 1954 (NV0049192 [1954]), where it stated that “the wind failed to follow the predictions but shifted south of [the predicted] line and the little islands of Rongelap, Rongerik, and Uterik [sic] were in the path of the fall-out.” This story has subsequently been repeated and amplified to become perhaps the single most enduring staple in the BRAVO lore.

It was never the position of the task force scientific staff that the fallout on the inhabited islands was caused by an unexpected shift of the winds. This point is addressed clearly in Conclusion 6.f of the Clarkson-Graves memorandum of 12 April 1954 (Clarkson and Graves 1954):

Forecast for shot time winds at shot time was essentially correct. Variation from forecast trajectories was approximately 10 degrees in significant upper levels: unfortunately, the variation was in the wrong direction. The small variations observed at lower levels were also in an unfavorable direction. Nevertheless, the accuracy of the winds aloft forecast approached the limits of accuracy of the wind observations themselves and were well within the normal forecast error.

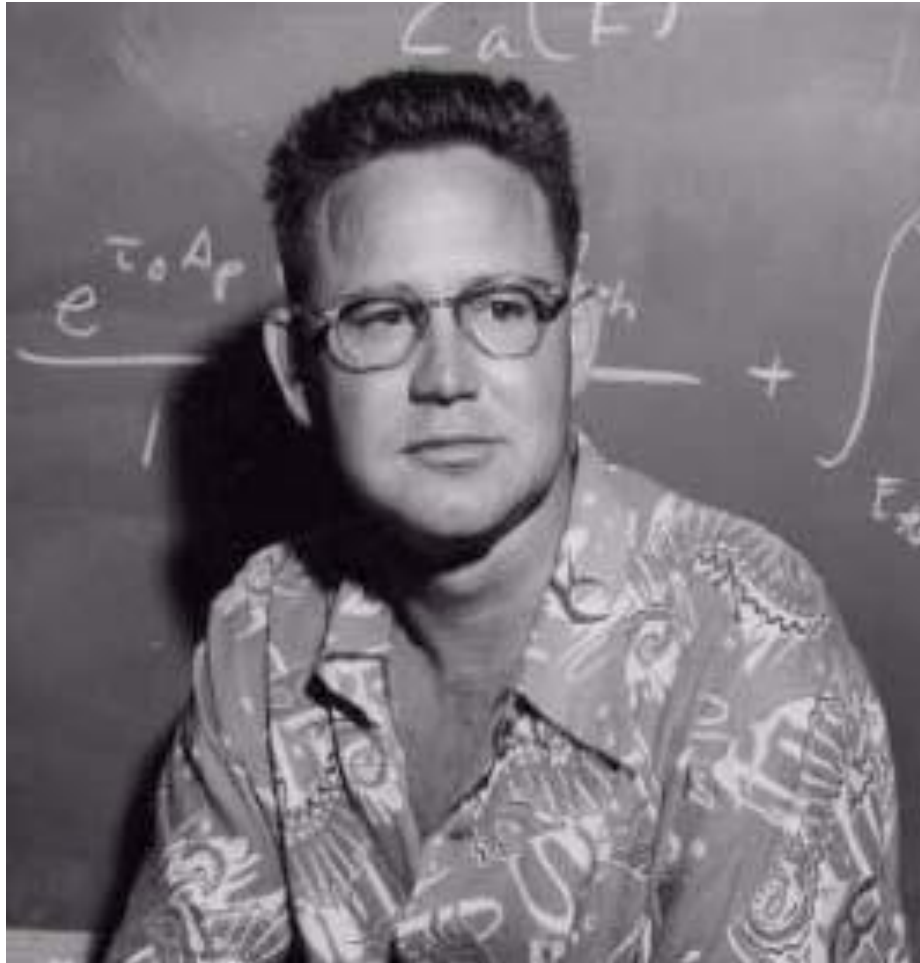
In response to the statement from Chairman Strauss, on 9 April 1954, JTF Command sent a message to AEC headquarters advising that there were, in fact, only small differences between the forecast and the actual winds (NV0116123 [1954]). The task force weather officers were concerned that they had been “unjustifiably placed in a bad light,” and that the statement from Mr. Strauss “had been amplified to the discredit of the Air Force Weather Service.” On 13 April 1954, they sent a memorandum to their commander expressing their views on the situation (NV0093059 [1954]). On 2 June, Brigadier General Howell Estes, commander of TG7.4, wrote to the commander of the Air Weather Service, expressing his concern that “the press releases concerning the 1 March test have misrepresented the quality of the weather forecast.”

Commissioner Strauss’s “shift of the winds” statement was perhaps based on information provided to the GAC on 31 March 1954 indicating that the region in which heavy fallout was then known to have occurred was a very narrow strip, about 20 mi wide (NV0073409 [1954], 13). Such a narrow band of fallout could only have resulted from a relatively small cloud blown directly over Rongelap, Rongerik and Uterik by a “shift of the winds.” As subsequently argued by Luedecke (1955), it is possible that the winds at 20,000 to 30,000 ft did indeed shift enough to cause a small portion of the cloud stem to pass over Rongelap and Rongerik. As detailed in Section 3.1 of this report, this effect contributed in no significant way to the fallout on these islands.

3.4 Yield Effects

The yield of the BRAVO device was much larger than the best preshot estimates. Legend has it that this came as a complete surprise to both the weapon designers at Los Alamos and to the task force, and it was this unexpectedly large yield that caused the fallout on the inhabited atolls.

The 15 Mt yield was not a total surprise. The nuclear device designers and task force scientists thought the maximum possible yield of BRAVO could be this large. This upper yield limit, “which is not expected but should be allowed for in safety considerations,” had been calculated by the Los Alamos nuclear device designers at the specific request of the task force scientific staff, and was communicated to Dr. Graves and Dr. William Ogle, commander of the Scientific Task Group (Figure 3-18), in a radiotelegram sent on 18 February 1954 (JF-2130 [1954]). This same message gives the final estimate of the most probable yield to be substantially less than the maximum possible yield. Throughout Operation CASTLE, it was the policy of the task force that personnel protection measures were to be predicated on the maximum possible yields, while protection measures for “things” were to be based on the most probable yields. In December 1953, even as he pressed the Los Alamos device design team for an official yield statement, Dr. Ogle instructed that shot-time aircraft separations (JF-3069 [1954]) and other personnel safety measures for BRAVO be predicated on his personal perception of an upper-yield limit larger than 15 Mt. His appreciation for the uncertainties inherent in the nuclear device may have prevented prompt loss of life in the detonation.



Photograph taken during Operation CASTLE

Figure 3-18. William Ogle, commander, TG7.1, scientific group

Although the 15 Mt yield certainly contributed to the BRAVO off-site fallout, it only exacerbated the situation. Had the design yield occurred, the inhabited atolls still would have been contaminated. This is because the height and shape of the resulting mushroom cloud do not depend strongly on the yield of a nuclear device. Had the BRAVO yield been closer to design, a very large stratospheric cloud still would have formed. This point is illustrated by the behavior of the 7 Mt CASTLE UNION event (refer to Figure 3-19). The cloud from UNION rose to a height of 94,000 ft, and spread in 10 minutes to form a still rapidly growing stratospheric cloud 45 mi in diameter (WT-933); these values are not greatly different from those of BRAVO. It is evident that had the BRAVO yield been near design, the stratospheric cloud still would have been so large that fallout would have occurred on Rongelap and Rongerik. In actuality, all of the Operation CASTLE tests conducted at Bikini resulted in measured contamination at Rongelap (Breslin and Cassidy 1955; also refer to Table 4-1). The high yield of the BRAVO device was not in itself the cause of the fallout on the inhabited islands.



Figure 3-19. The CASTLE UNION nuclear cloud
This image was taken 9 minutes after detonation from an altitude of 40,000 ft,
and at a distance of 50 nm east of GZ.

3.5 Testing Techniques

A major difference between BRAVO and UNION was that BRAVO was detonated on an artificial extension of Namu Island (refer to Figure 3-20)—in essence over a coral reef covered by shallow water—while UNION was detonated on a barge in the deep water of the lagoon. The BRAVO cloud, therefore, contained more large solid particles, principally the remains of the reef, than did UNION. Since it is the larger solid particles that fall quickly back to earth, the local fallout potential was greater for BRAVO. In an attempt to reduce the local fallout from the high-yield CASTLE tests, and to prevent needless destruction of real estate, the techniques required for fielding the nuclear devices on barges were developed by the task force (J-15297D [1952]), and four of the six shots were done from barges (Figure 3-21 through Figure 3-24). The task force was well aware of the potential for contamination from the high-yield CASTLE detonations, and developed the shot barge testing technique in part to reduce the local fallout from these tests.²⁵

²⁵ Not everyone agreed that reducing the local fallout was a good idea. Dr. Willard Libby, head of the SUNSHINE project and a member of the GAC to the AEC, believed that radioactive materials clinging to the surface of the coral debris would be scavenged from the mushroom cloud as local fallout. “Hence, there might be a much greater danger of distant [global] contamination in the case of barge shots” (NV0073409 [1954], 27). Increasing local fallout by sacrificing reefs and islands was thus viewed as a benefit; others on the committee regarded this thesis as implausible and unproven. Since sufficient data were not available, the disagreement remained unresolved. However, by Operation REDWING in 1956 Libby was a commissioner, and, regardless of the scientific merit of the idea, he insisted that silica sand be placed aboard the shot barges in an attempt to reduce global contamination by increasing the local fallout. Given the relatively trivial amount of sand that could be placed in the ballast tanks of the barges, this had no perceptible effect whatsoever on the fallout, local or global (Ogle 1985, 27). In a similar vein, the Operation HARDTACK OAK event was moved from a comparatively deep mooring in the lagoon at Bikini Atoll, to a position on the reef at Eniwetok Atoll in order to increase the proportion of solid particles in the radioactive cloud.



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Figure 3-20. The BRAVO shot islet

Looking to the southwest, the vacuum line-of-sight pipes ran along the causeway to the recording bunker on Namu Island, out of frame to the left. The towers rising from the shallows around the cab contained turning mirrors to image the nuclear fireball.



Figure 3-21. Operation CASTLE device barge
The second shot, ROMEO, was carried on a barge moored in the BRAVO crater.
Photograph taken on 4 March 1954.

BRAVO was the most highly instrumented shot of Operation CASTLE. Despite its appearance, the BRAVO device was not a weapon. It was an experiment to gain the basic data needed to design practicable high-yield nuclear devices. Because extensive diagnostics measurements were required to determine whether it worked as anticipated, it was necessary to locate BRAVO on a land surface. For these same reasons, the KOON shot of 6 April 1954 was executed on the ground surface at Eninman Island.

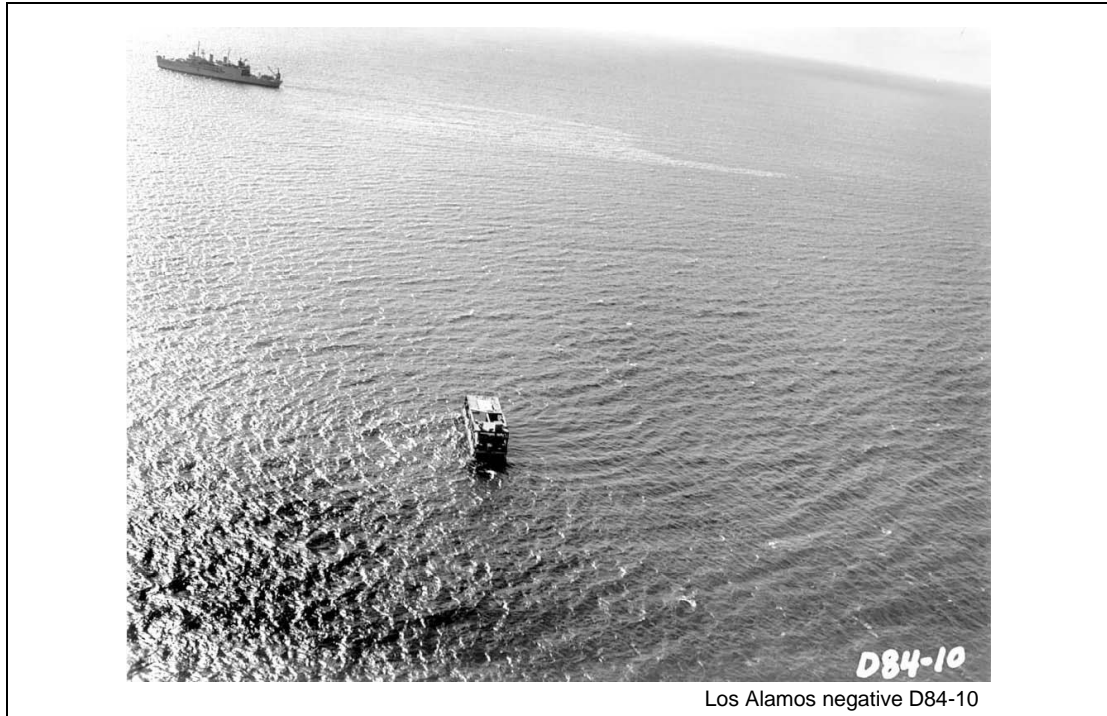


Figure 3-22. The UNION device barge
For the UNION test of 25 April 1954, the device was carried on a barge moored in the lagoon 1 mi from the reef off Yurochi (DOG) Island. This same location was subsequently used for the YANKEE test of 4 May 1954. Photograph taken on 29 January 1954.

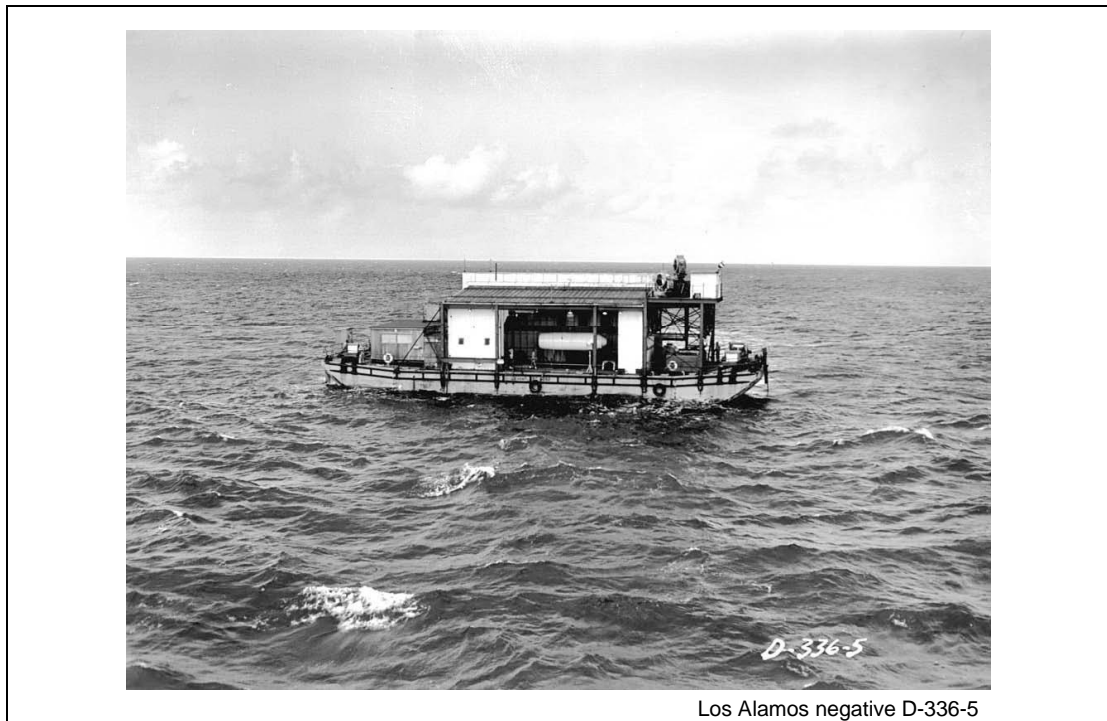


Figure 3-23. The NECTAR shot barge
The last test of Operation CASTLE, NECTAR, was conducted from a barge moored in the MIKE crater at Eniwetok Atoll. Photograph taken on 5 April 1954.



Figure 3-24. The YANKEE device in a barge cab
YANKEE was detonated on 4 May 1954 from atop the UNION crater in the lagoon off Yurochi Island.

During the early planning of Operation CASTLE, consideration was given to conducting one or more of the tests as airdrops (J-17833 [1953]). This would dramatically reduce the amount of fallout. For the IVY KING test of November 1952, air detonation had proven entirely satisfactory. However, about the only weapon diagnostic information needed or obtained from KING was the device yield. The CASTLE test devices were much more complicated and unproven, and the diagnostic experiments were of the highest importance. It was evident that they could not be air dropped with sufficient accuracy to permit successful diagnostic measurements, and that “it seems unsound to plan an airdrop in a [test] series in which obtaining information is of paramount importance” (J-18980 [1953]).²⁶

²⁶ The first airdrop of a megaton-yield weapon was conducted in 1956 as the CHEROKEE test of Operation REDWING. The bomb fell about 4 mi distant from the intended explosion point, and nearly all device diagnostic information was lost.

Safety was an additional consideration in the decision not to conduct any of the Operation CASTLE tests as airdrops. Given the anticipated weights of the CASTLE test devices, there was doubt whether even the 10-engine Consolidated Vultee B-36D *Peacemaker* heavy bombing aircraft could carry any of them off the Eniwetok runway (Figure 3-25). It would have been necessary to use Hickam Air Force Base (AFB), Oahu, Hawaii, for final device assembly and takeoff (J-18928 [1953]). The CASTLE devices were not military weapons, and did not contain the safety features to prevent accidental detonation that were incorporated into production units. As put by Dr. Bradbury, the Director of Los Alamos Scientific Laboratory, “the possibility of taking off in the vicinity of Honolulu under these circumstances is a very dubious one.”



Figure 3-25. The Consolidated Vultee B-36D heavy bombing aircraft was the largest ever in service. Although this aircraft was used to drop the IVY KING device in November 1952, even it was not sufficiently powerful to safely carry any of the CASTLE test devices. Photograph taken at Eniwetok, 24 February 1954.

3.6 Device Considerations

Five high-yield tests were conducted during Operation CASTLE. Each of these resulted in measurable contamination on inhabited islands throughout the central Pacific and contributed to the burden of global fallout. A common perception in the lore is that the task force was a collection of “boys with toys,” and that nuclear devices were detonated nearly at whim. As was more delicately put in the 1956 *Report of the Committee on Genetic Effects of Atomic Radiation*, “[t]he question arises in the minds of many thoughtful persons whether the number and power of bombs exploded in the tests are being kept at the minimum consistent with scientific and military requirements.”

In fact, the principal of keeping to a minimum the number and power of the bombs exploded was observed during Operation CASTLE.

Several types of experimental thermonuclear weapon designs were to be tested during Operation CASTLE (Figure 3-26). The success of the Los Alamos BRAVO device made certain other types of device designs instantly obsolete. The Los Alamos device then intended for detonation as CASTLE YANKEE was one such suddenly obsolete design. Although the device itself was already on-site and assembled, and elaborate test preparations were far advanced, Dr. Graves and Dr. Ogle decided to cancel the shot (*Science* 3128 [1954]). For the many people who had devoted years of their lives to the project, this was a great disappointment. From a financial point of view, vast sums already had been expended, and it would now be necessary to spend even more to disassemble the device and ship the pieces home. But as Dr. Graves explained to both Los Alamos senior management and AEC headquarters, this might well have been the highest-yield American device ever tested, and there was insufficient justification for such a detonation. Later in the CASTLE series, a second test was stricken. Based on the results of the Livermore KOON event, it was evident that a nuclear device to be tested in a subsequent shot would not work as intended, and once again, although the device was ready to go, the test was cancelled.



Figure 3-26. Task force scientists Don Ehler (Los Alamos) and Herbert York (Livermore) in General Clarkson's briefing room with models of the devices to be tested, 17 March 1954

3.7 The Danger Area

There is evident confusion in the BRAVO lore concerning the purpose of the Danger Area encompassing the PPG. The Danger Area²⁷ in effect during Operation CASTLE was a rectangular area stretching about 335 mi east-to-west and 150 mi north-to-south. A common perception is that the Danger Area included all locations in which significant fallout might occur, and that the task force expected anyone outside of the Danger Area to be safe from harm; refer to, for example, Lapp (1958, 160) or Weisgall (1994a).

²⁷ Various types of navigational restrictions for special-use areas are recognized by international law. These include Prohibited, Alert, Danger, and Restricted or Warning zones. Such areas are indicated on navigational charts by internationally recognized numerical identifications. Notices to Airmen and Mariners designate limited-duration exclusion areas. In the spring of 1954, the United States had a total of 447 Warning and Danger areas.

In fact, the Danger Area was of little significance for radiation safety purposes (NV0101430 [1952]). It was, instead, an exclusion zone routinely patrolled by task force security ships and aircraft. The area was established “to deny information to enemy nations as to the yields of the devices being tested” (JF-3803 [1954]). As in previous operations,²⁸ there was lingering concern that foreign powers might attempt an attack for “the obvious aim of neutralizing our atom bomb superiority for a considerable period of time by canceling out a large number of our specialists” (NV0069943 [1948]). Task force security ships and aircraft were therefore specifically authorized to attack and destroy unresponsive intruders within the Danger Area. The principal danger for unauthorized aircraft and vessels was not radiation, but the possibility of being sunk or shot down.

The exclusion area surrounding Eniwetok Atoll and the PPG was first established on 2 December 1947 by US State Department notification to the United Nations (NV0029635 [1954]). Following the SANDSTONE test series, the decision was made to continue the closure for an indefinite period, and necessary international notices were posted. The original Danger Area remained in effect through Operation GREENHOUSE and Operation IVY. When consideration was given in late 1952 to expanding the PPG to include Bikini Atoll, an enlarged exclusion area was proposed. The original configuration of the enlarged Danger Area arbitrarily set the eastern boundary 60 nm east of Bikini, a location crossing just to the west of Rongelap Atoll. Enforcement of this boundary would have cut Rongelap off from nearby Ailingnae, a location essential to the Rongelap people for fishing and gathering breadfruit. Strict enforcement of security provisions might have necessitated removal of the civilian population (Thomas 1953). After due consideration, the Chief of Naval Operations concluded that the civilians resident at Rongelap presented no threat whatsoever to the security of the task force, and the boundary could be moved safely to meet their needs. Following the recommendation of the high commissioner (Thomas 1953), the boundary was adjusted to lie just west of Ailingnae Atoll. The expanded exclusion area was officially closed by United Nations action on 2 April 1953.

The region in which potentially harmful fallout might occur was a pie-shaped sector 15 mi in initial diameter and 30° in angular width extending 500 mi outward from the shot site. This region of potential radiation hazard was known as the “Significant Quadrant.” Its orientation was determined by the winds aloft, and thus varied from shot to shot. The entire area was swept for transient ships and aircraft before and after each test. The Significant Quadrant was, of course, not permitted to include inhabited islands.

²⁸ Robert Burns’s Associated Press story of 23 August 1995 gives information concerning physical security during Operation GREENHOUSE in 1951. This story ran in the *Santa Fe New Mexican* under the headline “U.S. feared Soviets would try to take ‘atomic wonderland.’”

4.0 Radioactive Contamination

The value of historical measurements is immense.

—Dr. Steve Simon, Director of the Nationwide Radiological Study,
Republic of the Marshall Islands



Figure 4-1. The radiation survey party comes ashore on Rongelap Island, 20 April 1954

Radioactive contamination from the BRAVO detonation was detected on many of the islands and atolls in the central Pacific. The amounts of fallout from BRAVO, and from the other five Operation CASTLE nuclear tests, were documented by airborne radiation monitoring; fixed instruments located on islands; surface radiation surveys; and water and soil sampling at the most heavily contaminated locations.

In planning for Operation CASTLE, the AEC and the Department of the Army decided that the JTF would be responsible for radiological monitoring within the Danger Area, and for tracking the radioactive clouds as they drifted away from the shot sites. The task force thus established a program that included both extensive fallout measurements within the Danger Area, Project 2.5a (J-22866), and specially outfitted aircraft to follow the radioactive clouds as they moved over the ocean. The responsibility for documenting radiation contamination at locations outside the Danger Area was assigned to the Health and Safety Laboratory (HASL) of the New York Operations Office (NYOO), working with the US Navy CINCPAC. HASL, thus, established a program for off-site monitoring that included both ground stations on islands throughout the central Pacific and long-range patrol aircraft outfitted with sensitive gamma-ray detectors to measure surface contamination levels. This was the same basic division of responsibility for radiation monitoring established for the IVY test series (Bugher 1953).

4.1 Airborne Radiological Surveys

Airborne monitoring was conducted by the Task Force WILSON cloud-tracking aircraft and the HASL aircraft. The WILSON cloud trackers were Air Force Boeing WB-29 modified heavy bomber aircraft provided by TG7.4 (Figure 4-2). Their plan of operation is documented in NV0051031 ([1954] 37 through 43). This plan was developed in the fall of 1953, in coordination with CINCPAC, the military organization responsible for off-site safety (NV0051031 [1954], C-16). Because they were intended for shot day monitoring, the WILSON aircraft were configured to operate in radiologically “hotter” conditions than the HASL aircraft. HASL flights were not made on shot days so that their highly sensitive instruments, intended to detect relatively low levels of surface fallout, would not be rendered impotent due to flight through contaminated air. Since the purpose of the HASL survey flights was to document the amount of fallout outside the Danger Area, it was necessary to wait until the radioactive cloud had passed the area of interest before it was surveyed.



Figure 4-2. The task force WB-29 WILSON cloud tracker, Eniwetok, 12 February 1954

Planning for the HASL radiation measurement program began with a CINCPAC conference held on 24–25 July 1953 (Eisenbud 1953). Survey patterns were planned (NV0051031 [1954]; also refer to NV0051072 [1954] J-24 and HASL-154 [1953]) that utilized Lockheed P2V *Neptune* patrol bomber aircraft from US Navy Patrol Squadron Twenty-Nine (VP-29) (Figure 4-3). NYOO survey pattern flights ABLE, BAKER, and CHARLIE originated from Kwajalein and covered the northern and southern Marshall Islands, and the islands to the southwest. Flights GEORGE and ITEM originated from Oahu and covered the Hawaiian Islands, while flight EASY originated from Guam and covered that area. These six survey missions were routinely flown after each shot. One special survey flight, KING, was flown on 6 March 1954 to monitor the Gilbert Islands for contamination from BRAVO. British authorities approved this flight, and the results were forwarded to the US Naval Attaché, London, to inform the British government (JF-4806 [1954]). These seven survey patterns comprised a total air distance of approximately 9500 nm. A total of 71 islands and atolls throughout the central Pacific were monitored.



Figure 4-3. HASL Navy P2V *Neptune* fallout monitor, Fred Island (Eniwetok),
12 February 1954

Follow-up survey missions were flown over routes on which substantial fallout had been detected in the course of the initial survey. These supplementary surveys were intended to confirm radioactive decay computations and to detect and measure any possible “secondary” fallout. Secondary fallout was a phenomenon first observed after the IVY MIKE detonation as a period of relatively minor contamination occurring approximately 24 hours after the initial, primary fallout had terminated. It was probably due to debris, initially carried east at high altitude, falling down to the trade winds, and then being blown back in a western direction and deposited on islands near the test site. This secondary fallout did not prove to be significant (refer to Appendix A) from the standpoint of radiological hazard (NV0011020 [1954]).

The results of the aerial surveys conducted during the first 5 days following the BRAVO detonation are given in the Memorandum for Record by Lt. Col. R. A. House written on 19 April 1954 (NV0051072 [1954], H-42). This document was declassified for public release on 8 June 1979. The information was supplied to Lt. Col. House by Mr. Breslin, the HASL supervisor aboard the USS *Estes*. Comprehensive records of the airborne surveys are given in the original, unclassified, handwritten HASL records from 1954 (NV0011020 [1954], NV0011025, NV0011028, and NV0011030) and in the formal report, *Radioactive Debris from Operation CASTLE, Islands of the Mid-Pacific* (Breslin and Cassidy 1955). The ABLE survey of the northern Marshall Islands was flown a total of 15 times during Operation CASTLE; the BAKER survey of the southern islands was flown 7 times. A total of 27 survey flights were conducted. Surface gamma-ray intensities following the BRAVO detonation are reported for many of the individual islands within the atolls visited by these flights.

4.2 The HASL Fixed Instrument Network

A second source of fallout data came from the automatic recording radiation monitors placed by HASL on Majuro, Kwajalein, Rongerik, Ujelang, Wake, Johnston, Kusaie, Ponape, Truk, Yap, Guam, and Iwo Jima (HASL-154 [1953]). This “fixed instrument network” recorded fallout gamma-ray intensities throughout Operation CASTLE. The stations at Rongerik, Kwajalein, Kusaie, Ponape, Truk, Guam, and Ujelang also monitored for beta-dust contamination, but this effort was largely unsuccessful due to equipment failures. The individual station records are shown graphically in NV0011020 [1954], along with a table reporting cumulative doses. A summary table giving radiation, dust, and precipitation readings at 6-hour intervals in the period from 20 February to 18 May 1954 is in NV0011025. This and additional information is given in NYO-4623 (1955).

4.3 Soil and Water Sampling

The final source of fallout data comes from surface radiation surveys, and from soil and drinking water samples collected in the northern Marshall Islands during the weeks after the BRAVO detonation. Samples were taken from Likiep, Jemo, Ailuk, Mejit, Utirik, Ormed (Wotje), Kaven (Maloelap), Wotho, Dalap (Majuro), Rongelap, and Eniwetok (Rongerik) islands. Teams of scientists journeyed by ship or amphibian aircraft to the various islands to collect these samples (Figure 4-4, Figure 4-5, and Figure 4-6). A survey on 6 and 7 March to Likiep Atoll, Jemo Island, Ailuk Atoll, and Mejit Island by the USS *Renshaw* (DDE-499) found contamination readings of about 3 mR/hr at these locations (Crea 1954; Bell 1979). A Navy amphibian aircraft was used for survey trips on 5–7 March to the Wotje, Erikub, Maloelap, Wotho, and Majuro atolls, where similar contamination was found (White 1954). The USS *Nicholas* (DDE-449) (Figure 4-4) carried a survey party to the four most heavily contaminated atolls on 8–10 March (Scoville 1954). These same sample collection mission reports are in NV0051072 ([1954] Tab H), and additional information is contained in *Operation CASTLE, Radiological Safety* (WT-942 [1954]).



DTRIAC item 22-1290

Figure 4-4. The radiation survey party from the USS *Nicholas* (DDE-449) lands at Rongelap Island. Note anticontamination booties worn over shoes. 9 March 1954.



DTRIAC item 22-1021

Figure 4-5. Mr. Strobe taking sand samples for radiation tests, Sifo Island, 10 March 1954



DTRIAC item 22-1122

Figure 4-6. First Lt. W. J. Larson gathering soil samples, Utirik Island village, 3 March 1954

Drinking water samples from Rongelap, Kwajalein, and Utirik islands also were obtained and analyzed. The initial samples from Rongelap, collected during the evacuation on 3 March, were followed to the end of the operation for decay characteristics (refer to Figure 5.2 in WT-942 [1954]). The specific activity of these samples indicated that the water was contaminated from 2 to 25 times above the AEC operational tolerance. No appreciable activity was found in drinking water at Naval Station Kwajalein. Samples taken on the survey trip to Rongelap and Utirik islands on 8–10 March indicated an average specific activity of less than one quarter of the operational tolerance; two samples from Rongelap contained no activity.

In late April, the *Philip* (DDE-498) traveled to the Rongelap and Utirik atolls (NV0051072 [1954]; NV0407636). During this expedition, additional soil and water samples were obtained, and radiation measurements made. The atoll magistrates were brought along, and they directed efforts to preserve and safeguard valuables left behind during the evacuation.

4.4 Summary of Radiation Exposures

A summary of Operation CASTLE radiation exposures throughout the Marshall Islands and at other locations in the central Pacific as determined from the HASL aerial surveys is given in Table 4-1; the information is taken from NYO-4623 (1955). This table gives cumulative whole-body external gamma radiation doses that would have been received by an individual living at the listed location continuously during and after the CASTLE test program. It is important to note that these radiation dose determinations may not be the best available, and do not include internal exposures. At locations where ground surveys were made, or repeat aerial surveys flown, more accurate dose estimates may exist. For example, Maynard (1954) estimated a total exposure at Ailuk of 13,000 mR, while Table 4-1 indicates only 5000 mR at this heavily populated atoll.

Table 4-1. Operation CASTLE cumulative doses by event and location (exposures in milli-Roentgen)

Island	BRAVO: 15 Mt (mR)	ROMEO: 11 Mt (mR)	KOON: 0.11 Mt (mR)	UNION: 6.9 Mt (mR)	YANKEE: 13.5 Mt (mR)	NECTAR: 1.69 Mt (mR)	Total (mR)	Distance from Bravo GZ (mi)
Lae	5.5	12	12	7.5	78	9.5	125	174
Ujae	6	32	17	9.5	48	1.4	114	155
Wotho	250	270	110	55	95	4	784	125
Ailinginae	60,000	3400	3300	8	600	70	67,000	90
Rongelap	180,000	11,000	6000	3400	1700	300	202,000	125
Rongerik	190,000	9000	5000	550	1400	280	206,000	155
Taongi	280	60	9.5	10	10	no dose	370	300
Bikar	60,000	3000	1200	650	1700	150	67,000	340
Utirik	22,000	1200	700	100	330	50	24,000	315
Taka	15,000	800	1000	120	380	50	17,000	310
Ailuk	5000	410	110	100	500	20	6140	315
Jemo	1200	410	130	18	200	20	1978	320
Likiep	1700	170	80	30	200	16	2196	310
Namu	1.8	90	10	0	25	0	216	335
Ailinglap	7.2	140	100	8	0	0	255	390
Namorik	20	160	70	2	0	0	252	470
Ebon	20	250	50	8	25	0	353	550
Kili	20	200	70	0	0	1.3	291	500
Jaluit	20	300	70	8	0	2.6	401	500
Mili	60	160	200	20	0	1.3	441	600
Arno	60	200	300	8	25	1.3	594	560
Majuro	200	200	50	20	0	1.3	471	535
Aur	40	200	50	8	40	2.6	341	475

Table 4-1. Operation CASTLE cumulative doses by event and location (exposures in milli-Roentgen)

Island	BRAVO: 15 Mt (mR)	ROMEO: 11 Mt (mR)	KOON: 0.11 Mt (mR)	UNION: 6.9 Mt (mR)	YANKEE: 13.5 Mt (mR)	NECTAR: 1.69 Mt (mR)	Total (mR)	Distance from Bravo GZ (mi)
Maloelap	350	120	50	0	25	4	549	470
Erikub	390	200	50	0	0	6.5	647	385
Wotje	1800	300	200	13	220	10	2543	380
Kwajalein	150	480	250	12	320	17	1235	275
Majuro	156	137	5	2	2	0.7	351	470
Kusaie	85	4.2	0.7	0.2	0.5	0.1	90	450
Ponape	5.5	20	31	21	38	6.2	132	570
Truk	29.1	1.3	2.3	0.9	15.1	no dose	49	970
Yap	no dose	no dose	no dose	8.7	4.7	4.6	18	1860
Guam	no dose	no dose	no dose	no dose	no dose	no dose	no dose	1400
Iwo Jima	no dose	no dose	no dose	6.8	12.7	2.0	22	1860
Ujelang	85.4	no dose	176	52	142	no dose	455	295
Wake	3.3	1.9	3.0	2.2	1.2	0.7	12	560
Johnston	110	28	66	no dose	no dose	no dose	204	1765

4.5 Radioactive Contamination from Operation IVY

Operation IVY involved two detonations at Eniwetok Atoll, the 10.4 Mt MIKE shot conducted as a surface burst in a building on Elugelab Island, and the 500 kt KING shot conducted as free airburst over the reef off Runit Island. Because of its higher yield and its configuration as a surface burst, MIKE was expected to result in more severe contamination. Since the fallout aspects of very high-yield tests were completely unknown, the population of Ujelang, the nearest inhabited atoll, was evacuated before the MIKE detonation. The people were awakened and brought on deck to view the MIKE detonation, which destroyed a portion of their homeland. The evacuees were kept aboard the landing ship transport (LST) for 3 days before being returned to their homes.

Radioactive contamination at off-site islands and atolls was measured by both HASL and NRDL. The results are given in the reports *Radioactive Debris from Operation IVY* (NYO-4522 [1953]) and *Nature, Intensity and Distribution of Fall-out from MIKE Shot* (WT-625). No radioactive contamination above background level was found at Ujelang following the MIKE detonation. This was confirmed by both the HASL aerial survey and by NRDL gummed-paper fallout collectors fielded on an LST off Ujelang.

From 2 to 8 days after the MIKE detonation, secondary fallout covered an extensive area of the central Pacific. The secondary fallout was composed of particles less than 25 μm in diameter that originated in the stratosphere. The highest radiation levels found in the Marshall Islands were at Likiep, Jemo, and Ailuk, where aerial surveys flown the second day after MIKE found surface gamma-ray contamination of 0.5 mR/hr. The highest contamination was found in the Marianas, where a rate of 1.5 mR/hr was detected at Agrihan the third day after MIKE. This same secondary fallout was detected and measured by gummed-paper collectors on Majuro, Kwajalein, Bikini, Eniwetok, Kusaie, and Ponape. Figure 5.2 of WT-625 shows the fallout at these locations during the 6 days after the MIKE detonation.

The day after the IVY KING detonation, fallout contamination of 0.3 mR/hr was measured at Ujelang by the HASL aerial survey (NYO-4522 [1953]). The NRDL gummed-paper recorders were not fielded at Ujelang for this test, and a HASL fallout monitor on the island had not been reset. Because the fallout arrival time is not known, only a rough estimate can be made of the total radiation exposure. The lifetime whole-body radiation dose at Ujelang from IVY KING was, however, not larger than 50 mR.

4.6 The Nationwide Radiological Study

In 1989, the Republic of the Marshall Islands government made arrangements for a comprehensive survey of the amounts of residual radioactive contamination on each of the atolls throughout the two island chains. Five international experts in environmental radiation science were appointed to staff the Scientific Advisory Panel to the Nationwide Radiological Study. Working under the auspices of the panel, a field team, led by Dr. Steve Simon, took 5 years to complete the study and publish their findings (Simon and Graham 1994). Because of the three-decade lapse since the end of American atmospheric nuclear testing at the PPG, the only remaining radioactive material left to be studied was ^{137}Cs , a 33-year half-life isotope of cesium produced in relatively large amounts in the nuclear fission process. (Refer to Teller et al. [1968] for a succinct account of the production of residual radioactive materials in nuclear detonations.) Radioactive cesium is released to the environment mostly in the form of exceedingly small particles (fumes), which, along with the other fission-chain radionuclides, are incorporated into the larger solid particles that eventually settle to earth as fallout. The amount of residual radioactive cesium is therefore expected to relate directly to the total amount of fallout contamination.

It is of interest to compare the HASL aerial survey data summarized in Table 4-1 with the results of the Nationwide Radiological Study. This comparison is shown in Figure 4-7, where the measured amounts of residual radioactive cesium reported by Simon and Graham (1994) are plotted against the total amounts of Operation CASTLE fallout contamination as measured by HASL. Within the measurement uncertainties, there is overall good correspondence between the residual contamination and the initial fallout exposures. The nationwide study measurements were of sufficient sensitivity to detect the faint background due to global fallout from high-yield atmospheric nuclear tests by all five nuclear weapon states, but due largely to the exceedingly large detonations conducted by the Soviet Union at the Novaya Zemlya test site in 1961–62 (Mikhailov 1997). While global fallout is the principle source of cesium contamination for some of the atolls in the Marshall Islands, many other locales have residual contamination originating mostly from fallout from the Operation CASTLE tests, with the BRAVO shot being the largest source. The only place where the HASL measurements do not agree well with the results of the nationwide study is at Bikar, where much less contamination was found by the study than would be expected from the general pattern of results.

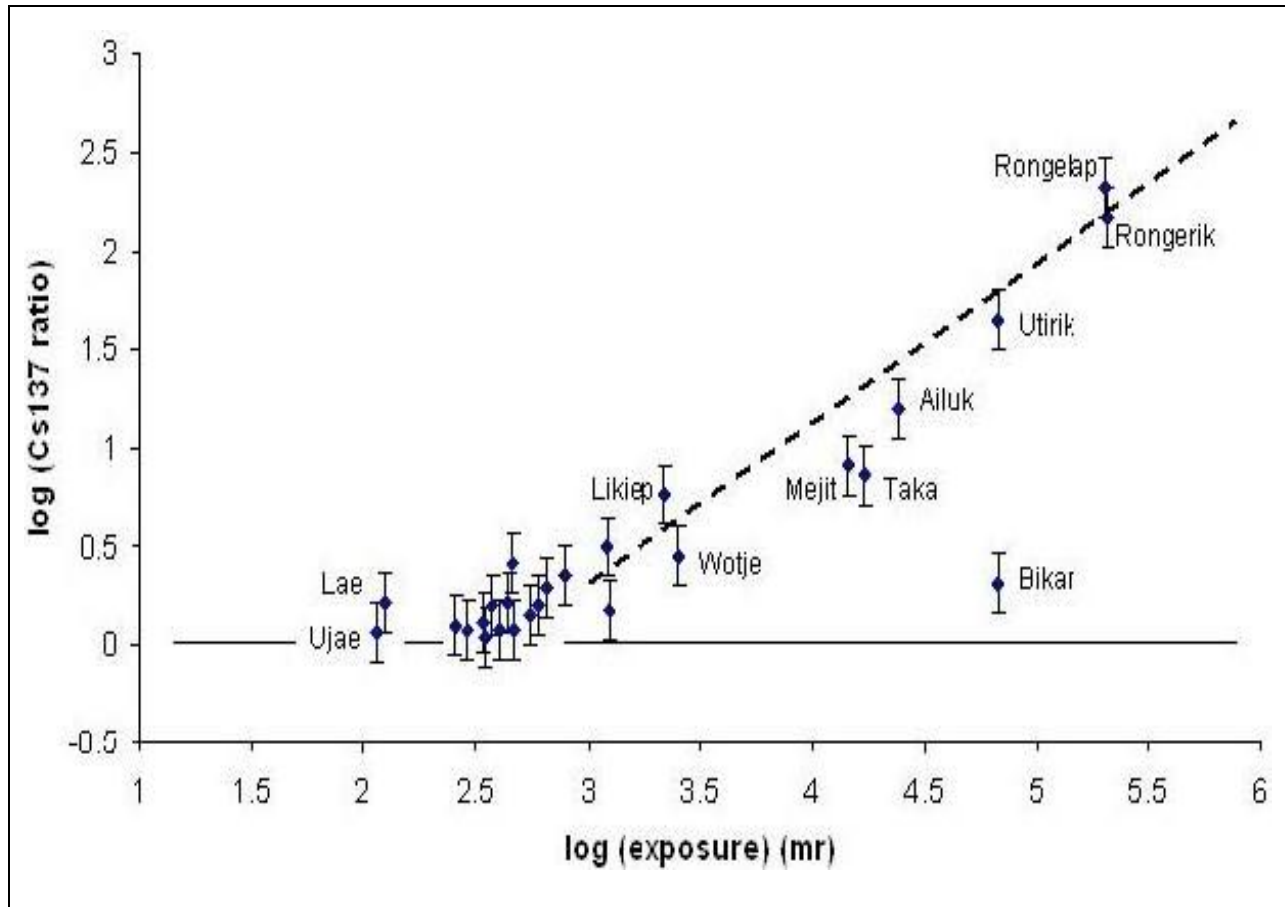


Figure 4-7. The levels of residual soil contamination throughout the Marshall Islands were measured during the Nationwide Radiological Study. The measured amounts of radioactive ^{137}Cs were reported as ratios to the amount due to global fallout. The contamination ratios reported in Table 5 of Simon and Graham (1994) are plotted here against the total amounts of surface fallout from all six Operation CASTLE nuclear tests. With the exception of Bikar, where much less soil contamination was found than expected, the two measurements are in excellent agreement. The solid line denotes the amount of contamination expected from global fallout; the dashed line indicates the excess, which is evidently mostly due to the Operation CASTLE tests.

4.7 Comments on the Operation CASTLE Radiation Exposure Records

The primary goals of the task force radiation protection program were to provide a complete historical record and to protect the US Government from unwarranted legal claims and actions. Although perhaps not entirely within the scope of a report focusing on the actions of the task force during the operational period of CASTLE, it is difficult to avoid some comment on how task force records subsequently have been used.

The basic reference to radiological safety during Operation CASTLE is the 743-page, two-volume document *Final Report, Radiological Safety, Operation CASTLE, Spring 1954*. This anthology of memoranda, planning documents, official letters, and draft reports was prepared in the summer of 1954 by Lt. Col. Richard A. House, the task force radiological safety officer, for the express purpose of gathering together all task force records concerning radiological safety and radiation exposures. The initial document classification was SRD, the normal classification of all task force reports. The portions most relevant to BRAVO, and in particular to the off-site radiation exposure measurements, were declassified in June 1979, and have been available at the DOE/NTA since its inception. The document was declassified in its entirety and released to the public in 1985, and has since been available as NV0051031 (1954) and NV0051072 (1954). Many individual sections of this anthology are additionally available as separate NTA holdings. This comprehensive report remains the best single source of information concerning the conduct and radiological consequences of Operation CASTLE detonations.

The results of the various radiation surveys and measurements conducted by the task force during Operation CASTLE are included in House (1954). The results of the CINCPAC-supervised HASL surveys are less well known. Although summaries of the HASL survey results are included in the task force records (House 1954, Tab H), complete reporting proved more difficult to find. In the spring of 1994, it was possible to locate copies of the original, handwritten, HASL records concerning measurements of radioactive contamination from the Operation CASTLE detonations in the DOE/NTA. It was not possible, however, to locate any formal report containing this same information and analysis. Although the HASL report of January 1955, *Radioactive Debris from Operation CASTLE, Islands of the Mid-Pacific* (NYO-4623 [1955]), was readily available in the Los Alamos classified reports library, a deletion declassified version released in April 1959 has been available since through the National Technical Information Center (NTIC) with report number NSA-13-011739. The document was not available at the DOE archive in the spring of 1994. Information about this 1959 version is available on http://www.osti.gov/energycitations/product.biblio.jsp?osti_id=4274357. The document can be viewed from OpenNet under accession number NV0058769.

During the following year, an exhaustive review of DOE document holdings was undertaken as part of the openness program. The HASL report was entered into the DOE/NTA collection during this time, and specifically called to the attention of the Marshall Islands government. A common bit in the BRAVO lore is that this information had remained unavailable until 1995 because it was classified. For example, one web-based history site reports that:

During 1995, a January 1955 report from the U.S. AEC entitled “Radioactive Debris from Operation Castle, Islands of the Mid-Pacific” was made available to the Republic of the Marshall Islands for the first time. That report, which had been classified for 40 years, includes tables listing radiation fallout doses as measured for 27 Marshall Islands atolls for each of the six tests conducted in the 1954 series (<http://www.nuclearhistory.tripod.com/>).

In actuality, the report had been declassified and made readily available to any interested researcher for 36 years.

In DOE documents concerning radioactive contamination from the CASTLE detonations, and BRAVO in particular, it is not unusual to also find such claims as “no survey data [are] available” or “there were no off-site measurements . . . for the other shots in the CASTLE Operation” (Bell). Such claims are not true. The authors may have been unaware of the data, but they do, in fact, exist. Published lists of “islands extremely unlikely to have received fallout from the Bikini or Eniwetok tests at levels higher than the background exposure of 200 mR/year” (Bell, 36) are patently incorrect. In fact, nearly all of the Marshall Islands received cumulative radiation exposures in excess of 200 mR from the CASTLE tests, with occasional doses of up to ten times this amount (refer to Figure 4-8 showing sample testing on Rongelap).

A particular example of poor scholarship concerns the visit of the USS *Renshaw* (DDE-499) to Likiep Atoll during the week after BRAVO to conduct soil and water sampling (Bell 1979). Details of the expedition are given in a letter of 8 March 1954 from Major R. D. Crea, the task force radiation safety officer sent on the voyage (Crea 1954), and the results of laboratory sample analysis are presented in the task force radiation safety report (House 1954, Tab H). As a boy growing up on Likiep, Senator Tony A. de Brum of the Marshall Island Republic witnessed the visit (de Brum 1994). On 16 May 1979, the senator sent formal inquiries to the US Department of Interior as to the results and findings of the survey. The outcome was a memorandum confirming that the *Renshaw* had indeed called at the island, but stating only “it is, of course, possible that when the landing party went ashore, some type of instrumentation might have been taken along. None of the currently available data, however, provides any information on the results of such measurements and it does not appear likely that any final reports would include results of such specifics as these.”

It is apparent that an incomplete job was done in researching and reporting Operation CASTLE off-site radiation exposure records. Directly relevant information specifically requested by the Marshall Islands government remained undisclosed for decades. Neither document availability nor classification restrictions were a problem; the relevant documents had been provided to the DOE testing archive soon after its inception, and had been available previously through the NTIC. This seems, rather, a story of inexperience and poor scholarship.

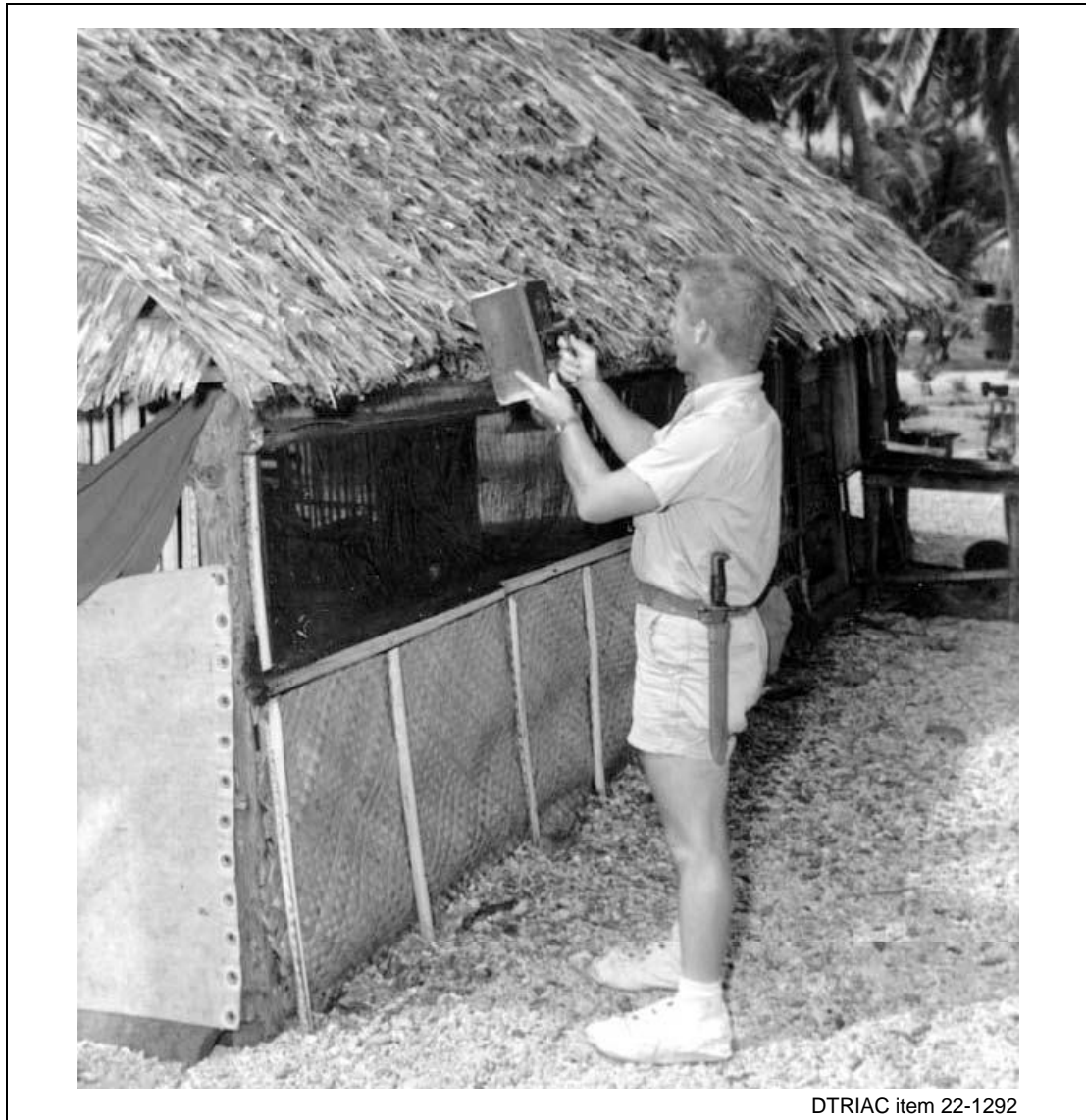


Figure 4-8. Rongelap village radiation survey, 9 March 1954. Note anticontamination booties worn over shoes.

5.0 Evacuation of the Off-Site Atolls

I greatly appreciate the prompt action by the Task Force in evacuating the affected islands.

—Dr. John Bugher, Director of Biology and Medicine,
AEC Headquarters

The evacuation had been accomplished with such speed that Rongelap, Ailinginae and Utirik became, for the moment, museum exhibits of Marshallese life, the huts furnished but empty, the native outriggers standing where they had been drawn up on the lagoon beaches, and the stone-bordered streets and walks of the communities bearing only the footprints of persons now gone.

—Neil Hines in *Proving Ground*



Figure 5-1. Utirik Island village, 3 March 1954

Fallout from the BRAVO detonation was first noticed on the islands surrounding the PPG at approximately March 01-10:00M 1954 by the population of Rongelap (Sharp and Chapman 1957). According to Billiet Edmond, then the schoolteacher at Rongelap, “At 11:30 the classes were dismissed and the students and I went out and were greeted by the powder-like particle as it began to fall on the land” (Figure 5-2). “The once blended green and yellow leaves of our coconut trees, breadfruits, and pandanus gradually took on the white colour of the falling stuff” (Firth 1987). The fallout process was evidently more similar to a rose dusting than a snowfall. When interviewed by General Clarkson on 5 March (NV0101490 [1954]), Warrant Officer J. A. Kapral, in charge of the Task Force Weather Station at Rongerik Atoll, reported that the fallout manifested as a “haze [that] closed in like a cloud and a dust was deposited on buildings and flat surfaces.” Others on Rongerik reported that, when sunlight illuminated against dark background, tiny particles of “silver grayish dust” could be seen drifting downward. Under a microscope, the particles looked like small, irregular crystals that proved insoluble in water. Jabwe,²⁹ the indigenous health practitioner on Rongelap, said that the fallout looked and felt more like taro or cassava powder than snow (Harris 1954), while the “top native” from Rongelap (probably John the magistrate) reported to General Clarkson that individual falling particles were not seen. “The fall-out powder whitened the hair and adhered to [the] skin as a salt-like film.” Particles subsequently recovered from soil samples had an average size about twice that of a human hair (WT-915). A Rongelapese fishing party at Ailingnae Atoll reported similar, but less striking fallout (ITR-923 [1954], 45). The magistrate from Utirik “saw nothing come down from the sky like dust or debris” (NV0101490 [1954]), and according to all contemporary reports, the fallout was not perceptible at Utirik or elsewhere in the Marshall Islands.

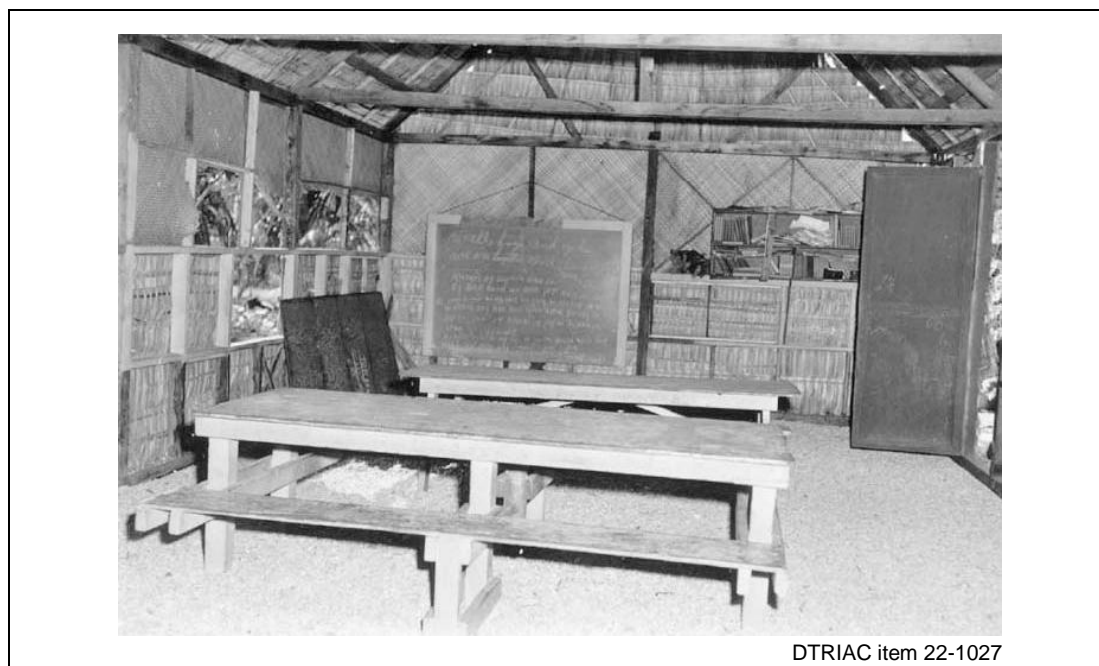


Figure 5-2. Rongelap village school, 10 March 1954

²⁹ Jabwe was trained in Japan during the years of the mandate, where he had seen snow.

The first quantitative detection of fallout on the islands surrounding the PPG came at 01-13:18M from the HASL gamma-ray monitor on Eniwetok Island, Rongerik Atoll. This automatic recording radiation detector required very little attention,³⁰ and except for a simple briefing, none of the personnel on Rongerik were pretrained in its use or in radiation safety.³¹ Radiation readings normally were appended to the routine weather information transmissions to Task Force Weather Central. Should “anything significant” be noted, Mr. Kapral had been instructed to contact Mr. Breslin, the HASL supervisor and liaison officer attached to the JTF Radiation Safety Office (NV0051031 [1954], Tab G). The radiation at Rongerik increased in intensity over the following half hour, until at 01-14:50M, the pen on the HASL instrument was off-scale high.³² A radio message reporting this fact³³ was sent to the Airways and Air Communications Service Center at Eniwetok, where it was received at 01-15:43M and delivered to the Army Communications Center at Eniwetok at 01-15:47M for retransmittal to JTF headquarters aboard the command ship USS *Estes* (TGCD-370). Mr. Breslin received the message aboard the *Estes* at about 01-16:00M (NYO-4623 [1955], 51). (Refer to Figure 5-3 for a map of the principal task force radio circuits.)

³⁰ Lt.Col. Barney (1952) reported during Operation IVY that “the [HASL] equipment was so simple to operate and maintain that an orangutan chained nearby could have handled [it].”

³¹ The HASL report (NYO-4623 [1955]) states, “A particularly gratifying achievement of this program was the utilization of personnel, untrained in radiation instrumentation, for the operation of the automatic monitoring equipment.”

³² The HASL TN-3-A Automatic Gamma Monitor displayed readings on a linear-recording milli-ampmeter. To interpret recorder readings as radiation exposure rates, it was necessary to know that the instrument was logarithmically configured, with a range of 0.01 to 100 mR/hr. Because the military personnel had no training as to what the readings actually meant, MSgt Pletsch of the Rongerik weather detachment referred to this instrument as “one screwy recorder” (Harris 1954).

³³ The entire text of this message was: “Attention Mr. Breslin, Information Commander, Weather Reporting Element, Provisional. GR 12 MIKE over 100 CHARLIE—Over 100.” Due to the fact that the “GR 12” was included in the address instead of the body of the message, it never made its way to the Weather Reporting Element. For additional information on problems with radio communication with the Weather Islands, refer to NV0076407, 10.

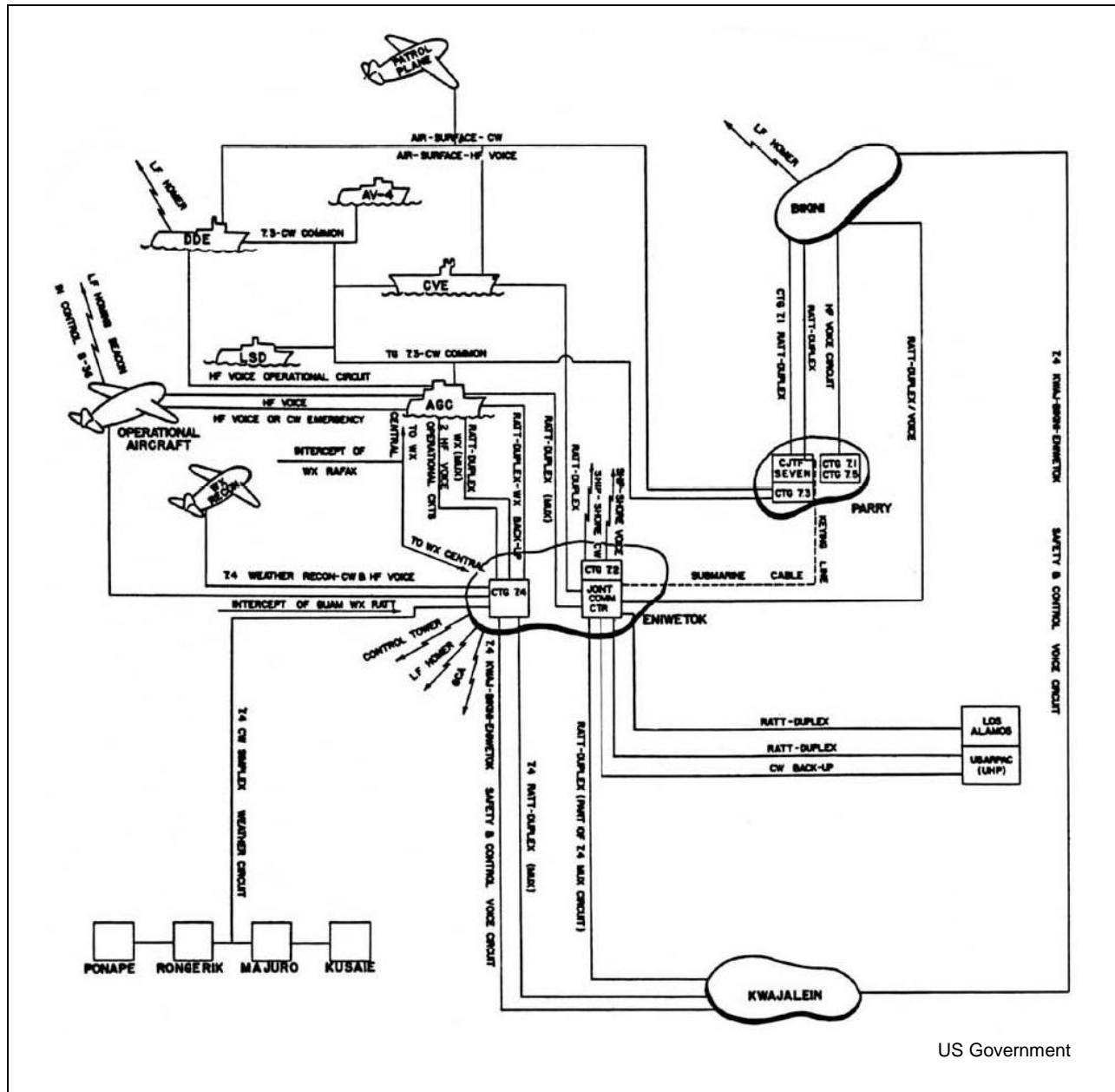


Figure 5-3. Principal task force HF radio circuits

The task force command ship USS *Estes* was the “AGC” shown toward the center of the diagram. The square labeled “CTG 7.4” on Eniwetok was the Airways and Air Communications Service Center; the “CTG 7.2” square on Eniwetok was the Army Communications Center. Reproduced from Appendix I to Annex E of Operation Plan No. 1-53 (J-22100 [1953]). Radio communications could be difficult with the Weather Island service detachments, including the unit at Rongerik. “The location of the Weather Central antenna was found to be too close to the Air Operations Center (AOC) and Combat Information Center (CIC) receiving circuit, causing garbled reception. An investigation into the situation revealed no practical solution other than eliminate, as much as possible, conversation between the AOC and CIC during the time weather information is being received.” (NV0076407, 12)

Aerial monitoring for possible fallout radiation in the area near Rongelap and Rongerik was planned for that afternoon by the task force WILSON cloud-tracking aircraft, which were to use Rongerik as a turning point in their upwind search patterns (NV0051031 [1954], C-16). At approximately 01-15:50M, when it was expected to be in the Rongerik area,³⁴ the WILSON-2 aircraft reported no airborne contamination. It had previously reported maximum contamination at a location approximately 150 nm from GZ on a bearing of 60°. These reports appeared to verify forecast trajectories indicating the upper segment of the atomic cloud would leave the PPG on an approximate bearing of 70°, thus avoiding the populated atolls. The position of the reported contamination was in good agreement with preshot expectations, as shown in Figure 2-4.

During the late afternoon of BRAVO day, Task Force Command received conflicting information concerning the situation on Rongerik. The WILSON-2 aircraft did not report airborne radiation while believed to be in the Rongerik area, and found the main cloud at the expected location. The HASL automatic monitor, observed by untrained personnel, was reported as “over 100.” From this bit of information, Mr. Breslin surmised that the instrument was actually off-scale (NYO-4623 [1955], 51). Registering off-scale high is often an indication that a Geiger-Mueller vacuum tube detector is “gassy” or otherwise inoperative. The HASL radiation monitors had previously suffered from “mechanical and electrical defects after short periods of operation” (NYO-4623 [1955], 8) that had partially disabled most of the units. The negative report from the WILSON-2 aircraft cast doubt on the veracity of the HASL instrument. What Task Force Command did not learn until several days later is that, due to a misunderstanding of control procedures, the WILSON-2 aircraft had overstayed in the preshot holding pattern to the east of Bikini, and had then altered its search pattern so that it did not, in fact, pass near Rongerik (NV0051072 [1954], K-47a). It was the report from the WILSON-2 cloud tracker that was in error, not the HASL monitor reading.

³⁴. As was standard procedure for the time, actual aircraft positions were not included in radio messages, but instead inferred from the elapsed time along the planned flight path. If the flight plan were altered, then the inferred position would be incorrect.

A 100 mR/hr fallout reading starting 7 hours after detonation would not have been cause for immediate health concern. Normal fallout decay characteristics (Glasstone and Dolan 1977, Chapter 9) would result in a total lifetime whole-body external dose not exceeding the task force maximum permissible exposure of 3900 mR. With this calculation in mind, and with no confirmation of radiation at Rongerik, Task Force Command decided to await further reports from the WILSON aircraft before deciding what, if any, action needed to be taken concerning Rongerik, Rongelap, and the other off-site atolls (Figure 5-4). NYOO Flight ABLE was not requested at this time “to diminish the possibility of [the] aircraft passing through the radioactive cloud.”

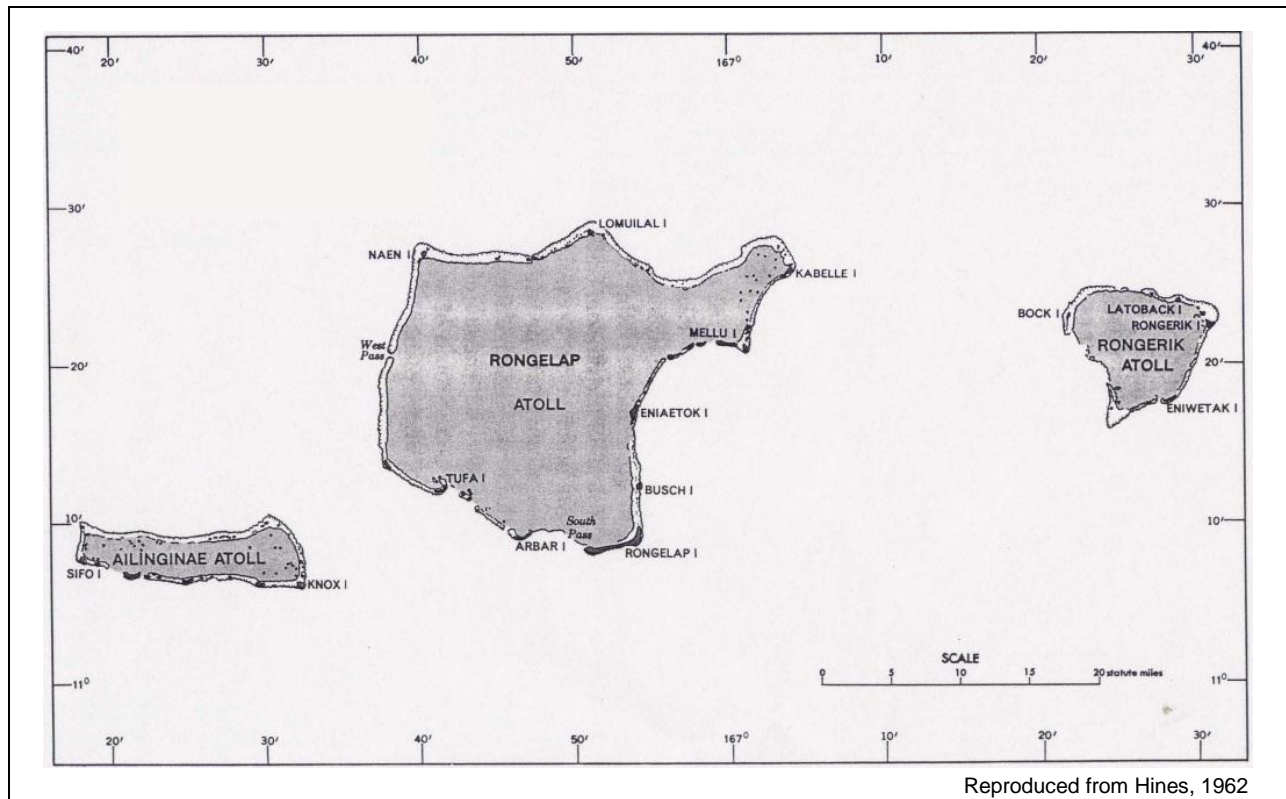


Figure 5-4. Rongelap and surrounding atolls

At 01-19:45M, the WILSON-3 aircraft, during its preplanned upwind search, reported contamination in the Rongerik area (Wignall 1954). During the next hour, airborne contamination of up to 100 mR/hr was found in an area to the north-northeast of Rongerik Atoll (NV0051072 [1954], K-47b). Task Force Command apparently believed at this time that the same secondary fallout reported by task force ships early that afternoon (NV0051072 [1954], K-51) also had touched Rongerik. Command was, however, concerned. At 01-20:00M, a message was originated to TG7.4 requesting that the then-airborne WILSON-3 aircraft alter its search pattern to monitor “the populated islands to the east” (Wignall 1954), and a separate message sent to Navy Squadron VP-29 at Kwajalein requested that NYOO Flight ABLE conduct an immediate, nighttime survey of fallout radiation throughout the northern Marshall Islands (NYO-4623 [1955], 51). Night survey flights were not considered during HASL planning for Operation CASTLE (HASL-154 [1953]), and the eventuality had not been discussed with the squadron personnel. However, in view of the potentially serious nature of the fallout situation, a night mission was, nevertheless, felt to be necessary.

At about 01-21:00M, a second message from Rongerik arrived at the *Estes*, stating that the recording pen on the HASL meter had been off-chart since early afternoon and requesting an acknowledgment from Mr. Breslin (TGDC-370 [1954]). This message was copied to the commander, Test Services Unit (TSU), in charge of the Weather Island service detachments, where it was received at 01-20:49M. After conferring with the TSU commander, a message was sent to Rongerik at 02-00:10M ordering personnel there to immediately cease all operations and remain inside metal buildings until further notice (TGDC-370 [1954]). Little was known by the TSU about the HASL instrument or its reliability (NV0076552), and in order to establish the true situation, a trained radiation safety monitor was immediately dispatched to Rongerik (NV0076554 [1954]).

A radiation dose rate on Rongerik of 100 mR/hr at 01-21:00M would not have been cause for undue alarm. The lifetime dose would be about 8500 mR³⁵, but it would take an additional 42 hours to build to 3900 mR, the task force maximum permissible exposure. Task Force Command apparently believed there to be sufficient time to establish the actual situation on Rongerik, and judged there to be no need for precipitate action. It should have been realized, however, that the WILSON-3 measurements, while in apparent good agreement with the HASL monitor, might not be representative of the actual situation on the ground, and that the radiation dose rate might be larger than the upper limit of the HASL detector. Whatever the reasoning, by 01-21:00M, Task Force Command had received the information necessary to deduce that Rongerik, and by inference, Rongelap, would need to be evacuated; the question remaining was how quickly the evacuations need be accomplished. It was believed that the already requested airborne surveys would soon provide answer to this question.

³⁵. The anticipated total dose would be larger at 01-21:00M than at 01-13:18M because the dose rate is taken as 100 mR/hr at both times. A reported dose rate of 100 mR/hr at 01-21:00M meant that the rate must have been higher at earlier times.

The two survey aircraft requested by Task Force Command to monitor for surface contamination at Rongelap and Rongerik both failed to promptly accomplish their missions. Due to communications procedural errors, neither deployment message cleared the radio room on the *Estes* for about 12 hours. The NYOO ABLE survey flight did not depart Kwajalein until noon the next day. The same communication problems prevented the WILSON-3 flight from complying with the request for an immediate survey at Rongelap and Rongerik.

5.1 Rongerik

A task force radiation monitor, Captain Louis B. Chrestensen, USAF, flew to Kwajalein during the night to catch the Weather Island service flight scheduled to depart at March 02-08:30M the next morning for the weather station on Eniwetak Island at Rongerik Atoll. Captain Chrestensen participated in planning for the Weather Island Radiation Safety Services, and he was familiar with the monitoring program for Rongerik (NV0076552). Upon arrival over Rongerik at 02-09:45M, he measured potentially dangerous levels of radiation, and on his own initiative, started evacuation of the island at 02-11:30M (NV0076552). The Navy PBM-5A amphibian aircraft from Navy Squadron VP-29 that brought Captain Chrestensen to Rongerik was used to evacuate the 28 military personnel to Kwajalein in two sections (Figure 5-5). Eight men, selected by alphabetical order, were taken in the first section. The remaining 20 men embarked at 02-16:45M.

Upon arrival at Kwajalein, the men from Rongerik were in good spirits and had no medical complaints. They were taken directly to the decontamination center, where multiple showers were used to reduce skin contamination. Their total external gamma dose was estimated to be 78,000 mR (Dunning 1968). Initial blood counts were in the normal range. During the next 2 days, a few complained of mild malaise and two of mild burning of their eyes. Over the next weeks, definite hematological changes developed, along with mild skin lesions and questionable epilation [hair loss] in a few individuals. On 8 March, the men were moved to the Eniwetok medical facilities. When the Project 4.1 medical team started operations on 11 March, the servicemen were returned to Kwajalein (NV0028554 [1954]) for observation. During the next month, their medical condition remained excellent, with no subjective symptoms of radiation illness. The only clinical findings were mild to moderate reductions in the number of white blood cells and platelets, and two cases of superficial skin irritations indicative of beta-radiation burns (NV0093132 [1954]).



Figure 5-5. Men of the Rongerik service detachment, Naval Station Kwajalein, 20 March 1954

By mid-April, observation and investigation of the Rongerik servicemen was complete, and the staff surgeon recommended they be sent to a major medical center for a complete and detailed medical workup prior to being returned to duty (NV0093132 [1954]; Cronkite 1954). Walter Reed Army Medical Center was recommended as the agency best suited to perform the examinations. However, the Department of the Army and the AEC requested that the servicemen be held in the forward areas until CASTLE test operations were completed (NV0028557 [1954]). Preparations were therefore made to send the group to Tripler Army Hospital, Moanalua, Oahu (NV0116071 [1954]), and on 29 April the servicemen were flown to Honolulu.³⁶ By mid-June, their hematological results had returned to normal, and after thorough medical examination, all of the servicemen were returned to their parent military organizations in the continental United States. It was recommended that they not be exposed to additional radiation, other than essential diagnostic and therapeutic X-rays, for a period of at least 6 years (JF-8584 [1954]; NV0093132 [1954]).

³⁶ Arrival of the Rongerik contingent in Hawaii was covered by the *Honolulu Advertiser* (refer to the attachment to NV0093132 (1954)).

5.2 Rongelap

At approximately March 02-12:00M, Task Force Headquarters was advised of the ongoing evacuation of Rongerik. Captain Chrestensen attempted to contact Task Force Command earlier that morning by direct radio transmission from the PBM-5A aircraft over Rongerik, but only a garbled fragment was received and the full transmission had to await relay through Kwajalein. The actual radiation readings made at Rongerik were received at approximately 02-13:00M; this was Task Force Command's first knowledge of the true severity of the off-site fallout. A special conference was convened aboard the *Estes* at 02-13:30M between the commander and the scientific director, the task force radiation safety officer, the staff radiological medical officer, and the TG commanders to consider the possible situation on the inhabited atolls. During this conference, at 02-13:40M, a radio report was received from NYOO Flight ABLE confirming potentially dangerous radiation levels at both Rongelap and Ailinginae. The commander ordered evacuation procedures to begin at once, and directed HASL to immediately execute NYOO flights BAKER and CHARLIE to search for possible contamination elsewhere in the surrounding islands.

Because CINCPAC had declined to supply dedicated emergency evacuation capability for the populated islands (NV0051031 [1954], C-8), it was planned that the task force destroyer escort (DDE) security ships would be used should evacuation be necessary (NV0051031 [1954], C-13 and C-19). Since it took several hours for these ships to steam from their established patrol positions near Bikini to Rongelap Atoll, it was not possible to evacuate Rongelap and Ailinginae that afternoon. As these were Trust Territory domains, it also was necessary to advise both CINCPAC and the Trust Territory government, and to receive concurrence and permission before evacuation could commence. The Trust Territory representative and the interpreter, prepositioned by the task force at Kwajalein for just this contingency, were requested to fly by Navy amphibian aircraft to Rongelap the next morning.

Upon returning to Kwajalein from Rongerik at approximately 02-14:00M, Captain Chrestensen signaled his commander (CTG7.4), “Suggest immediate survey of inhabited islands of Rongelap. High possibility exists that immediate steps must be taken to evacuate natives” (TGDC-370 [1954]). Radiation monitors from TG7.4 flew by SA-16 amphibian aircraft to Rongelap that afternoon to investigate the surface radiological conditions. An average radiation reading of 1400 mR/hr measured in the living area of Rongelap Island at approximately 02-18:30M confirmed the need to evacuate. Contact with the inhabitants was apparently made through Jabwe. The Marshallese were instructed to wash the fallout material from their skin, hair, and clothing, and to remain indoors as much as possible. Jabwe already had closed the local wells and cisterns, and told the people not to drink the water³⁷ (Harris 1954; Sharp and Chapman 1957; Kabenli 2000).

The destroyer escort *Philip* (DDE-498) got under way from Bikini at 02-21:45M, and, at the request of the Trust Territory government, began evacuation of Rongelap Island at sunrise the next morning (Figure 5-6). A detailed account of the evacuation of Rongelap and Ailinginae atolls on the morning of 3 March 1954 was written by the commanding officer of the *Philip* (Albin 1954). The PBM-5A amphibian aircraft from Navy Squadron VP-29 that brought Mr. Marion Wilds, civilian representative of the Marshall’s district administrator, and Mr. Oscar deBrum, the Marshallese interpreter, was utilized to transport 15 of the pregnant, sick, and elderly, accompanied by the medical practitioner, to Kwajalein. John, the magistrate of Rongelap, selected the members of this party (Figure 5-7). They arrived at Naval Air Station Kwajalein at approximately 03-11:00M. “They were taken directly to the decontamination center and took multiple showers using fresh water and soap. Fresh clothing was issued following showering. Some difficulty was encountered in obtaining cooperation for repeated personal decontamination procedures” (ITR-923 [1954], 24).

³⁷. The BRAVO detonation flash was seen from Rongelap, and heat of the fireball could be felt. Both the positive and negative phases of the shock wave were apparent, and seven sharp booms were reported (Harris 1954). In February, the leaders of Rongelap were informed that nuclear tests would be occurring at neighboring Bikini Atoll later that year (<http://www.antenna.nl/wise/454/4498.html>). It was surmised from the evident blast effects that the Americans had conducted one of the hydrogen bomb tests, and that the powder-like material from the sky was fallout. Although no precautionary measures were circulated among the Marshallese for their use in case they suspected or underwent radioactive fallout (NV0093120 [1954]), Jabwe acted on his own initiative to prevent drinking of contaminated water. It was a time of drought in the northern Marshall Islands, with little rainfall for the past 6 months; the Rongelapese were rationed to a single half-liter tin of water per day.



Figure 5-6. The USS *Philip* (DDE-498)



Figure 5-7. John, the magistrate of Rongelap, Naval Station Kwajalein, 20 March 1954

The remaining 48 Marshallese on Rongelap Island³⁸ were embarked on the *Philip* by 03-11:30M. Having been warned of the dangers of remaining, they were not reluctant to leave. The *Philip* steamed to nearby Eniaetok Island, where a shore party verified that it was uninhabited. The ship then proceeded to neighboring Ailinginae Atoll and picked up a fishing party of 18 at Sifo Island,³⁹ departing the island at 03-18:00M. Immediately after embarking, all evacuees showered to remove contamination.⁴⁰ Their clothing was laundered and returned within 4 hours. “All children were provided milk shortly after decontamination. The Marshallese went through the regular mess line for meals and had the same ration as the crew. The meat course was the least popular. The majority of the party asked for more soup, bread, and vegetables. Hot soup was most in demand. Ice cream was the natural favorite of all the children” (Albin 1954). Many of the evacuees were subsequently nauseous (NV0400082 [1954]). The crew made arrangements for the people to spend their night aboard the *Philip* in relative comfort and privacy. “The Marshallese were excellent passengers, most cooperative, never demanding and exemplary in conduct” (Albin 1954). They arrived at Naval Station Kwajalein at 04-08:30M.

Upon arrival at the naval dispensary on Kwajalein, 18 of the 64 people evacuated from Rongelap Island complained of itching and burning of their skin and eyes⁴¹ (Cronkite, Conard, and Bond 1997; ITR-923 [1954], 45) and of anorexia and nausea. Although usually attributed to radiation sickness (Conard 1961), some portion of the queasiness and loss of appetite may have resulted from a combination of seasickness and the unusually large and unfamiliar meals consumed en route (Harris 1994). None of the evacuees was acutely ill (JF-4619 [1954]). It was believed that the whole-body external radiation doses were approximately 130,000 mR for the people on Rongelap Island, and 80,000 mR for the fishing party on Sifo Island (Clarkson and Graves 1954). The medical staff of the naval dispensary, with the advice and assistance of the task force medical officers, initially treated the patients. On 11 March, responsibility for their medical care was assumed by the newly established Project 4.1 medical research team (refer to Section 5.6 and Figure 5-8). A joint meeting between the task force, the Navy, and Project 4.1 was held at Kwajalein on 14 March to review the medical condition of the exposed groups and to plan for their future care (NV0093129 [1954]).

³⁸ No foreign (non-Marshallese) nationals are known to have been on Rongelap at the time of the BRAVO detonation. Because of persistent drought, many people (perhaps as many as 194) who normally lived there were, at the time, elsewhere; a colony of 115 were living at Rita Island, Majuro Atoll.

³⁹ In an interview conducted with task force medical officers soon after the evacuation (Harris 1954), Jabwe reported that the 18 people fishing at Ailinginae had returned to Rongelap Island before noon on BRAVO day to discuss the blast phenomena they had felt and heard. They subsequently returned to Sifo Island, where the *Philip* picked them up. This story contradicts other reports locating the fishing party on Ailinginae the entire time.

⁴⁰ Radiation readings taken before and after decontamination procedures are reported in Enclosure (2) of Albin (1954) and in Sharp and Chapman (1957).

⁴¹ Red, itchy eyes (conjunctivitis) are apparent sequelae of exposure to “moderate” amounts (100,000 mR) of external radiation.



Figure 5-8. Jabwe, the Rongelap health practitioner, assists Nurse Lt. M. Smith and Dr. Lt. J. S. Thompson, during a medical examination on Kwajalein, 11 March 1954

Over the next weeks, the medical condition of the Rongelapese progressed [worsened] to include superficial skin lesions, epilation [hair loss], and hematological changes. The most severe clinical manifestation was beta-burns,⁴² which appeared after a lapse of 2 to 4 weeks. These developed on exposed parts of the body not protected by clothing, with the worst being on the tops of feet. Most of the lesions were superficial and without blistering, and healed rapidly after formation of dry scab. (Refer to Cronkite, Bond, and Dunham [1956] for a complete description and pictures of these injuries, and of all other medical observations.) A mild upper respiratory epidemic, apparently unrelated to the radiation exposure, swept through the group (NV0077854 [1954]). In early April, the white blood cell and platelet counts began to increase, indicating that maximum effect of the radiation damage had passed and that regeneration was taking place (NV0093132 [1954]). By late April, the medical condition of the Rongelapese was improving, and it was evident that the acute phase of their radiation exposure had passed (NV0093132 [1954]). On 22 May, General Clarkson provided a statement to Mr. Bill Waugh, the Associated Press representative in Honolulu, about the circumstances and consequences of the BRAVO test (Clarkson 1954) that summarized the condition of the exposed people, the medical treatments provided, and plans for their future care.

Both the Project 4.1 director and staff surgeon (JF-8581 [1954] and NV0093132 [1954]) recommended that the exposed Rongelapese should be exposed to no further radiation, external or internal, for at least 12 years; that their medical status should be closely monitored; and that they should be located where medical care was easily and quickly available, and where satisfactory communications existed. These recommendations virtually prohibited the return of the group to their home. The exposed Rongelapese were moved in June to Majuro, where a village had been constructed for their use. It was believed that they would be able to return home in about a year.

⁴² Beta particles are electrons released in the nuclear decay process. These move only a very short distance (several hundred micrometers) through body tissues or other solid materials before losing energy and stopping. The “beta burns” resulted from fallout particles in intimate contact with the skin destroying the underlying dermal layers from which new skin grows. It takes few weeks for the existing skin to naturally slough off and the “burn” to become manifest.

Concurring with CINCPAC's view that "restoration to pre-evacuation standards is [an] inescapable moral responsibility" (NV0093127 [1954]), the task force soon began work on rebuilding Rongelap to its preevacuation standards, and to return the inhabitants at the earliest appropriate date. Over the next 3 years, ten surveys and radiological samplings were made at Rongelap Atoll, seven by the Applied Fisheries Laboratory of the University of Washington and three by NRDL. A decision was made upon evaluation of the radiological assay results taken after the conclusion of Operation REDWING in 1956 that the Rongelapese could return home in the summer of 1957.⁴³ Working with the Native Council, plans were drawn up and island facilities were rebuilt. An excellent account of the repatriation on 29 June 1957 is given in *Proving Ground* (Hines 1962, Chapter 9). A more detailed account of the rebuilding and repatriation of Rongelap village, complete with a pictorial review, is given in Holmes & Narver Engineering and Construction Company contract report AT-(29-2)-20 [1957].

The medical condition of the exposed Rongelapese has been monitored closely throughout the intervening years. Fifty-four publications dealing with their health and medical condition appeared during the first 15 years alone (Conard 1971). The frequent medical examinations, coupled with statements such as "[t]he group of irradiated Marshallese people offers a most valuable source of data on human beings who have sustained injury from all the possible modes of [radiation] exposure" and "the habitation of these people on Rongelap Island affords the opportunity for a most valuable ecological radiation study on human beings," have quite naturally left some feeling that they are being used as guinea pigs.

It is clear beyond doubt that the people evacuated from Rongelap, especially the children, have suffered medically from their fallout radiation exposure; basic facts concerning concomitant radiogenic illness are reported, for example, by Glasstone and Dolan (1977) and by Lessard et al. (1985). Potential effects on their longer-term health remain unknown.

⁴³. The measured gamma dose rate on Rongelap Island in the summer of 1957 was approximately 500 mR per year (Hines 1962, 317), or about eight times larger than normal background in the Marshall Islands. In addition to this external radiation, internal exposures might result from the consumption of local foods. In view of the medical recommendation of "no further radiation external or internal . . . for at least 12 years," it is arguable whether the exposed population should have been returned so soon.

5.3 Utirik

The full report from NYOO Flight ABLE was received by Task Force Command at approximately March 02-19:00M 1954, several hours after the decision to evacuate Rongelap was reached. The ground contamination at Utirik, the next atoll in the path of the fallout, was 240 mR/hr at 02-16:51M. Based on this fact, the decision was made to send a separate destroyer to Utirik in anticipation of an order to begin evacuation at dawn on 4 March, the earliest practicable time given the duration of the 400 mi voyage.⁴⁴ While the destroyer was en route, task force radiation monitors were sent by Navy PBM amphibian aircraft to conduct a ground survey (Figure 5-9). Readings of 160 mR/hr recorded at 03-18:30M indicated that the infinity dose would be approximately 58,000 mR. The formal decision to evacuate Utirik was made, and the destroyer was ordered to commence evacuation the following morning.



Figure 5-9. The shadow of the Navy PBM seaplane crossing Utirik Atoll, 3 March 1954

⁴⁴ If dispatched immediately, it actually would have been possible for a destroyer escort to have reached Utirik by midafternoon of the following day.

The story of the evacuation of Utirik by the USS *Renshaw* (DDE-499) (Figure 5-10) is told in an informal narrative from 18 March 1954 (Alford 1954). Because the channel into the lagoon is too shallow to allow passage of such a large ship, it was necessary to conduct the evacuation from the ocean side of the reef. The *Renshaw* hove to about 500 yd just south of Utirik Island, the only inhabited location in the atoll, at 04-07:35M and prepared to send a party ashore. Although Trust Territory officials and interpreters had not yet arrived, the commanding officer decided to proceed at once, hoping to find an English speaker in residence. The party had difficulty landing through the surf, and the executive officer finally beached in a one-man life raft. At about this same time, the Trust Territory officials and interpreters arrived from Kwajalein by Navy seaplane. With assistance from the residents, the ship's officers and a radiation safety survey party finally were brought ashore.



Figure 5-10. USS *Renshaw* (DDE-499), 15 February 1954

While preparations for evacuation were being made, the radiation safety officer and his team made a survey of the island and its occupants (Figure 5-11). Readings of 100-130 mR/hr were found throughout the village, including over the bodies of the residents. It was believed that these readings were due mostly to a background intensity of approximately 100 mR/hr measured in the air over the entire middle section of the island. Drinking water samples collected from four of the most commonly used cistern reservoirs in the village were subsequently found to be little contaminated (NV0051031 [1954], H-52). The very low contamination of the drinking water was attributed to the roofs over each reservoir.

Evacuation started at about 04-10:50M (Figure 5-12). An inflatable life raft was used to shuttle people over the reef and through the surf to whale boats standing about 50 yd off shore. This was a hazardous process. As the wind freshened, the tide flooded and the surf rose, and the operation became increasingly hazardous. Two raft loads of evacuees were very nearly upset in the surf. The assistance of local men who were strong swimmers proved invaluable in limiting injuries to minor coral cuts and abrasions. The last raft left the beach at about 04-12:45M, and by 04-12:51M, all were aboard the *Renshaw*. It was evident to all involved that the task force security ships were not well suited for this type of work; a smaller vessel able to operate within the lagoon would have been preferable (NV0051031 [1954], H-42).



Figure 5-11. Utirik Island radiation survey
1st Lt. W. J. Larson (USAF) and Ensign R. P. Keiser (USNR) conduct a radiation survey, 3 March 1954. In the background, the PBM *Neptune* seaplane is moored in the lagoon.



Figure 5-12. Awaiting evacuation, Utirik village, 3 March 1954

Once aboard the *Renshaw*, the 154 evacuees⁴⁵ were fed their first Western meal—they didn't like the meat loaf—and then sent to the showers to wash off some of the residual skin contamination. Each had been monitored as they came on board and readings were around 7 mR/hr, substantially lower than the average readings of 20 mR/hr on the beach. The scalp was typically the most contaminated body area, the traditional coconut oil hair dressing effectively trapping the fallout. Wading out to the rafts and the subsequent surf ride had reduced the amount of fallout material on the skin and clothing. After a well-received supper of boiled fish and rice with tomatoes and lima beans mixed in,⁴⁶ the evacuees passed the night comfortably. The party was disembarked at Kwajalein at about 05-09:00M the next morning.

⁴⁵There was initial confusion as to the total. Records kept by a “native chief” indicated that there should have been 161 people. Upon review, it was found that this number included several “imminent but as yet unborn” babies and at least two infants who had died a day or two before. The cause of death was not reported.

⁴⁶ Robert Jenkins (2003), then a *Renshaw* crew member, recalled, “While [aboard], we cooked fish and rice for them, which they liked very well. But then we thought it would be nice to treat them with some ice cream. This was a huge mistake because we finally ran out of ice cream and they got downright mad about it. An interpreter had to be called in to explain the situation.”

The whole-body external gamma radiation dose for the Utirik people was calculated to be approximately 17,000 mR (Clarkson and Graves 1954). Clinical manifestations would not be expected from such an exposure, and upon medical examination, no signs of acute illness or symptoms suggestive of exposure to radiation were found. All blood counts were essentially within normal range. On arrival at Kwajalein, each person was monitored for residual contamination (Figure 5-13). Surf baths and shampoos were used to reduce the levels of contamination to below the detection threshold. It was soon apparent that the Utirikese had not received acutely serious radiation exposures, and when it was determined that they would not suffer medically, they were moved to the island of Ebeye in Kwajalein Atoll. To preclude the possibility of further radiation exposure, they were kept at Ebeye during the remainder of Operation CASTLE. The Utirik people were returned to their homes in June, and were furnished adequate water and food supplies (NV0051031 [1954], H-86).



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Figure 5-13. Decontamination procedures performed at Naval Station Kwajalein
Left: Nurse Lt. M. Smith washes hair while Capt. DeMent, MD, looks on,
11 March 1954. Right: Westbrook monitoring island girl, 5 March 1954.

5.4 Ailuk

Task Force Command discussed the fallout situation at Ailuk at approximately March 02-20:00M 1954, about an hour after the results of the NYOO Flight ABLE survey were received. Ailuk was the nearest inhabited atoll south of Utirik, with a listed population of 401.⁴⁷ Based on the HASL aerial measurement, a lifetime dose of somewhat less than 20,000 mR was expected at this location. Because this was less than the standard set for the task force cloud-sampling aircraft crews, and because it was felt that no medical problems would occur from this level of exposure (Maupin 1954), the decision was made not to evacuate Ailuk. Subsequent survey measurements led to an estimate of 13,000 mR cumulative dose (Maynard 1954).

It can be argued that the decision not to evacuate Ailuk was incorrect. The maximum permissible exposure (MPE) for task force personnel was 3900 mR total body external gamma radiation (J-19161 [1953], 6). Any exposure in excess of this limit had to be approved in advance by Task Force Command (J-22107a [1953]). The maximum allowable exposure on waiver was 7800 mR, and all those individuals exceeding the MPE were given cause celebre treatment (Campbell 1985). The infinity dose exposure at Ailuk certainly was known to be larger than that permitted task force personnel. The fact that the projected lifetime exposures would be less than the permissible limit for the sampling aircraft crews is not relevant; these elite crews were volunteers who had received special indoctrination to the health effects of exposures to low levels of ionizing radiation. Another important distinction between the civilian population of Ailuk and the American military sampling crews is that while the aircrews received only external exposures (WT-1320 [1960]), the people of Ailuk were at risk to internal radiation through ingestion of fallout on foods and in drinking water. The potential hazards of internal radiation were certainly known to Task Force Command.

During the morning of 3 March, the commander in chief, Pacific Fleet, made the destroyer escorts *Munro* (DDE-422) and *Silverstein* (DDE-534) available to the commander of TG7.3 to assist in evacuation of the populated atolls. This offer was accepted, and CTG7.3 assumed operational control of both vessels (NV0079980 [1954], 145). *Munro* steamed from Kwajalein to assist in the evacuation of Utirik, but arrived just as the *Renshaw* was completing the task. Both the *Munro* and *Silverstein* were, thus, available for an evacuation of Ailuk. Between the two, the entire population could have been evacuated (NV0032669 [1953], C-II-2).

⁴⁷. This number came from the June 1951 report "Trust Territory of the Pacific Islands" (OPNAV P22-100-M [1951], 80). The authors are unaware of any firm accounting of the population on Ailuk during Operation CASTLE.

Evacuation of Ailuk on the afternoon of 4 March would have reduced the cumulative lifetime exposures by a factor of three, and perhaps have kept the exposure to within the MPE limit. Preshot planning indicated that up to 600 evacuees could be accommodated easily at Naval Station Kwajalein (NV0076407). Adding the 401 people from Ailuk to the 246 island evacuees already on route to Kwajalein would have only somewhat exceeded the preshot planning limit. It thus seems that CINCPAC and Task Force Command had at their disposal the assets needed to evacuate Ailuk, and the certain knowledge that, without evacuation, radiation exposures to the civilian population would exceed established permissible limits for task force personnel. Yet the island was not evacuated.

In deciding whether to evacuate the 400 people of Ailuk, it was necessary to weigh the benefits against the hazards involved. As demonstrated by events at Utirik, an unplanned evacuation is potentially dangerous. As demonstrated by the history of the Bikinians, evacuation would permanently alter the nature of the community. At the time, there were no preestablished standards to apply in deciding whether to evacuate off-site civilian populations, so both CINCPAC and Task Force Command were operating in uncharted waters. In a paper written 14 years afterward, Gordon Dunning discussed some of the considerations leading to the evacuation of Utirik, but does not mention Ailuk (Dunning 1968). Perhaps the best reason why Ailuk was not evacuated may be suggested in Dunning's remark: "Suppose there had been unfortunate accidents during the evacuation—perhaps deaths. Would the decision to evacuate have been judged as wise?"

5.5 The Fortunate Dragon

No history of BRAVO would be complete without mention of the *Daigo Fukuryu Maru* "Fortunate Dragon" No. 5, a Japanese long-line tuna fishing boat operating just outside the eastern boundary of the Danger Area at the time of the BRAVO detonation. During the 12 hours prior to the shot, the little vessel had traveled due west on a course that took it about 28 mi north of Rongelap Atoll. It reached a position roughly 25 mi outside of the Danger Area before stopping and deploying fishing lines, some 85 mi east of GZ. By some odd coincidence in timing, the vessel was not detected during preshot aerial radar searches of the Significant Quadrant (DNA 6035F [1984]). The task force was unaware of the *Fukuryu Maru* until the story of its contamination with "Bikini ash" broke in the international press on 16 March. So much has been written about the boat and its crew, and the effects of the BRAVO contamination on the Japanese economy and the political relationship with the United States, that there is little point in retelling the full story. Complete accounts may be found, for example, in Hines (1962) and Lapp (1958).

It is, perhaps, unusual that the *Fukuryu Maru* was operating in the waters north of Rongelap, as the area was well known to be poor fishing grounds. “Commercial fishing is not conducted to any appreciable extent [anywhere] in the [Trust] Territory [of the Pacific Islands]. The largest commercial fishing company is the Saipan Fishing Company, which has only three small vessels. Other persons are licensed to fish, but the operations are sporadic and seasonal and the sales are local” (OPNAV P22-100-M [1951], 92). “No more than one percent of the total Japanese [tuna] catch comes from the entire [Marshall Islands] area. Prior to [WWII], when this group of islands was completely controlled by the Japanese, they did very little fishing in this region. It seems to have become popular with them now that the Marshalls are being used for weapons testing” (Bugher 1954a). Fishing proved so poor for the *Fukuryu Maru* that the weight of tuna caught was less than that of the bait expended (Lapp 1958). In order to arrive at the economically profitless locale north of Rongelap on the very morning of the BRAVO test, the *Fukuryu Maru* had, at the urging of the radio operator, and over the objections of the Fishing Master (“the real master of the boat”), left the other ships of the Japanese fishing fleet near Midway Island on 12 February to proceed alone to the Marshall Islands area (Lapp 1958). These circumstances led AEC Chairman Lewis Strauss to suggest to President Eisenhower’s press secretary that the vessel was probably a “Red spy ship.” International reaction to this remark can be imagined.

Upon docking in Japan, little of the radioactive material that fell on the *Fukuryu Maru* could be found (Matsue 1956; Kikuchi et al 1954). The total amount of Bikini ash recovered amounted to no more than 50 mCi (Eisenbud 1954). The only reported laboratory analysis of material recovered from the ship after returning to port involved a single specimen found on a diving mask. It was hypothesized by the Japanese scientists that most of the radioactive materials had either dissolved or been washed off the vessel on its journey back to port. However, the gamma radiation intensity measured shortly after the ship reached port was 45 mR/hr (Eisenbud 1954), which translates to a total whole-body radiation exposure of 100,000 mR resulting from just the small amount of residue still aboard. To have medically survived their radiation exposure, the actual integrated dose must not have been over 500,000 mR. These facts, together, indicate that nearly all of the ash (more than 90%) had, in fact, been washed off the ship as soon as it fell; this conclusion is confirmed by the story told by Lapp (1958).

The Japanese Committee for the Compilation of Report on Research in the Effects of Radioactivity (Committee 1954) reviewed medical and clinical observations of the 23 members of the *Fukuryu Maru* crew following their return to Japan. The condition of the crew and the contamination of their tuna catch drew worldwide interest and intense Japanese scrutiny for years.

The only unique insight into the *Fukuryu Maru* incident provided by task force records and personnel is the reaction of the medical officers to reports of the medical care provided to the crew. Soon after the *Fortunate Dragon* returned to its homeport of Yaizu, Japan, on 14 March 1954, and its contamination with Bikini ash became known, the AEC attempted to establish the condition of the crew and to monitor the medical treatments provided. Dr. John Morton, of the Atomic Bomb Casualty Commission (ABCC), and HASL Director Mr. Merrill Eisenbud were asked to render whatever support and assistance possible (Morton et al. 1954; Eisenbud 1991). Tension soon developed between the Americans, who believed that the only medical care indicated was clinical monitoring and support as necessary, and the Japanese physicians, who believed aggressive treatment measures to be in order (Eisenbud 1954). By mid-April, “every treatment imaginable had been used” (NV0033589 [1954]). These treatments included auto-blood transfusion, a medical procedure in which 20 to 30 ml of whole blood would be drawn from a vein and reinjected intramuscularly, usually in the upper arm.⁴⁸ This puzzling procedure is said to have been a widely employed tenet of World War II Japanese combat medicine (Harris 1994). Autotransfusion was used in the treatment of victims from the Hiroshima atomic bombing (NP-3036 through 3041 [1951], 30 [3H]). Why the procedure was thought to be of any medical value for acute radiation sickness is not known, nor is the reasoning behind its application to civilian casualties.

Dr. Clinton Maupin, the task force staff surgeon, witnessed auto-blood transfusions administered by Japanese military medical personnel during wartime (Harris 1994). Dr. Maupin, who was captured by Japanese forces at Corregidor, spent the bulk of the hostilities in the infamous Jinsen (Inchon) prisoner of war camp in Korea (Mansell 2004), where he was senior medical officer. Dr. Maupin’s opinion was that this painful medical procedure, which he likened in consequence to being hit in the arm with a baseball bat, was of no medical benefit (Harris 1994). Moreover, a rather common side effect was septicemia (blood infection). On 23 September 1954, Aikichi Kuboyama, radio operator of the *Fukuryu Maru*, died of complications to infective septicemia (Bugher 1955). It was the opinion of some task force medical personnel that the cause of death was more likely attributable to the treatment than the illness. The ABCC physicians in Japan also believed the death likely attributable to “serious overtreatment,” and noted that as of early September, the patient had received no fewer than 73 blood and plasma transfusions and that “there were a number of deficiencies and inconsistencies in his care and case records” (NV0408174). Medical misadventure adversely affected many other *Fukuryu Maru* crewmembers; fully two-thirds were stricken with infectious hepatitis (Lapp 1958). Hiroshi Kozuka, who received “a large blood transfusion at a national hospital,” suffered from jaundice, a symptom of hepatitis, for 3 months afterward (Shimbun 2003). One popular-press report states that, as of 2001, eight crew members had died of liver diseases, and many of the survivors still suffer from hepatitis.

⁴⁸ This medical procedure is in no way similar to, and should not be confused with, the current-day practice of autologous blood donation.

5.6 The Project 4.1 Medical Research Studies

Many different kinds and types of scientific investigations were conducted during nuclear test detonations. Research and development projects were undertaken by both the AEC and its laboratories, and by the Department of Defense (DoD) and its contractors. During planning for each test series, a comprehensive listing of all such investigations was developed. A document entitled *Outline of Scientific Programs* was then prepared to uniquely identify by number each individual project, and to organize the many individual projects into established programs (Figure 5-14). Biomedical studies were commonly done in association with nuclear test detonations, and these comprised Project 4. Because these were weapon effects experiments, biomedical investigations were, following the usual division of effort, usually sponsored by DoD through Task Unit 13 of TG7.1.

During initial planning for Operation CASTLE, NRDL suggested an experiment to investigate the medical effects of neutrons on mice (J-16083 [1953]). It was provisionally designated as Project 4.1, and was the only biomedical investigation proposed for Operation CASTLE. This experiment was discussed at a planning meeting held at Los Alamos on 3 and 4 March 1953 (J-17390 [1953]). Here it was pointed out that, because blast and thermal effects become more serious relative to neutron effects as the nuclear yield increases, if the mice were to be placed close enough to the high-yield CASTLE detonations that the neutrons would hurt them, they would be incinerated. There was thus no point in the experiment. Although agreed that it would be reexamined, it was concluded that “probably the project will be dropped.” By the next Operation CASTLE planning meeting, held on 2 and 3 April 1953, Project 4.1 had been stricken, and there were no proposed biomedical research projects (J-17595 [1953]).

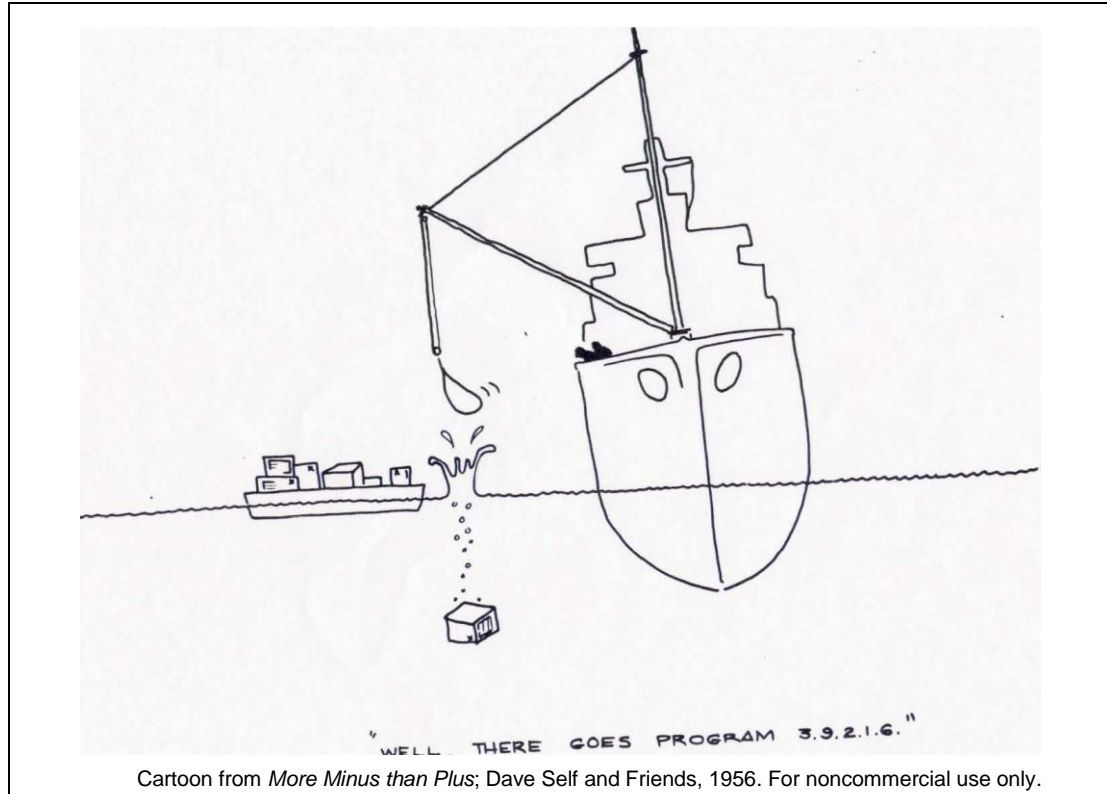


Figure 5-14. Individual research programs were uniquely identified by number

Planning for Operation CASTLE continued throughout the remainder of 1953 and into the beginning of 1954. In none of the many revisions to the *Outline of Scientific Programs* did biomedical experiments appear; revisions were distributed on 8 May 1953 (J-17930 [1954]), 1 July 1953 (J-18603 [1953]), and 10 November 1953 (J-21366 [1953]). There was no discussion of biomedical experiments during the Operation CASTLE Project Officers Meeting (J-18517 [1953]). The final planning document for the Operation CASTLE scientific programs, issued in December 1953 by AFSWP (J-22636 [1953]), similarly includes no biomedical studies. The classification guide for CASTLE, issued on 15 December 1953 (J-22088 [1953]), has no guidance for biomedical tests. No reference to biomedical experiments appears in the Los Alamos *CASTLE Handbook* dated 1 January 1954 (Ogle 1954, 257), which was designed to furnish experimenters in the field with a “reasonably concise” description of the CASTLE scientific programs. Prior to the BRAVO detonation, there was no plan for any biomedical research during Operation CASTLE.

Soon after the evacuation of Rongerik and Rongelap, it became apparent that scientific studies could be done as an adjunct to the medical treatment of the exposed populations. As stated in the commander's report from TG7.1 (WT-940 [1954]; also in ITR-923 [1954]), "the type of radiation received, and the manner in which the radiation dose was delivered, differed in several important respects from that seen in the Hiroshima and Nagasaki casualties, the Argonne or Los Alamos accidents,⁴⁹ or in the bulk of animal laboratory radiation exposures." "The groups of exposed individuals are sufficiently large to allow good statistics. Although no preexposure clinical studies or blood counts were available, it was possible to obtain Marshallese and American control groups that matched the exposed population closely with regard to age, sex, and background. Thus the conclusions which may eventually be drawn from group comparisons should be reliable." As put more succinctly by Thomas L. Shipman, MD, the Los Alamos health division leader, "Purely by luck, good or bad, we did manage to get some unusually good results on humans at Rongelap" (H-205 [1954]).

On 5 March 1954, 2 days after the evacuation of Rongelap, the AFSWP chief sent Task Force Command a message requesting permission to establish a joint study of "human beings exposed to significant gamma and beta radiation due to high yield weapons" (Preuss and Gilbert 1954). Navy Commander Eugene Cronkite was suggested to lead this effort.⁵⁰ Task Force Command quickly approved the request (NV0105490 [1954]), and ordered "all possible assistance including necessary assignment of class one priorities be rendered [to] CDR Cronkite for both the movement of personnel and equipment to Kwajalein." Operation CASTLE Program 4, Project 4.1—Study of Response of Human Beings Exposed to Significant Beta and Gamma Radiation due to Fall-out from High Yield Detonations—was formally established on 8 March 1954 by a letter sent to Commander Cronkite by Col. H. K. Gilbert, USAF, the commander of Task Unit 13 (TU-13-54-31S [1954]). "The objective of this project is to study the response of human beings in the Marshall Islands who have received significant doses due to the fall-out from the first detonation of Operation CASTLE."

⁴⁹ Dr. Graves, the task force scientific director, had himself been involved in the 21 May 1946 Los Alamos criticality accident that claimed the life of Dr. Lewis Slotin. Dr. Graves was standing just behind Dr. Slotin and observing the technique of "tickling the dragon's tail" by using a screwdriver as a lever to vary the separation of a hemispherical beryllium reflector atop a plutonium sphere. The accident occurred when the reflector slipped off the screwdriver blade. Dr. Slotin received a whole-body neutron-gamma radiation exposure estimated to be in the range of 1,200,000 mR (2100 rem) and died 9 days later. Dr. Graves received an exposure of approximately 200,000 mR (360 rem); he reported no particular symptoms of illness, although clinical observations and measurements showed distinct signs of hematological damage. Lore has it that Dr. Graves subsequently succumbed to radiation-related illness; in point of fact, he never experienced any medical sequela to his radiation exposure and died in July 1965 of a heart attack while vacationing at his summer cabin in Colorado.

⁵⁰ In May 1953, CDR Cronkite had been on the "short list" of candidates for the position of task force staff radiological medical officer (Byars 1953), a position subsequently filled by Col. Clinton S. Maupin (Coward 1953). At the time of BRAVO, CDR Cronkite was assigned to the National Naval Medical Research Institute in Bethesda, and he was physically present in Bethesda (ITR-923 [1954]). He had previously served as program director for Program 23, Biomedical Experiments, of the Civil Effects Test Group during Operation UPSHOT/KNOTHOLE in 1953.

Dr. John Bugher, the AEC director of biology and medicine, immediately dispatched his deputy, Dr. George LeRoy, to the Pacific. Dr. LeRoy carried a letter to General Clarkson outlining his mission (NV0028130 [1954]), which was to accompany the special medical team so as to keep Dr. Bugher informed “of any medical problems that develop in connection with this program,” and “to be of every possible assistance to [Clarkson] in meeting these difficult problems arising from the exposure of persons resident in the Trust Territory.” An additional message (NV0028136 [1954]) requested “as direct communication as possible” between Dr. LeRoy and the Division of Biology and Medicine. It thus seems that headquarters wanted to keep tight reins on the new project. On a more mundane level, on 11 March 1954, James E. Reeves, CTG7.5, sent a letter to the director of finance at the Santa Fe Operations Office wondering who was going to pay for it all (MC-538 [1954]).

Legend has it that Project 4.1 was established prior to the BRAVO detonation, and that exposure of the civilian population of Rongelap was an intentional experiment and not an accident. In a written statement of 5 July 1994, Senator Tony A. de Brum, Marshall Islands Parliament member, claimed that Project 4.1 “was pre-meditated and planned before the BRAVO shot.” His claim was based on an addenda attached to the *Outline of Scientific Programs* dated 10 November 1953 (J-21366 [1952]). Following distribution of this document, several alterations to the Operation CASTLE scientific programs were made. In the normal course of events, each such change was recorded as an addendum in the original document. Because of the restrictions on the issuance and reproduction of secret restricted documents, it was much easier to make such “pen and ink” changes than to send out a revised document. On 16 April 1954, a memorandum was issued by the commander of TG7.1 outlining changes to Operation CASTLE scientific programs (JF-7551 [1954]), including, specifically, the establishment of Project 4.1; this is clearly labeled as “Change #1 to J-21366, dated 10 November 1953.” These changes were dutifully recorded as addenda to the 10 November 1953 issue of the *Outline of Scientific Programs* by typing the indicated changes on small slips of paper and stapling or taping these slips to the original document. The proper control procedure is to initial and date each such change; this procedure was evidently not followed in the copy of the document that was made publicly available.

During their period on Kwajalein, Project 4.1 medical staff conducted many thousands of medical examinations and tests on “113 moderately exposed individuals, 157 lightly exposed, and a combined total of 297 American and Marshallese control individuals.” Daily clinical observations and routine sick calls were held for 298 Marshallese and Americans. By late April, their work was winding down as the health of the exposed groups improved. CDR Cronkite recommended (JF-8580 [1954]) that “since it is impractical to maintain a large group of highly skilled technicians, scientists, and physicians in standby status whenever testing of atomic weapons is in progress,” an on-call group be designated for immediate use in time of future need. “Since . . . subsequent studies will be on a lifetime basis it is recommended that Project 4.1 personnel be returned to the states in orderly fashion . . . and that the continued study be turned over to the responsible agency that may be designated.” The Brookhaven Laboratory was the agency so designated, and continues to this day to study and monitor the health of the exposed Marshallese.

A comprehensive report of the medical observations made by the Project 4.1 team is given by Cronkite, Bond, and Dunham (1956). Additional information and details concerning the staffing and operations of the Project 4.1 medical team are given in Cronkite, Conard, and Bond (1997), a history authored by three of the project medical doctors.

5.7 Evacuation Planning

The task force had available for its use four Martin PBM-5A *Mariner* general purpose “flying-boat” aircraft (J-19161 [1953], 19). These large, twin-engine amphibian naval transport aircraft could carry 20 passengers each. Two were stationed at Kwajalein and supported the weather islands and project instrumentation, and the other two were used for inter-atoll airlift between Eniwetok and Bikini. One of the Kwajalein aircraft was used to evacuate Rongerik.

Also included in the task force air fleet were two smaller Grumman SA-16 *Albatross* general purpose twin-engined amphibian flying-boats. Operating out of Eniwetok, these aircraft were used for air search and rescue. It is sometimes asked why these aircraft were not used to evacuate Rongelap, Ailinginae, and Utirik, and why preoperation evacuation planning was based on the destroyer escort security ships and not the amphibian aircraft.

In planning for Operation CASTLE, it was decided that evacuation of populated atolls would be conducted only if postshot radiological conditions indicated it to be necessary (CIC 32669, Section C-II-2). Preliminary evacuation was not considered necessary by the task force or politically desirable by CINCPAC. However, the possibility that postshot evacuation of some atolls might be required was recognized. As put by Tom Shipman (1953), “With detonations of high yield it becomes extremely difficult to predict the shape and location of the fall-out pattern. Some material obviously is coming down somewhere, and there can never be any positive assurance that some of this will not land on inhabited islands or on ships of the Task Force.” Plans were thus made to ensure that the task force was capable of effecting an evacuation on short notice (NV0079980 [1954], 142). Because amphibian aircraft could fly only to those atolls having lagoon landing areas cleared of coral heads, because they could not operate safely during hours of darkness (NV0028554 [1954]) nor during storms, and because they were not as safe and were mechanically less reliable than ships, it was felt that the destroyer escort security ships would provide the safest and most dependable means of evacuation. (Aircraft accidents were a major cause of loss of life during the Pacific testing operations.) Since these ships could each transport about 100 men and 50 women and children, most inhabited atolls could be evacuated in a single operation, as opposed to the numerous trips required by even the PBM-5A aircraft. Use of the amphibian aircraft for emergency evacuation was not ruled out, but these aircraft were viewed as an adjunct to the ships. For the evacuation of Rongelap, both ships and aircraft were employed.

5.8 Record Keeping

For both historic and legal purposes, it would be desirable to have a detailed and complete accounting of events occurring in Task Force Command Headquarters during the critical hours before and after detonation of the BRAVO device. A record of the discussions within the Radiation Safety Office in the Joint Operation Center aboard the USS *Estes* would be of particular value. In planning for Operation CASTLE, the potential value of such information was recognized, and a detailed plan was promulgated for saving written documents and for electronically recording and transcribing verbal discussions (House 1952). The goal of the record-keeping plan was to ensure that “all documents having a bearing on the shot will be preserved in order that the files may reflect a complete history of the event.” Refer to Figure 5-15 through Figure 5-21 for example documentary photographs.

Colonel House’s two-volume anthology *Final Report, Radiological Safety, Operation CASTLE, Spring 1954* (House 1954; NV0051031 [1954]; and NV0051072 [1954]) is the product of the record-keeping plan. This anthology does not, however, contain the transcriptions of verbal discussions called for in the planning document (House 1952). The version of Lt. Col. House’s preoperation planning document *RADSAFE Office Operations for Critical Times* (House 1952) that appears as Tab G of his postoperational report (NV0051031 [1954]) contains no reference to audio recordings. It thus seems that the requirement may have been removed in the weeks before BRAVO. An alternate possibility is that the recordings were made, but that they did not reflect well on the performance of Task Force Command during critical times, and were therefore omitted. Events following the BRAVO detonation were, by all accounts, hectic. As Bill Ogle (CTG7.1) said in his personal remembrances, “To call the result ‘Chaos’ is putting it mildly.”



DTRIAC item 22-1246

Figure 5-15. A typical house in the main part of Rongelap village, 8 March 1954



DTRIAC item 22-1296

Figure 5-16. A Rongelap village scene, 9 March 1954
Refer to Figure 2.1 of Sharp and Chapman (1957) for a village map.



DTRIAC item 22-1369

Figure 5-17. A cooking area at Sifo Island, 10 March 1954



DTRIAC item 22-1026

Figure 5-18. Checking radiation of drying copra in tent area, Sifo Island, 10 March 1954



DTRIAC item 22-C-447

Figure 5-19. Water catchment cistern, Rongelap village, 20 April 1954
Dried grass in foreground was due to persistent drought.



DTRIAC item 22-1047

Figure 5-20. General Clarkson visits with island evacuees, Naval Station Kwajalein,
5 March 1954



USAF LML; DTRIAC item 22-1207

Figure 5-21. Evacuated children at Kwajalein, 20 March 1954

6.0 The House Committee Hearing

How sad it is that the Department of Energy, at the February 24th hearing, chose to be represented only by a Deputy Assistant Secretary whose entire message may be summed up as follows: "It didn't happen on my watch, so I cannot comment on that, Mr. Chairman."

—Roger Ray, 9 March 1994



Figure 6-1. Mr. Jack Tobin, the Marshall district anthropologist, visits with John, the magistrate of Rongelap, and Komboj of Utirik, Kwajalein Navy Base, 11 March 1954

On 24 February 1994, the US House Committee on Natural Resources conducted a hearing into the conduct and consequences of the CASTLE BRAVO test. At the hearing, DOE made no attempt to answer specific questions or respond to issues raised by the various speakers. This chapter is intended to address some specific questions and issues raised during the hearing.

6.1 Comments on the Statement by Mr. Merrill Eisenbud

Mr. Merrill Eisenbud was one of the founding fathers of environmental radiation science. Among other professional positions during his long and prestigious career, he served as the director of the Environmental Protection Agency of New York City, the first such position in the United States. In 1954, he was the director of the AEC HASL, the organization responsible for Operation CASTLE off-site radiation measurements. He wrote about his experiences during Operation CASTLE, and the other American nuclear testing campaigns, in his book *An Environmental Odyssey* (Eisenbud 1991). Although too busy with administrative duties to be present in the Pacific, Mr. Eisenbud was nevertheless a key participant in the Operation CASTLE radiation protection program. His written Statement to the Committee (Eisenbud 1994) concerning management of the off-site radiation measurement program unfortunately perpetuates several common legends concerning the conduct and consequences of the BRAVO test.

Mr. Eisenbud wrote, in reference to the IVY MIKE detonation, “[HASL] concluded that whatever fallout had taken place was in the open ocean.” In fact, the written report *Radioactive Debris from Operation IVY* (NYO-4522 [1953]), issued on 28 April 1953 under Mr. Eisenbud’s name, contains no such conclusion. This seemingly minor point is significant because the absence of observed fallout from IVY MIKE was taken as support for the theory that most of the radioactive debris had been injected into the stratosphere and had remained trapped in the stratosphere. The invalidity of this stratospheric trapping theory led indirectly to the BRAVO incident. Mr. Eisenbud may be remembering the conclusion reached at the SUNSHINE meeting he attended in December 1953 that “if [MIKE] debris did in fact fall out, there was no fall-out measurement to detect it” (RM-1175-AEC [1953]). This is a very important conclusion, but one reached only more than a year after the MIKE detonation.

Mr. Eisenbud claimed that aerial confirmation of the fallout detected by the HASL gamma radiation detector on Rongerik “was not permitted.” In the sequence of events following the BRAVO detonation, there was no instance when aerial confirmation was requested, but not permitted. In his description of the events of BRAVO day, Mr. Breslin, the HASL supervisor on the *Estes*, states that the request for a survey flight was delayed for about 4 hours “to diminish the possibility of the survey aircraft passing thru the radioactive cloud” (NYO-4623 [1955], 51). When the WILSON-3 cloud-tracker aircraft confirmed possible contamination in the Rongerik area, an immediate request was made for NYOO Flight ABLE.

Each of the six “key points” enumerated in Mr. Eisenbud’s statement requires comment and clarification:

1. *There was a “general lack of initial preparedness for fallout monitoring” by the task force.*
In point of fact, an extensive fallout monitoring program—Project 2.5—was planned and undertaken by the task force (J-22866). The results of this program are documented in the NRDL report issued in January 1956 (WT-915). Task force planning explicitly included airborne monitoring in the area of Rongelap and Rongerik using the WILSON cloud-tracking aircraft (NV0051031 [1954], C-16; Chesney 1954, 37). The HASL off-site monitoring program (NYO-4623 [1955]) was intended to complement the task force fallout monitoring projects.
2. *The task force declined to provide a dedicated standby evacuation capability in the event that emergency evacuation of the populated atoll was required.*
It was CINCPAC and not the task force that declined to provide such capability. On 11 December 1953, General Clarkson had advised CINCPAC that “our operational planning anticipates a remote possibility of adverse [fallout] conditions out to populated atolls” (NV0051031 [1954], C-18). Despite this warning, there was no change in previous guidance from CINCPAC that task force assets would be required to accomplish any emergency evacuation of populated atolls. Prior to BRAVO, Task Force Command arranged for a Trust Territory official and an interpreter to be available on Kwajalein to assist in any emergency, and had developed an emergency evacuation plan utilizing the task force destroyer escort security ships and aircraft.
3. *The HASL instrument at Rongerik Atoll had warned of dangerous radiation levels soon after the detonation.*
The existence of dangerous radiation levels on Rongerik was confirmed to Task Force Command by the WILSON-3 cloud-tracking aircraft, and not by the HASL instrument. The radio message sent from Rongerik at March 01-15:15M 1954 indicated only that fallout may have occurred. Because the HASL meter, as observed by untrained personnel, was reported to be off scale and because the WILSON-2 aircraft had not reported contamination in the Rongerik area, Task Force Command decided to wait for the WILSON-3 overflight before acting on the message from the Rongerik weather detachment.

4. *Mr. Breslin, the HASL supervisor on the Estes, received notification around 01-13:45 (“about 7 hours postshot”) that the HASL meter on Rongerik was off scale.*

Mr. Breslin himself stated that he received this message at about 01-16:00M (NYO-4623 [1955], 51), a little more than 9 hours after the detonation. Mr. Eisenbud reported that he was notified “immediately” of the Rongerik radiation readings via radio-telegram to his New York laboratory. Such a message has not been found in task force communication records. It is not apparent how such a message could have made its way, without record, through communications security (J-21092 [1953]) and have been received and delivered in New York City at 10:15 p.m. Eastern Standard Time.⁵¹

5. *The initial report from Rongerik was ignored by Task Force Command.*
The initial report from Rongerik was certainly not ignored. In consideration of its origination from an untrained observer and the apparently contradictory measurements from the WILSON-2 cloud tracker, the message was initially discounted. Four hours later, the WILSON-3 aircraft confirmed contamination in the Rongerik area, and a second message from Rongerik reported that the HASL meter actually had been off scale continuously since early afternoon; action was taken immediately by Task Force Command to ascertain the true situation. It was not until the task force radiation monitor arrived at noon the next day that it became clear that Rongerik and Rongelap were in the primary fallout pattern, and that prompt evacuation would be required to ameliorate acute radiation injury.
6. *The task force initially provided no aerial monitoring capability beyond Eniwetok and Bikini.*

This is true. It was the agreed responsibility that Mr. Eisenbud and HASL, working with CINCPAC assets, would provide such monitoring capability. However, in response to CINCPAC concerns (NV0051031 [1954], C-7), the task force plans were modified in December 1953 (NV0051031 [1954], C-15) to provide additional aerial monitoring capability beyond Eniwetok and Bikini throughout Operation CASTLE (NV0051031 [1954], 37-43). The task force also offered at this time to supply film badges to civilian populations in the northern Marshall Islands in order to provide legally acceptable records of possible radiation exposures (NV0051031 [1954], C-17). CINCPAC, through the commander-in-chief, Pacific Fleet, declined this offer as “impractical in view of the numerous populated atolls” to which the Navy would have to provide transport (NV0051031 [1954], C-30).

⁵¹ In the early planning for Operation CASTLE, General Clarkson made clear his intent “to button it up absolutely tight, so that no [one] can send a message out of the task force area without approval of one of the Task Group Commanders” (Clarkson 1953a).

Mr. Eisenbud implied that the task force provided HASL with only grudging support: “a single billet aboard the command ship.” The actual relationships between the task force and HASL are detailed in the CASTLE radiological safety report (NV0051072, 43-46); these relationships were established more than 6 months in advance of the first detonation (Eisenbud 1953). The operational plan provided for one man (Mr. Breslin) to be stationed at the Task Force Command Post aboard the *Estes* as supervisor of HASL activities, and one man to perform the necessary maintenance and setting up of instruments at the ground stations. Task Force Headquarters made space and clerical assistance available in the Radsafe Office for the HASL supervisor; provided communications facilities to the outlying ground stations; provided transportation to all of the task force weather stations, Ujelang, and Wake; and provided transportation assistance to other sites outside task force control, as necessary. In addition, the Radiation Safety Unit of TG7.1 made space and equipment available for storage and repair of HASL instruments. Task Unit 9 of TG7.1 even produced a motion picture detailing HASL activities during Operation CASTLE.⁵²

Mr. Eisenbud believed that the AEC press statement from 11 March (NV0123485 [1954]; NV0125319 [1954]) concerning the BRAVO incident “left much to be desired.” The task force also believed that the AEC statement left much to be desired. When informed that the AEC intended to sidestep the issue, Dr. Graves replied (JF-4614 [1954]), “I am very much concerned reference the recent decision not to make a [press] release on evacuation of natives unless forced to do so. I hope that the fact that these natives are not United States citizens but wards of the Government was given appropriate weight.” “I should regret very much the impression that we are being furtive in our actions with regard to these people. I regret very much that I was unable to avoid this complication.”

6.2 Comments on the Statement by Mr. Jonathan Weisgall

Mr. Jonathon Weisgall is a Washington, D.C., attorney who has provided legal representation to the citizens of Bikini. His book *Operation CROSSROADS* is a detailed and comprehensive account of the 1946 test series at Bikini Atoll.

⁵². This film has not been found.

In his 1994 Statement to the Committee, Mr. Weisgall claimed that “the killing power of lingering radioactive fallout far surpasses the instant sledgehammer effect of the [atomic] bomb’s blast” (Weisgall 1994b). It should be clearly understood and emphasized that this legend is not true. The most vivid reminder of this fact is the medical outcome of the combat strikes that ended the Second World War. Approximately 103,700 people were killed in these two low-yield airburst detonations (NP-3036 through 3041 [1951]; Oughterson and Warren 1956; D’Olier and Alexander 1946).⁵³ This number includes all deaths occurring through November 1945. In the following few years, there were approximately 3000 additional “lingering plus premature” deaths attributable principally to festering blast and burn injury. As of 1985, there were 3435 cancer deaths in the 41,719 atomic bomb survivors who received radiation doses in excess of 500 mR (BEIR V 1990, 162; Cooper 1995, 102), approximately 375 more than expected from natural causes.⁵⁴ Delayed radiation fatalities, thus, accounted for less than half a percent of total mortality, and a very much smaller portion of the years of lost life.⁵⁵ While radioactive contamination from a surface burst would be much worse, the number of people killed directly by “the instant sledgehammer effect of the bomb’s burst” would, in all combat scenarios involving urban-industrial targets, greatly exceed the number of delayed radiation fatalities.

While lingering radiation may have caught the attention and concern of the popular press and general public, the blast and heat from any atomic strike in an urban area would kill vastly more people than residual radiation and fallout.

In a section of his testimony titled “Winds,” Mr. Weisgall makes two claims: (1) that the BRAVO fallout on the inhabited atolls was not caused by an unexpected shift of the winds, which is certainly true; and (2) that because the weather forecast indicated sufficient risk to move the smaller and slower task force ships further away from Bikini, the Marshallese people were known to be in danger, which is certainly not true.

As detailed in Section 3.3 of this report, it was not the position of the task force scientific staff that the fallout at Rongelap Atoll was caused by an unexpected shift of the winds.

⁵³ The best estimate of the population in Hiroshima at the time of the bombing is 255,200 and that of Nagasaki is 195,290. Total deaths through November 1945 were approximately 64,500 (25.5 %) in Hiroshima, while roughly 39,200 (20.1 %) of the population perished at Nagasaki. Because of wartime transient military and civilian populations, the numbers could not be determined more precisely. First-day deaths were perhaps 40,000 to 50,000 at Hiroshima and roughly 20,000 at Nagasaki.

⁵⁴ Having escaped from near the center of a destroyed and burning city, the survivors had potential exposures to many cancer-causing chemical agents; it is unlikely that all of the excess cancers were, in fact, caused by ionizing radiation.

⁵⁵ The overall health and life expectancy of the exposed group has been actually somewhat higher than in the control population. Although bomb radiation did result in a detectable increase in the number of cancer deaths, there was no concomitant increase in total age-group mortality.

The final preshot fallout predictions, as presented at both the midnight (01-00:00M) and final (01-04:30M) safety meetings, showed all of the populated northern Marshall Islands to be well south of any hazardous fallout. Rongelap Island was about 40 mi outside the RADEX area. Because the nearly calm winds between 5000 ft and 15,000 ft would keep more of the fallout closer to Bikini, the smaller and slower task force vessels were moved radially outward from a minimum of 30 mi to a minimum of 50 mi. The larger ships remained at 30 mi to maintain voice communication with the firing party on Bikini, and to maintain a helicopter evacuation capability for this party. Mr. Weisgall writes that “the final weather and radiological safety check shows that the AEC knew there was a problem,” but the problem was at Bikini, not, as Mr. Weisgall implies, at Rongelap or other populated atolls. The point is clearly made in the Clarkson-Graves memorandum:

(5.b.3) Outlooks for: Bikini: unfavorable; Eniwetok: favorable; Ujelang: favorable, and the native populated atolls in the southeast quadrant from ground zero favorable, since resultant winds in the direction of these areas were considered too slow to move significant fallout to the atolls involved.

The suggestion by Mr. Weisgall that Task Force Command detonated the BRAVO device knowing that thousands of men in task force vessels and the populations of Rongelap and Rongerik would be exposed to potentially harmful amounts of fallout is insulting nonsense. As put by AEC Chairman Strauss in 1954, “Such statements are utterly false, irresponsible and gravely unjust to the men involved.”

In his concluding remarks, Mr. Weisgall claimed that “the tests in the Marshall Islands cost hundreds of billions of dollars.” The actual cost of all testing operations at the PPG, corrected to the date of the hearing, was approximately \$8 billion. Detailed cost information is contained in documents then readily available through the DOE/CIC (now the DOE/NTA).

Mr. Weisgall voiced his perception that “the US government has continued to keep documents from the testing program classified, thus making it impossible to determine the extent of injuries and damages.” “Despite requests from myself and others, in litigation and negotiations, thousands of documents remained classified and were never produced.” This enduring staple of BRAVO lore is not true. Comprehensive review of the DOE and DoD classified records collections conducted in 1994 during the DOE openness program revealed no such documents. Nearly all of the identified relevant materials had by then been available through the DOE/CIC for a decade or more. Despite the existence of an extensive library of readily available reference materials, it seems that at the time of the hearing, Mr. Weisgall was, in fact, unfamiliar with even the most basic references to radiological safety during Operation CASTLE.

6.3 **Comments on the Statement by Mr. David M. Weiman**

Mr. Weiman introduced the hypothesis that the BRAVO fallout pattern was bigger, exposing more people and contaminating more lands than the AEC/DOE or the JTF ever admitted. In fact, HASL and the task force conducted and reported a thorough and complete survey of contamination throughout the islands of the central Pacific. The questions raised by Mr. Weiman concerning the extent and severity of the BRAVO fallout contamination are largely answered by the information and references given in Chapter 4.0. The bulk of this information was released to the public in 1959, and it was readily available through the DOE/CIC (now the DOE/NTA) for at least 4 years before the signing of the Compact of Free Association on 25 June 1983 and more than 6 years before the enabling legislation was passed by the US Congress on 14 January 1986.

Mr. Weiman stated that “DOE never displays or reveals [the] radiation footprint fallout pattern of all 66 [PPG] tests.” His attention seems never to have been drawn to the 1979 report *Compilation of Local Fallout Data from Test Detonations 1945–1962, Volume II—Oceanic US Tests* (DNA 1251-2-EX). He further remarked, “Declassification does not mean instant access or even awareness.” In actuality, the DOE/CIC (now the NTA) contains all publicly released documents in a single library. The document collection is well indexed and referenced, and the staff is thoroughly competent, exceedingly knowledgeable, and genuinely helpful.

Mr. Weiman called for “a full investigation of Safeguard C and why the Marshall Islands medical and environmental programs were incorporated into a standby readiness program to resume atmospheric testing.” The Safeguard C Test Readiness program was established in the Resolution of Ratification of the Threshold Test Ban Treaty of 1963. There was never any substantial connection between the Safeguard C Test Readiness Program and any of the DOE activities in the Marshall Islands. The only connection whatsoever was a plan to establish a weather station on Majuro and a communications link at Kwajalein, should there be a resumption of atmospheric nuclear testing. This plan was, of course, never carried out. While both programs were administered through the DOE Defense Programs Office, this management scheme does not imply any particular relationship; the Defense Programs Office managed many hundreds of separate programs within the department.

6.4 Comments on the Statements by Dr. Steve Simon and Dr. Thomas Hamilton

It seems that Dr. Simon, then director of the Nationwide Radiological Study, Republic of the Marshall Islands (Simon and Graham 1994), was, at the time of the hearing, unaware of the extensive fallout radiation exposure measurements made during Operation CASTLE. The references given in Chapter 4.0 of this report resolve many of his questions concerning CASTLE-related radiation contamination throughout the Marshall Islands. As Dr. Simon noted on page five of his statement, “The value of historical measurements is immense” (Simon 1994). It is, perhaps, unfortunate that the historical measurements were not known and considered during planning of the Nationwide Radiological Study.

The possibility of illness caused by nuclear test contamination is a central question of life for people living in the Marshall Islands today. Chief among the medical concerns is the possibility of thyroid abnormalities, including cancers and developmental disorders, resulting from ingestion of radioactive iodine carried on fallout particles. Even a very small amount of radioactive material, if retained in the body, can produce considerable injury.

In his Statement to the Committee, Dr. Simon reviewed certain statistical information concerning the prevalence of thyroid disease at various locations in the northern Marshall Islands. These data came from Dr. Hamilton and his colleagues, who conducted a 3 year investigation of manually palpable thyroid nodules (neoplasia) in the Marshallese people,⁵⁶ and reported their findings and conclusions directly to the US House Interior Committee in a confidential statement from March 1985, in the medical literature (Hamilton, van Belle, and LoGerfo 1987), and in the Statement to the Committee (Hamilton 1994). The results of the population survey are further reported in *Health Effects of Exposure to Low Levels of Ionizing Radiation* (BEIR V 1990). A “strong inverse linear relationship” was noted between the prevalence of manually palpable thyroid nodules and distance, in whatever direction, from the BRAVO test site (Hamilton, van Belle, and LoGerfo 1987, Fig. 3). From this mathematical correlation it was concluded that “radioactive fallout, specifically radioactive iodines, was the most likely cause of these thyroid neoplasms” (Hamilton 1994). But correlation is not causality, and the actual relationship between fallout radiation exposure and disease prevalence was not examined.

⁵⁶ The study was funded by the Marshall Islands Atomic Testing Litigation Project, a legal advocacy group in Los Angeles, California.

Because they were then unfamiliar with the HASL measurements and other Operation CASTLE off-site radiation surveys, a true “double-blind experiment” was inadvertently conducted in which both the examining physicians and population groups examined were, at the time of the work, unaware of actual fallout radiation exposures. Such controlled ignorance is not only desirable, but is actually vital to assuring proper scientific objectivity in medical research studies, and it adds greatly to the credibility of the data obtained in this survey. Using the actual fallout radiation measurements (Table 4-1), it is now possible to establish whether the distance from the BRAVO test site was, in fact, a proxy for fallout radiation dose, and whether the reported prevalence of palpable thyroid nodules are, in fact, statistically related to Operation CASTLE radiation exposures.

A glance at Table 4-1 shows that distance is not a proxy for fallout radiation dose; given the complex structure of the winds aloft, how could the situation be otherwise? Takahashi et al. (1997) also noted the lack of any correlation between distance and dose, “thus casting some doubt on the existence of a decreasing linear dose effect as a function of distance.” The “strong inverse linear relationship” noted by Hamilton is, in reality, nothing more than a mathematical mirage, and a textbook example of the lesson that correlation does not necessarily imply causality.

It is instructive to compare the age-adjusted prevalence of palpable thyroid nodules observed in the Marshall Islands 30 years after Operation CASTLE (Hamilton, van Belle, and LoGerfo 1987, last column of Table 3) with the actual amounts of radioactive surface contamination, as measured by the HASL survey flights (Table 4-1). With the exception of people then living on Rongelap, the prevalence of palpable nodules is found to be unrelated to the amount of fallout contamination from BRAVO alone or from the six Operation CASTLE nuclear tests combined. No statistically significant variations in the prevalence of palpable thyroid abnormalities are apparent in population groups having received cumulative external fallout radiation exposures of 60 to 20,000 mR; the prevalence remained constant at $5.7 \pm 0.5\%$ throughout this exposure range. (Refer to Figure 6-2.) This result is in agreement with an independent determination of the prevalence of manually palpable thyroid nodules in the general adult Marshallese population of 6.3% (Lessard et al. 1985). For comparison, palpable thyroid nodules occur in 4 to 7% of the adult American population (Welker and Orlov 2003; Hebra, Miller, and Thomas 2004).

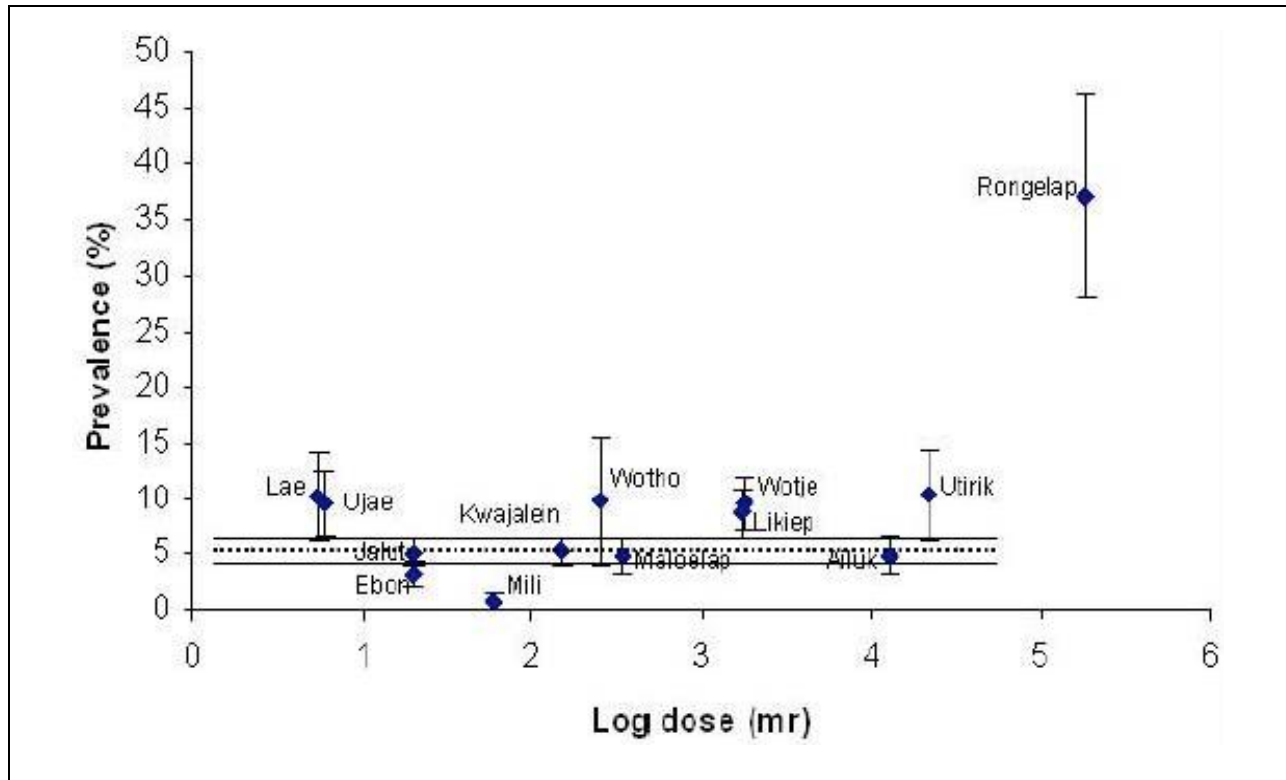


Figure 6-2. Prevalence of manually palpable thyroid nodules in relation to BRAVO fallout radiation exposures
The data from Hamilton, van Belle, and LoGerfo (1987), Table 3, are compared to actual amounts of BRAVO fallout radiation on 13 atolls in the Marshall Islands. Errors have been estimated from resultant Poisson statistics. The dashed line shows the average observed prevalence of 5.7%; the lines above and below indicate the range in the adult American population. The only Marshallese population group showing higher than average prevalence is on Rongelap. The small error for the Mili Atoll data is an artifact of the mathematical processes; if an expectation uncertainty is assigned, the three-sigma band encompasses the average.

In contrast to the situation prevailing in the general Marshallese population, the elevated prevalence of palpable thyroid nodules at Rongelap clearly indicates medical harm from the BRAVO fallout contamination.

Thyroid abnormalities can result from ingested iodine. Because the amounts of ingested radioactive materials concomitant to nuclear test contamination depend on both fallout particle sizes and chemical composition, and on local food preparation practices (Glasstone and Dolan 1977; Lessard et al. 1985), it is difficult to make any precise connection between external fallout radiation exposure and thyroid dose from ingested radioactive iodine. Assuming, however, that local conditions of fallout and food preparation were roughly similar for each of the population groups examined, Dr. Hamilton's data tend to support either a "practical threshold" dose-response mode (Evans 1943, 1974) with natural background, in which some minimum fallout radiation exposure is required to produce any additional disease, or a linear dose-response model with natural background, in which the incremental probability of disease increases directly with exposure.⁵⁷ Whichever dose-response model may be correct, the data do show that a minimum fallout radiation exposure of roughly 25,000 mR was required to produce a detectible increase in the prevalence of manually palpable thyroid nodules. This threshold corresponds to internal radioiodine thyroid exposures of, very roughly, 1,250,000 mR.⁵⁸ It is perhaps significant to note the agreement of this result with the threshold for radium-induced bone and head cancers in humans (Evans 1943, 1974; Cooper 1995, 233).

⁵⁷For this model, the prevalence of manually palpable nodules is related to exposure by the equation

$$p = 5.7 + 1.76 \times 10^{-4}d,$$

where p is the prevalence in percent and d is the fallout radiation exposure in milli-Roentgen; the slope constant is determined by the 37% prevalence observed by Hamilton, van Belle, and LoGerfo (1987) among the people of Rongelap.

⁵⁸The correlation between external whole-body gamma ray dose and total thyroid-absorbed dose is estimated from the dose reconstructions presented by Lessard et al. (1985), Table 23, for Utirik Atoll, which suggests a rough population average factor of 50 between external fallout radiation dose and total thyroid dose.

A subsequent investigation into the prevalence of thyroid nodules in people then living at Ebeye Island, Kwajalein Atoll, was conducted between 1993 and 1996 by Takahashi et al. (1997) at the behest of the Nationwide Radiological Study Scientific Advisory Panel. This study involved not only manual examination, but also high-resolution ultrasound imaging, which allowed smaller nodules to be discovered. A total of 815 people who were alive during the BRAVO test were examined, and these were divided into cohort groups by atoll of residence in 1954. The overall prevalence of nodules was found to be $32.6 \pm 2.0\%$. For comparison, nodules are found incidentally on ultrasonography in 19 to 67% of the adult American population (Welker and Orlov 2003). As for the Hamilton study, no statistically significant causal relationship is evident between the age-adjusted prevalence of thyroid nodules (Table 1, column 10 in Takahashi et al. [1997]) and the amounts of fallout contamination from BRAVO alone or from the six Operation CASTLE nuclear tests combined (refer to Figure 6-3). It is curious that the 11 people from Rongelap examined in this study (Takahashi et al. 1997) had a relatively normal prevalence of total thyroid nodularity ($45 \pm 20\%$ versus $33 \pm 2\%$), but, as previously demonstrated by Hamilton, van Belle, and LoGerfo (1987), had an elevated prevalence of the larger, palpable nodules ($36 \pm 18\%$ versus $16 \pm 2\%$); perhaps the major effect of their radiation exposure was to increase the number of smaller nodules growing sufficiently large to be detected on manual examination.

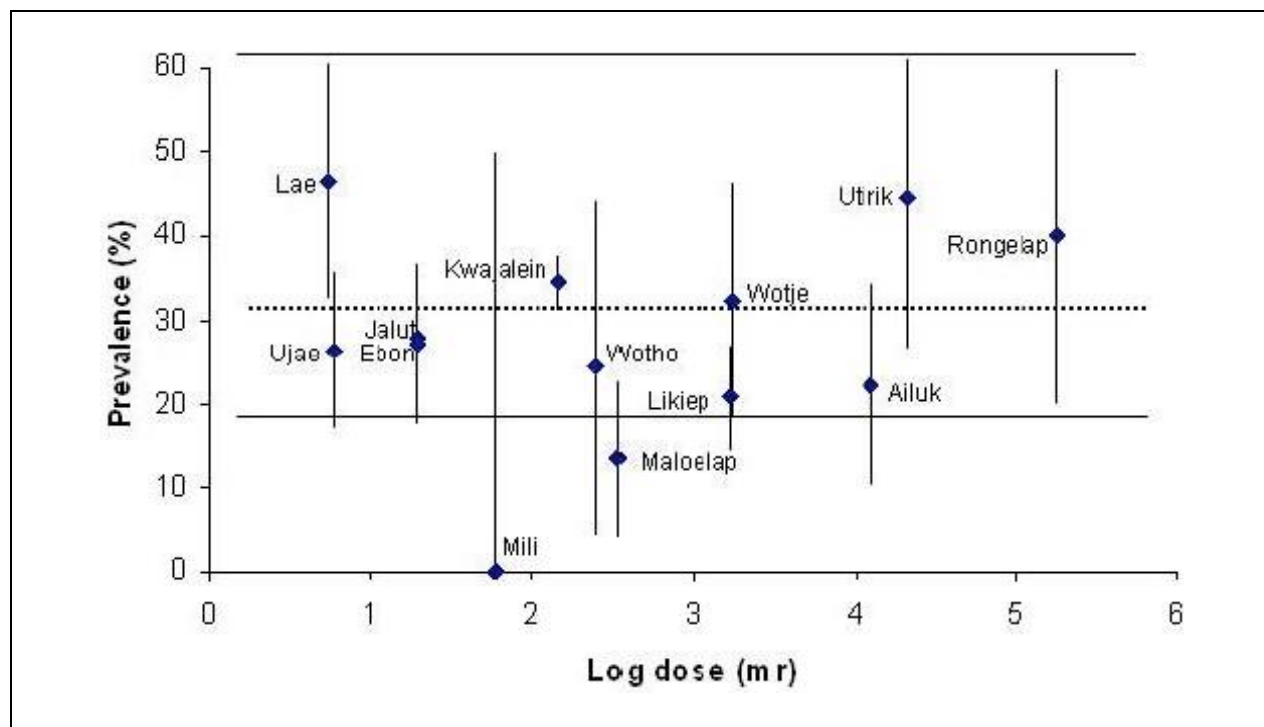


Figure 6-3. Prevalence of ultrasonically detected thyroid nodules in relation to BRAVO fallout radiation exposures

The data from Takahashi et al. (1997) (Table 1 column 10) are compared to actual amounts of BRAVO fallout radiation on 13 atolls in the Marshall Islands. Errors have been estimated from resultant Poisson statistics. The dashed line shows the average observed prevalence of 33%; the solid lines above and below indicate the range in the adult American population.

A second population study utilizing ultrasound detection techniques was conducted in 1994 by Howard, Vaswani, and Heotis (1997). This study focused on the exposed populations of Rongelap (47 people) and Utirik (70 people) compared to a comparison group (47 people) comprised largely of Rongelapese living at Rita Island, Majuro Atoll, in the spring of 1954. The overall prevalence of ultrasonically detectable nodules in those not having previous thyroid surgery (117 people) was $28.2 \pm 5\%$, a result in excellent agreement with the findings of Takahashi et al. (1997). Also in agreement with the Takahashi study, there were no statistically significant differences in prevalence between the exposed groups at Rongelap ($22 \pm 10\%$) and Utirik ($31 \pm 8\%$) and the comparison population ($28 \pm 9\%$). (Refer to Figure 6-4.)

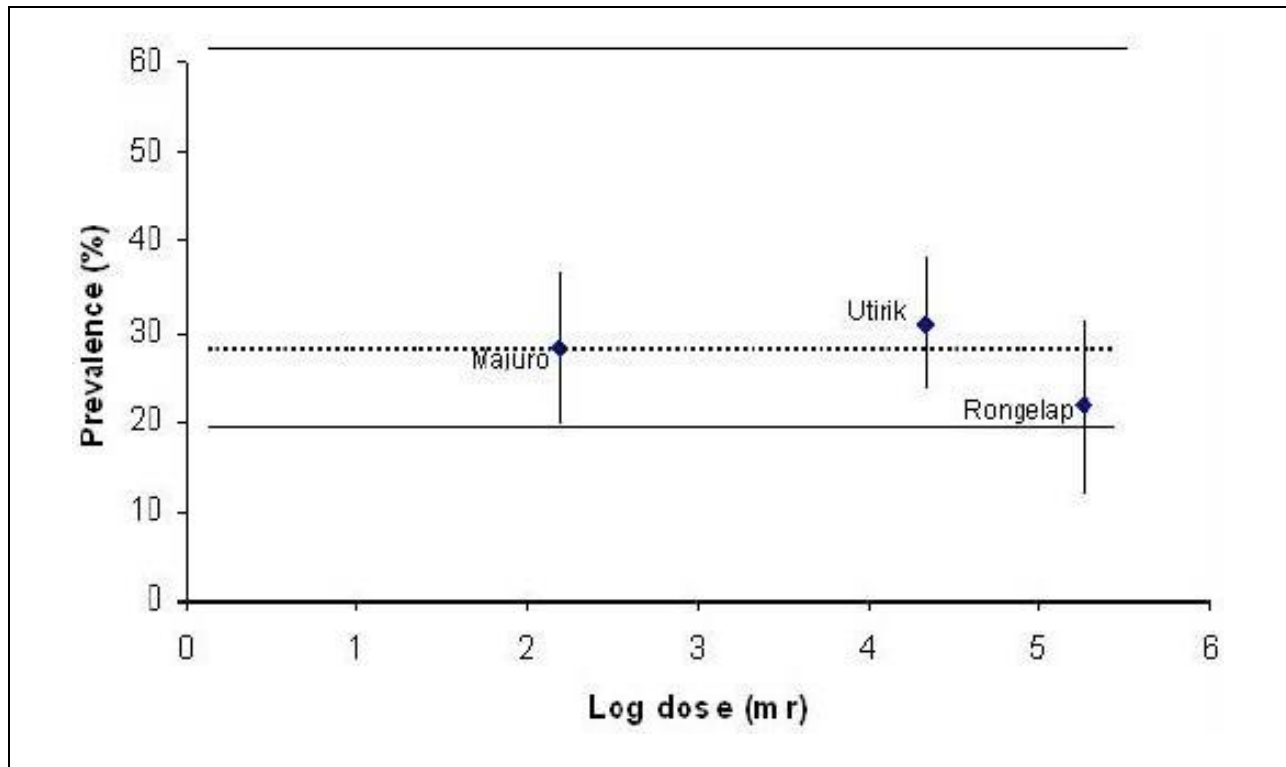


Figure 6-4. Prevalence of ultrasonically detected thyroid nodules in relation to BRAVO fallout radiation exposures
The data from Howard, Vaswani, and Heotis (1997) (Table 4 column 5) are compared to actual amounts of BRAVO fallout radiation. Errors have been estimated from resultant Poisson statistics. The dashed line shows the average observed prevalence of 29%; the solid lines above and below indicate the range in the adult American population.

It is evident from the findings of these three carefully designed and executed population surveys that the overwhelming majority of thyroid nodules found occurring in the Marshall Islands people from 30 to 40 years afterward were unrelated to fallout from the Operation CASTLE nuclear tests. Established lore to the contrary, the overall prevalence of thyroid nodularity in Marshall Islanders alive at the time of BRAVO is no larger than in the United States. In the original paper, Hamilton, van Belle, and LoGerfo (1987) wrote, “[w]ithout thyroid dose estimates for people living on 12 of the 14 atolls in this study, radiation exposure cannot be proved as the cause of these neoplasms,” using the observed amounts of fallout as a proxy for thyroid absorbed dose, it can, in fact, be demonstrated that fallout contamination was not the cause of the neoplasms.

Voicing his perception that the prevalence of palpable thyroid nodules in the Marshall Islands is higher than in other human populations, Dr. Hamilton asked rhetorically in his Statement to the Committee, “[Besides fallout radiation] what other known risk factors for thyroid nodules exist in the Marshall Islands?” In his list of risk factors, he did not mention that “there is a wide variation among reports of the spontaneous thyroid cancer incidence among different Polynesian populations” (BEIR V 1990, 291); that “there is accumulating evidence that populations resident on island countries, in particular those in the tropical waters of the Pacific, have higher than normal incidence rates for thyroid cancer” (Takahashi et al. 1997); and that the unusual amount of seafood in the traditional Marshallese diet places this group at risk for thyroid abnormalities and cancers (Harris 1994; Takahashi et al. 1997).

The population study by Hamilton, van Belle, and LoGerfo (1987) documented a total of 142 cases of palpable thyroid abnormality among the 2273 persons then examined that were alive in 1954. How much of this might have resulted from Operation CASTLE fallout exposures? Assuming the correctness of the zero-threshold linear dose-response model with a background prevalence of 5.7 %, and a slope of 1.76×10^{-4} % per mR of external radiation exposure, as set by the prevalence found at Rongelap, and taking fallout radiation exposure as a proper surrogate for subsequent thyroid dose, then the total number of excess palpable thyroid cases then occurring can be estimated to be roughly 25. Most of these are statistically expected among the exposed populations at Rongelap (14 of 17 cases), Utirik (3 of 6 cases), and Ailuk (5 of 8 cases), with the remaining three cases anticipated at Kwajalein (1 of 25 cases), Wotje (1 of 14 cases) and Likiep (1 of 14 cases).

Dr. Hamilton also compiled and reported “certain historical observations” from people living in the northern islands in March 1954 that he believed provided “compelling information” that BRAVO fallout “likely extended to other atolls in the Marshall Islands.” He stated that these anecdotal personal histories “suggest the possibility” that there was sufficient fallout at Ujae Atoll to cause acute radiation sickness. Examination of the HASL survey data reported in Table 4-1 shows, however, that Ujae received a total cumulative external gamma-ray dose from all of the Operation CASTLE detonations of only 114 mR; this exposure is a factor of a thousand less than the minimum needed to cause acute radiation sickness (Glasstone and Dolan 1977, Table 12.108). As chance would have it, Ujae Atoll, which lies only 155 mi south of the shot site, received less fallout from BRAVO itself, and from all six CASTLE tests combined, than did any other location in the Marshall Islands. The dearth of fallout at Ujae was confirmed by Simon and Graham (1994), who measured amounts of residual radioactive soil contamination no larger than expected from global fallout (refer to Figure 5-3). As might be anticipated from the small amount of contamination, the people of Ujae were found by Hamilton, van Belle, and LoGerfo (1987) and by Takahashi et al. (1997) to have a prevalence of thyroid abnormalities not significantly different from average.⁵⁹

In addition to the possibility of radiogenic diseases, such as thyroid neoplasia caused by direct exposure to radioactive fallout during the years of the American atmospheric nuclear testing program, concern often has been raised as to the potential for illness subsequently induced by long-term exposure to the residual radioactive contamination. Such concern has allowed nongovernmental special interest groups to panic island residents into untoward and perhaps unnecessary evacuations of inhabited atolls. The true situation is most likely close to that reported by the Scientific Advisory Panel to the Nationwide Radiological Study in their letter to the president and government of the Republic of the Marshall Islands (Simon and Graham 1994):

We believe that the current levels of radioactive contamination of the territory of the Marshall Islands pose no risk of adverse health effects to the present generation. Similarly, on the basis of current genetic knowledge, we judge the risk of hereditary disease to future generations of Marshallese to be no greater than the background risk of such diseases characteristic of any human population.

⁵⁹ Perhaps the most interesting lesson to be drawn from Dr. Hamilton’s historical study is that signs and symptoms suggestive of acute radiation sickness can result from idiopathic distress.

6.5 The Lulejian Report

In the written statement provided by Mr. Merrill Eisenbud, reference is made to “a highly classified report” prepared by Lt. Col. Norair M. Lulejian, USAF, which “was recalled within days after I had received it.” Mr. Eisenbud subsequently spoke of this “recalled” report in an interview on the *Nightline* television news program. The implication made was that this report would have had an adverse effect on planning for BRAVO, and that it was therefore suppressed.

The report to which Mr. Eisenbud alludes is *Radioactive Fall-Out from Atomic Bombs*, issued by ARDC in November 1953 (Lulejian 1953a). The initial classification was “SRD,” the normal classification level for all test-related documents. Dr. Graves received the report at Los Alamos on 4 December 1953. A supplement to this report was issued in December 1953 (Lulejian 1953b). Neither report was ever recalled. In fact, an unclassified version was released on 29 September 1959. As a secret document, distribution of the Lulejian report was, however, rigidly controlled; only 45 copies were printed, and further reproduction was not authorized.⁶⁰ The fact that Mr. Eisenbud is not on the report distribution suggests that he may have been loaned a copy to read and subsequently asked to return the document to its proper owner, thus starting the legend about the report being recalled.

Lt. Col. Lulejian’s report is a basic reference to fallout from atomic detonations. It contains a thorough description of the fallout process along with detailed fallout patterns for all of the TUMBLER/SNAPPER and UPSHOT/KNOTHOLE tests conducted at the NPG in 1952 and 1953. A section is devoted to forecasts of radioactive fallout from megaton yield bombs. As related by Mr. Eisenbud, Lt. Col. Lulejian pointed out that multi-megaton surface detonations might severely contaminate large areas downwind. In his words:

Personnel remaining within an area 30 to 40 miles [downwind] of ground zero may receive a 400 to 800 Roentgen dose. If this hypothesis is true then it has some rather important military implications. For example, it may be that if a 10 megaton bomb is exploded on or near the surface in Washington D. C., Baltimore may have to be evacuated.

The task force was well aware of the potential radiological hazards of high-yield detonations. Lt. Col. Lulejian’s work played an important role in quantifying these hazards. His method of fallout forecasting using “elliptical approximations,” first presented in the November 1953 report, was developed and used throughout the CASTLE test series (NV0051031 [1954], 57). Fallout plots made using this technique (NV0051031 [1954], D-3 and D-4) were presented during the preshot command briefings (NV0051031 [1954], 62), and played a role in the decision to execute the BRAVO event.

⁶⁰ This was the normal procedure for all SRD documents, and is what is meant by “restricted.”

The gist of Mr. Eisenbud's accusation is that Lt. Col. Lulejian's work confirming "that lethal levels of fallout could occur at great distances from near-surface explosions of megaton weapons" was ignored, or even suppressed, by the task force. In fact, safety planning for Operation CASTLE assumed that the radioactive debris clouds could be hazardous for up to 24 hours, and that during this time, they could travel approximately 500 nm (NV0051031 [1954], 56). Lt. Col. Lulejian believed that "extrapolation of the fall-out information . . . to the case of 10 megaton bombs exploded on the surface indicates that lethal concentration of radioactivity may extend 30 to 50 miles downwind" (Lulejian 1953a, 4). Planning for Operation CASTLE envisioned significant fallout during the first 12 hours postdetonation (NV0051031 [1954], 57), during which time the clouds could move up to 250 mi. The challenge for the fallout forecasters was to determine how large the clouds would be and where within this vast area they would actually move.

Appendix A Units and Measures

Throughout this document, radiation exposures are given in units of thousandths-of-Roentgens, or milli-Roentgens, denoted by the abbreviation “mR.” During the time of Operation CASTLE, the Roentgen, or rad or R, was the basic unit of radiation dose, being physically equivalent to 100 ergs of absorbed ionizing radiation per gram of tissue. In the intervening years, the rad has been replaced with the MKS metric system-based unit of the “gray,” which is equivalent to one joule per kilogram. A tissue dose of 1 gray is thus equivalent to 100 rads or 100,000 mR. Because the original documents and records all employ the earlier measurement system, the mR has been maintained as the unit of radiation exposure (dose). The dose rate, expressed in milli-Roentgens per hour (mR/hr), tells how fast the exposure is accumulating. The total exposure depends on the integral summation of the dose rate. For example, a constant dose rate of 1 mR/hr maintained for an entire day would result in an absorbed dose of 24 mR, while a dose rate of 24 mR/hr maintained for 1 hour would result in the same total radiation exposure.

The Roentgen is commonly used as a measure of external gamma radiation exposures. For exposures to neutrons, or for radiation doses accumulating from internal emitters, the dose must be adjusted to reflect the biophysical setting. The Roentgen equivalent man (rem) exposure attempts to take into account the differing situations. For external exposure to gamma radiation, the rem is equal to the rad. For external exposures to neutrons, the rem is approximately 20 times larger than the rad; that is, for equal amounts of deposited energy, neutrons cause 20 times more damage than gamma rays. Internal radiation exposures, which tend to build slowly over time and typically involve short-range alpha (helium nuclei) and beta (electrons) radiations, are normally given in units of rem, or as in this document, millirem.

Much of this report is directed toward the radioactive fallout on the islands surrounding the PPG. Basic information concern measurements of radiation and its effects on the body are given in many references; perhaps the most authoritative of these is *Health Effects of Exposure to Low Levels of Ionizing Radiation* (BEIR V 1990). This book, authored by the US National Academy of Science Committee on the Biological Effects of Ionizing Radiation, is updated periodically and is the accepted standard. A less technical, but still rigorous publication presenting a comprehensive history of the measurement of ionizing radiation and its biological effects is the Los Alamos National Laboratory publication *Radiation Protection and the Human Radiation Experiments* (Cooper 1995).

In discussion of radiation exposures, it is common to encounter the adjective “significant.” But what is actually meant by this word? The standard word usage by the task force during Operation CASTLE was that “significant [is] defined as greater than 10 R [10,000 mR] dose” (NV0051031 [1954], 57).

Appendix B Acronyms and Conversions

This section includes the list of acronyms and the conversion table.

List of Acronyms

Acronyms	
ABCC	Atomic Bomb Casualty Commission
AEC	Atomic Energy Commission
AFB	Air Force Base
AFSWP	Armed Forces Special Weapons Project
ARDC	Air Research and Development Command
CIC	Coordination and Information Center
CINCPAC	Commander in Chief, Pacific
DMA	Division of Military Application
DNA	Defense Nuclear Agency
DoD	Department of Defense
DOE	Department of Energy
DTRA	Defense Threat Reduction Agency
DTRIAC	Defense Threat Reduction Information Analysis Center
GAC	General Advisory Committee
GZ	ground zero
H&N	Holmes and Narver Engineering and Construction Corporation
HASL	Health and Safety Laboratory
JTF	Joint Task Force
JTF-7	Joint Task Force Seven
LANL	Los Alamos National Laboratory (Los Alamos Scientific Laboratory)
LST	Landing Ship Transport
MLC	Military Liaison Committee
MPE	maximum permissible exposure
NPG	Nevada Proving Ground

Acronyms	
NRDL	Naval Radiological Defense Laboratory
NTA	Nuclear Testing Archive
NTIC	National Technical Information Center
NYOO	New York Operations Office
PPG	Pacific Proving Ground
RADEX	RADiological EXclusion
REM	Roentgen equivalent man
SRD	secret restricted data
TG	task group
TSU	Test Services Unit
VP-29	Patrol Squadron Twenty-Nine

Conversion Table

This table includes conversion factors for changing US customary measures to metric (SI) units of measurement, and vice versa.

Multiply US \longrightarrow by Conversion \longrightarrow To Get SI
 To Get US \longleftarrow by Conversion \longleftarrow Divide SI

US Measurement	Conversion	SI Measurement
angstrom	$1.000\ 000 \times E^{-10}$	meters (m)
atmosphere (normal)	$1.013\ 250 \times E^{+2}$	kilo pascal (kPa)
bar	$1.000\ 000 \times E^{+2}$	kilo pascal (kPa)
barn	$1.000\ 000 \times E^{-28}$	meter ² (m ²)
British thermal unit (thermochemical)	$1.054\ 350 \times E^{+3}$	joule (J)
calorie (thermochemical)	4.184 000	joule (J)
cal (thermochemical/cm ²)	$4.184\ 000 \times E^{-2}$	mega joule/m ² (MJ/m ²)
curie	$3.700\ 000 \times E^{+1}$	*giga becquerel (Gbg)
degree (angle)	$1.745\ 329 \times E^{-2}$	radian (rad)
degree Fahrenheit	$t_k = (t_f + 459.67)/1.8$	degree kelvin (K)
electron volt	$1.602\ 177 \times E^{-19}$	joule (J)
erg	$1.000\ 000 \times E^{-7}$	joule (J)
erg/second	$1.000\ 000 \times E^{-7}$	watt (W)
foot	$3.048\ 000 \times E^{-1}$	meter (m)
foot-pound-force	1.355 818	joule (J)
gallon (US liquid)	$3.785\ 412 \times E^{-3}$	meter ³ (m ³)
inch	$2.540\ 000 \times E^{-2}$	meter (m)
jerk	$1.000\ 000 \times E^{+9}$	joule (J)
joule/kilogram (J/kg) radiation dose absorbed	1.000 000	Gray (Gy)
kilotons	4.183	terajoules
kip (1000 lbf)	$4.448\ 222 \times E^{+3}$	newton (N)
kip/inch ² (ksi)	$6.894\ 757 \times E^{+3}$	kilo pascal (kPa)

US Measurement	Conversion	SI Measurement
ktap	$1.000\ 000 \times E^{+2}$	newton-second/m ² (N-s/m ²)
micron	$1.000\ 000 \times E^{-6}$	meter (m)
mil	$2.540\ 000 \times E^{-5}$	meter (m)
mile (international)	$1.609\ 344 \times E^{+3}$	meter (m)
ounce	$2.834\ 952 \times E^{-2}$	kilogram (kg)
pound-force (lb avoirdupois)	4.448 222	newton (N)
pound-force inch	$1.129\ 848 \times E^{-1}$	newton-meter (N-m)
pound-force/inch	$1.751\ 268 \times E^{+2}$	newton/meter (N/m)
pound-force/foot ²	$4.788\ 026 \times E^{-2}$	kilo pascal (kPa)
pound-force/inch ² (psi)	6.894 757	kilo pascal (kPa)
pound-mass (lbm avoirdupois)	$4.535\ 924 \times E^{-1}$	kilogram (kg)
pound-mass-foot ² (moment of inertia)	$4.214\ 011 \times E^{-2}$	kilogram-meter ² (kg-m ²)
pound-mass/foot ³	$1.601\ 846 \times E^{+1}$	kilogram/meter ³ (kg/m ³)
rad (radiation dose absorbed)	$1.000\ 000 \times E^{-2}$	**Gray (Gy)
roentgen	$2.579\ 760 \times E^{-4}$	coulomb/kilogram (C/kg)
shake	$1.000\ 000 \times E^{-10}$	second (s)
slug	$1.459\ 390 \times E^{+2}$	kilogram (kg)
torr (mm Hg, 0° C)	$1.000\ 000 \times E^{+2}$	kilo pascal (kPa)

* The becquerel (Bq) is the SI unit of radioactivity; 1 Bq = 1 event/s.

** The Gray (GY) is the SI unit of absorbed radiation.

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A wealth of primary historical records and references concerning Operation CASTLE and the radiological protection program exists. The Department of Energy Coordination and Information Center (DOE/CIC) in Las Vegas, Nevada (now the DOE Nuclear Testing Archive [NTA]) is specifically chartered with archiving and managing unclassified records pertaining to the US atmospheric nuclear test program. The DOE/NTA record holdings are so plentiful that establishing a bearing on a particular research subject can be difficult. A primary purpose of this document is to provide an accurate, reasonably concise guide to the literature concerning Operation CASTLE off-site radiation exposures. Most of the DOE/NTA documents referenced in this report are available online at <https://www.osti.gov/opennet/>. The basic reference to radiological safety during Operation CASTLE is the 743-page, two-volume document *Final Report, Radiological Safety, Operation CASTLE, Spring 1954*. This anthology of memoranda, planning documents, official letters, and short reports was prepared in the summer of 1954 by Lt. Col. Richard A. House, the task force radiological safety officer, for the express purpose of gathering together all task force records concerning radiological safety. The initial classification was SRD, the normal (default) classification of task force reports. The two portions most relevant to BRAVO were declassified in June 1979. The document was declassified in its entirety and released to the public in 1985. It is available from DOE OpenNet (<https://www.osti.gov/opennet/>) as NV0051031 and NV0051072. Many of the individual sections of this anthology are available as separate NTA holdings. This comprehensive anthology remains the best single source of information concerning the conduct and radiological consequences of the Operation CASTLE detonations.

The Defense Nuclear Agency (DNA), as Executive Agency for DoD, prepared an exhaustive study of task force activities during Operation CASTLE. The DNA report *CASTLE Series 1954* (DNA 6035F [1984]) is a portion of the United States Atmospheric Nuclear Weapons Tests Nuclear Test Personnel Review, and it is widely available through the public library system. This comprehensive report is perhaps the best single-source document concerning the entire history of Operation CASTLE. The Defense Threat Reduction Agency (DTRA) is the current-day successor to the DNA. The Defense Threat Reduction Information Analysis Center (DTRIAC) in Albuquerque, New Mexico, is the central repository of DoD records dealing with the nuclear weapon testing program. Available in the DTRIAC collection are hundreds of unclassified photographs showing task force activities during Operation CASTLE; these include numerous pictures of island evacuees, in both formal portrait and casual settings. The Memorandum for Record of 1 May 1954 included in NV0407536 (1954) provides a listing of many of these pictures.

In addition to the primary historical records and US governmental reports, there are a number of popular-press books and movies dealing with Operation CASTLE and the BRAVO test in particular. Among the best is Neil Hines's book *Proving Ground: An Account of Radiobiological Studies in the Pacific, 1946-1961* (Hines 1962).

Many of these references and records originally were issued by Los Alamos Scientific Laboratory J-Division and by the Joint Task Force. During the period of Pacific testing, J-Division ran its own mail office and supplied the “J” series numbers to communications. During the Operation CASTLE period, the Joint Force operated a mail room, which assigned the “JF” series numbers. TG7.1 had its own document control system, which assigned the “Science” series numbers. The “WT” series numbers are formal reports from the weapon test programs and projects; most are available through the DOE/NTA.

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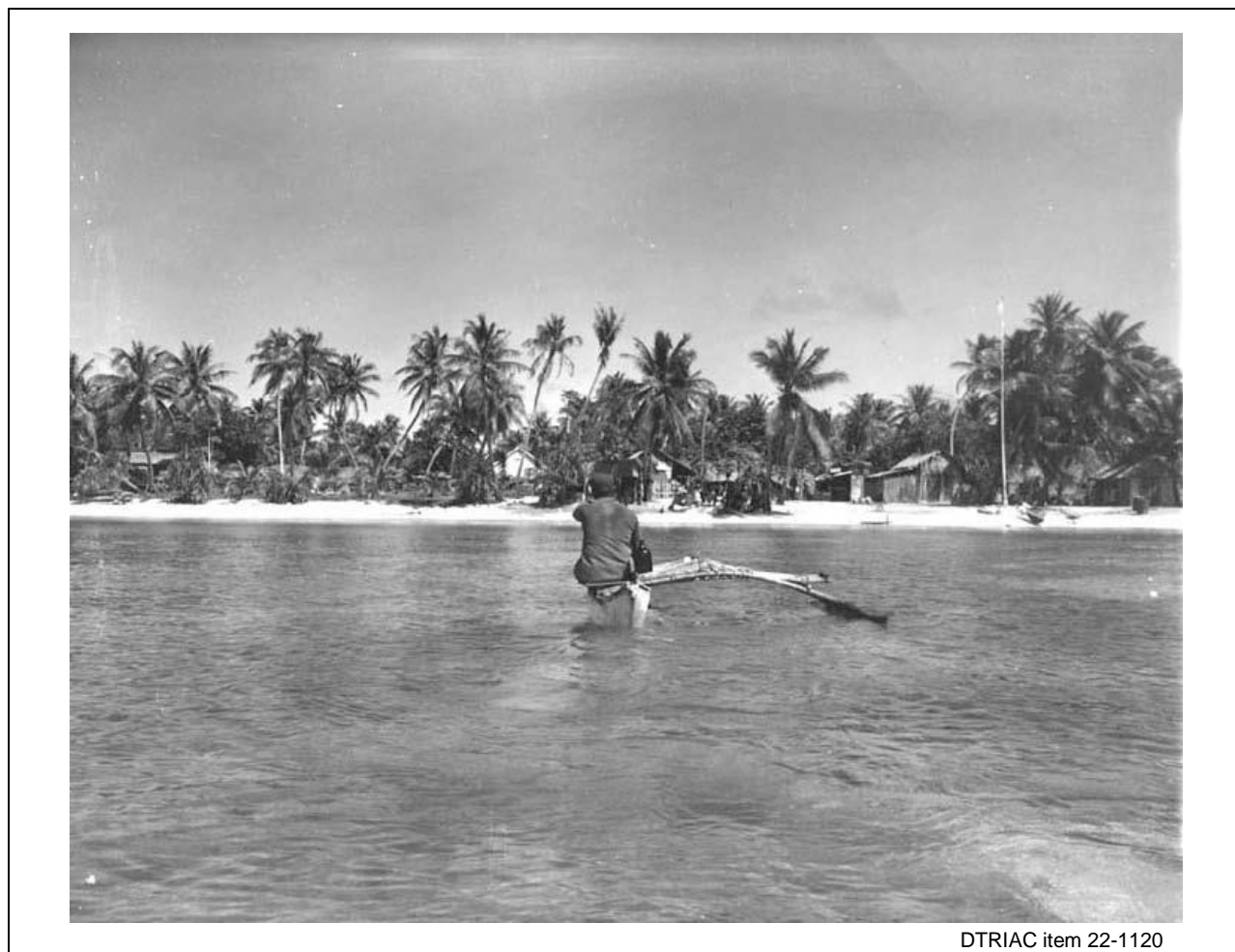


Figure 6-5. Native outrigger paddling toward the beach, Utirik Island lagoon, 3 March 1954

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