Chapter 6

ENVIRONMENTAL REMEDIATION OF RADIOACTIVE CONTAMINATION

8/5/2022

6.1 INTRODUCTION

After World War II, the USA assumed responsibility of the Marshall Islands under the trusteeship system of the United Nations. In 1947 president Harry S. Truman authorized a nuclear testing zone in the Marshall Islands located 2,400 miles southwest of the Hawaiian Islands.

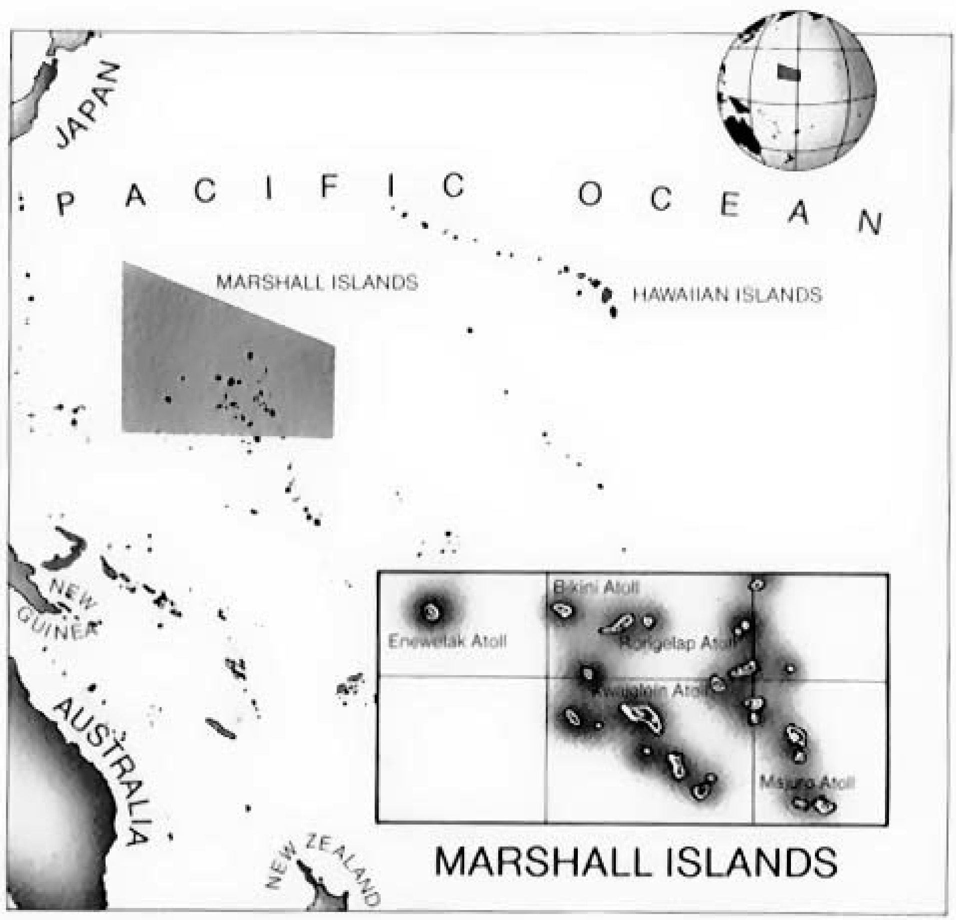


Figure 1. Location of the Marshall Islands in the Pacific Ocean.

The Republic of the Marshall Islands consists of 34 atolls covering an area of about 1.3×10^6 square kilometers in the Pacific Ocean. The atolls consist of collections of coral reefs. The largest of them is the Kwajalein Atoll. Majuro is the capital island. The atolls are clustered within two groups designated as the Ratak and the Ralik chains. Nuclear testing was conducted in the northern Bikini, Enewetak and Rongelap atolls. These atolls after World War II offered isolation, stable weather, a small number of inhabitants to relocate, and a large stretch of open-ocean to their west without a human population.

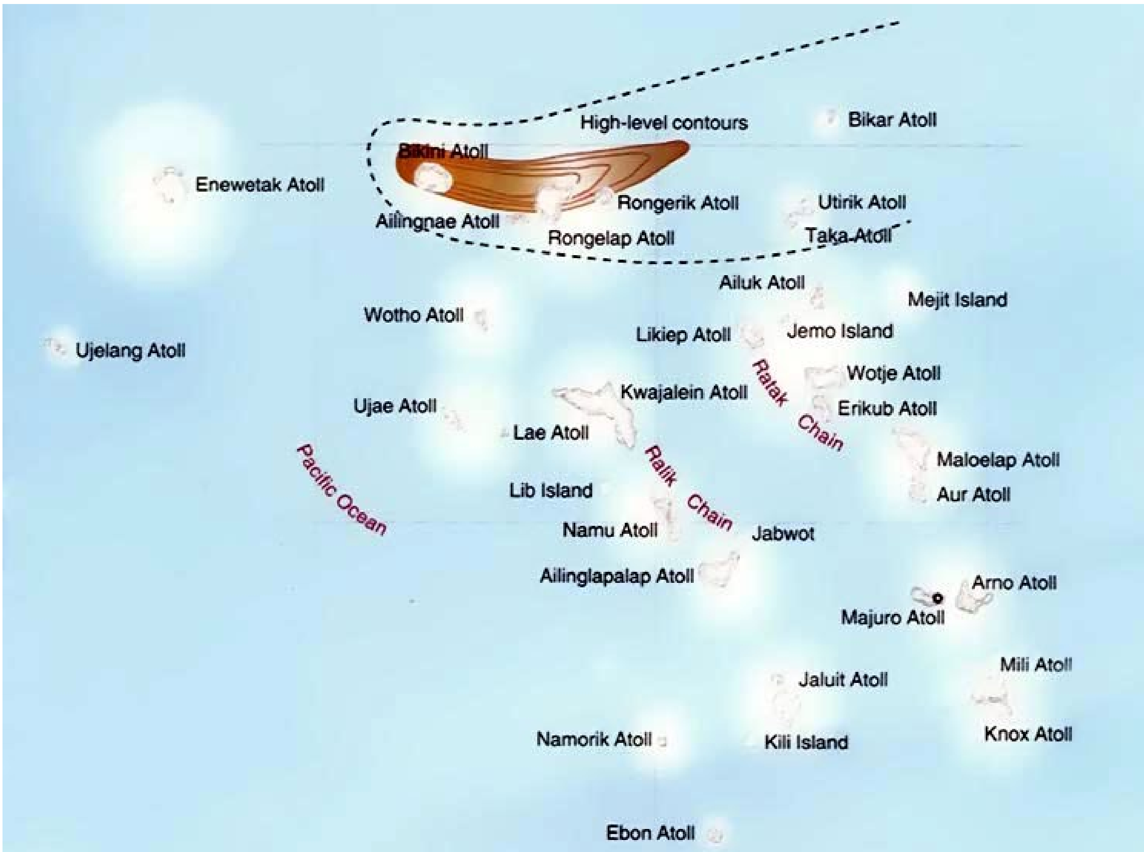


Figure 2. Fallout dose contours originating from the Bikini Atoll in the Marshall Islands from the Castle-Bravo test on March 1st, 1954.

Inspired by the news-making nuclear testing at the Bikini Atoll in the same week; on July 5, 1946, the French fashion designer Louis Réard unveiled a daring two-piece female swimsuit by the same name at a swimming pool in Paris, France.

It is of interest to study how radioactive contamination resulting from nuclear testing in the 1950s was addressed then remediated and its lingering effects, since this offers clues about how to address similar problems that occurred from the nuclear testing in French Polynesia, the Chernobyl accident, the Fukushima accident, the use of Depleted Uranium (DU) munitions in Kosovo, Bosnia, Kuwait, Saudi Arabia, Iraq, Afghanistan, Yemen, Syria, Somalia, Lybia and other areas of conflict, and the remediation efforts that may occur in future conflicts or nuclear accidents.

6.2 NUCLEAR TESTING PROGRAM

The USA conducted a Nuclear Testing Program (NTP) in the Marshall Islands between 1946 and 1958. Over a period of twelve years, the USA detonated 67 fission and thermonuclear nuclear devices which had a total yield of 108.496 Megatons (MT) of TNT equivalent, which was 7,233 times the tonnage of the 15 kilotons (kT) Hiroshima device used during World War II. One kT of TNT equivalent is equivalent to the release of 10^{12} calories of energy.

In 1952, the world's first thermonuclear detonation, the Mike Shot was conducted at the Enewetak Atoll in the Marshall Islands.

The seven-kilometer "Shrimp" shot in operation Castle-Bravo, detonated at the Bikini Atoll on March 1, 1954, was a 15 MT of TNT-equivalent thermonuclear device releasing about 1,000 times the energy from the Hiroshima device. The destructive power unleashed by the explosion was three times as high as the experts had predicted because of the lack of complete knowledge at the time about the nuclear tritium breeding properties of the Li^6 and Li^7 isotopes, and dug a crater two kilometers in diameter into the island. A mushroom cloud rose 40 kilometers into the atmosphere.

Other testing occurred in the continental USA at the Nevada test site, and even in the states of New Mexico, Mississippi and Colorado in the continental USA.

6.3 THE MARSHALL ISLANDS

Many Marshall Islands inhabitants served as scouts on the side of the USA troops against the Japanese forces in the Pacific theater during World War II. Fighting occurred on the atolls of Enewetak, Majuro, Mili, Kwajelan and Wotje in 1944. The tragic human cost was 3,000 American troops and more than 11,000 Japanese casualties. The USA Navy consequently occupied the Marshall Islands.

In July 1947, the United Nations (UN) agreed to place the Trust Territory of the Pacific Islands into the care of the USA Government. The USA government thus administered the United Nations Trust Territory of the Pacific Islands. This Trust Territory extended across six districts: the Marianas, Palau, Yap, Truk, Pohnpei and the Marshall Islands, and was the only UN Trusteeship Territory designated as a strategic trusteeship.

From 1946 to1958, the USA tested 67 devices on land, in the air, and in the sea surrounding the Marshall Islands.

Some of the islanders had to be relocated then resettled back to their native islands. However, the Bikinians, the Rongelapee, and the Enjebi community from Enewetak were evacuated. Some returned but most have not returned to their home atolls, from fear of radioactive contamination.

Most Bikinians reside on Kili, a single island, not an atoll, with no sheltered lagoon and with rough seas for many months of the year. The traditional lifestyle, one that depends largely on fishing, and marine and natural resources, is difficult to maintain on Kili as an island rather than an atoll with a sheltering lagoon. People throughout the Marshall Islands are concerned about the effects of radiation on their future generations. The Rongelapese reside on Mejatto, Kwajalein, Ebeye and Majuro. The Enjebi people live primarily on Davor.

In 1986, a Compact of Free Association was signed by the Republic of the Marshall Islands with the USA. In exchange for helping the Marshall Islands move towards greater economic self-reliance, the Compact gives the USA sole military access to the Republic of the Marshall Islands more than 700,000 square miles situated between Hawaii and the Pacific Rim. A separate land lease agreement enables the USA army to research and test missile defense systems at the Kwajalein Atoll in the Marshall Islands. The Republic of the Marshall Island is a member of the UN with voting usually aligned with the USA.

The Marshall Islands and the rest of Micronesia's populations may have to be relocated once more. This time their calamity may be caused by global climatic change due to the greenhouse gases emissions, leading to an expansion of the ocean waters, a rise of sea water level and drowning of their low elevation coral atolls.

Figure 3. View of the Bikini Atoll in the Marshall Islands.

Figure 4. Relocation of the Bikini Atoll islanders.

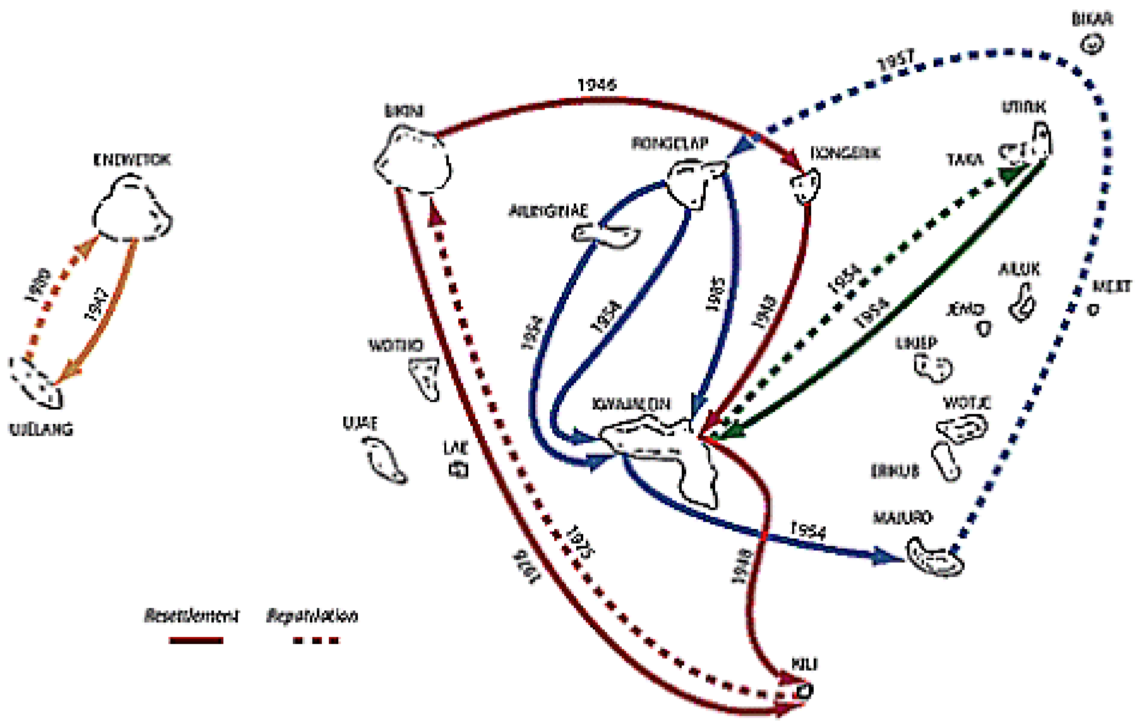


Figure 5. Relocation and resettlement paths of the Marshall Islands population.

6.4 NUCLEAR TESTING IN THE MARSHALL ISLANDS

The Bikini atoll, a semicircular chain of 30 islands, was selected in the spring of 1946 as the location of the nuclear testing operation of Crossroads. Bikini was 250 miles away from the island of Kwajelein, which was used as a base for the bombers used in the tests. On the Bikini Island in the Bikini Atoll, 160 inhabitants where asked to leave the island for the "welfare of all men." Translators not knowing the island's word for "bomb" told the islanders that they had a powerful new "god" that they wanted to bring to the island. Publicity films at the time suggested that: "The islanders are a nomadic group and are well pleased that the yanks are going to add a little variety to their lives."

On March 7, 1946, after being promised safe return back to Bikini after the series of tests, the residents of Bikini Island left on naval landing crafts and were relocated to the Rongelik Island, 140 miles east of Bikini.

6.5 OPERATION CROSSROADS, THE ABLE AND BAKER TESTS

With 42,000 military personnel, and several hundred civilians; runways, bunkers, docks, chapels, recreational facilities and support bases, were constructed. A collection of 150 aircraft and 200 naval ships as well as captured ships from the Japanese and German naval fleets such as the Nagato were gathered at Bikini to answer the question of what would happen to a moored naval fleet if a nuclear blast is directed at it in the format of the previous attack on Pearl Harbor. Of the naval ships, 73 were placed near ground zero as targets.

On June 30, 1946 at the local time 9:00:34 am, a nuclear device was dropped over the Bikini Atoll from a B-29 bomber with the name Davis Dream. It was the fourth atomic device ever used, after the Trinity (Alamogordo), Big Boy (Hiroshima) and Fat man (Nagasaki) devices, and it was nicknamed "Gilda" after an actress Rita Hayworth's movie, with her picture stenciled on the bomb.

The device was detonated at 1,000 feet above the target airplanes and ships, with experimental animals on them. The animals included 200 goats, 200 pigs and 4,000 rats. The device fell off target by two miles, leading to the observers thinking that it was much smaller and weaker than originally thought. Nevertheless, 5 ships sunk immediately, and 9 ships were severely damaged.

The second test of the Crossroads series of tests was code named "Baker." It was designed to test the effects of an underwater explosion. It was expected that a column of water half a mile in diameter would rise thousands of feet in the air generating a tidal wave or tsunami.

There was no tidal wave after the explosion but large clouds of steam blanketed the test site. When radioactivity could not be washed with water off the target ships, the paint was sandblasted off. Decontamination crews were not required to wear protective gears, trying to estimate the time that it would take a naval fleet to start moving on its own power after a nuclear attack.

The nuclear testing was expanded to the Enewetak Atoll. The 142 native inhabitants of the Bijire and Aomon Islands were relocated.

Another operation designated as Sandstone was meant to test design improvements to increase the efficiency of use of weapons-grade plutonium. This included three tests detonated from 200-feet high towers. The X-Ray test was carried out on Enjebi Island on April 15 1958. Yoki was conducted on Aomon Island on May 1st 1948, and Zebra on Rinit Island on May 15, 1948.

In March 1946, the USA Navy evacuated 167 Bikini Islanders to Rongerik Atoll, 125 miles to the east, to make way for the first post World War II nuclear weapons tests. Out of concern for fallout, in May, islanders from Enewetak, Rongelap and Wotho Atolls were also relocated for the duration of Operation Crossroads.

In July 1946, Operation Crossroads was launched with the Able and Baker nuclear tests at the Bikini Atoll. Both tests used Hiroshima-yield fission devices. Baker, an underwater test, targeted a fleet of decommissioned World War II ships positioned in the Bikini lagoon.

Figure 6. Admiral and Mrs. Langley inaugurating operation Crossroads cutting an atomic cake and wearing an atomic hat.

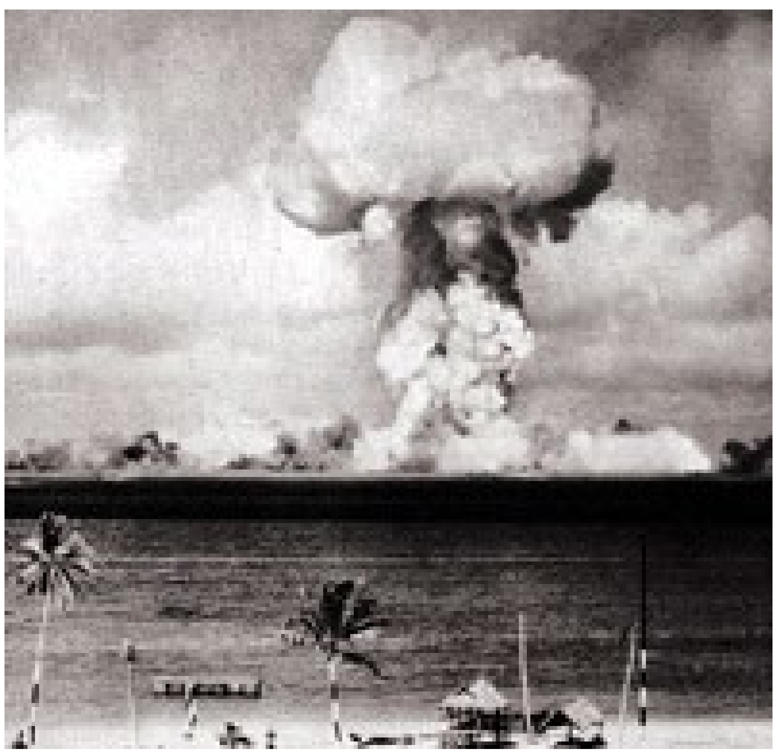
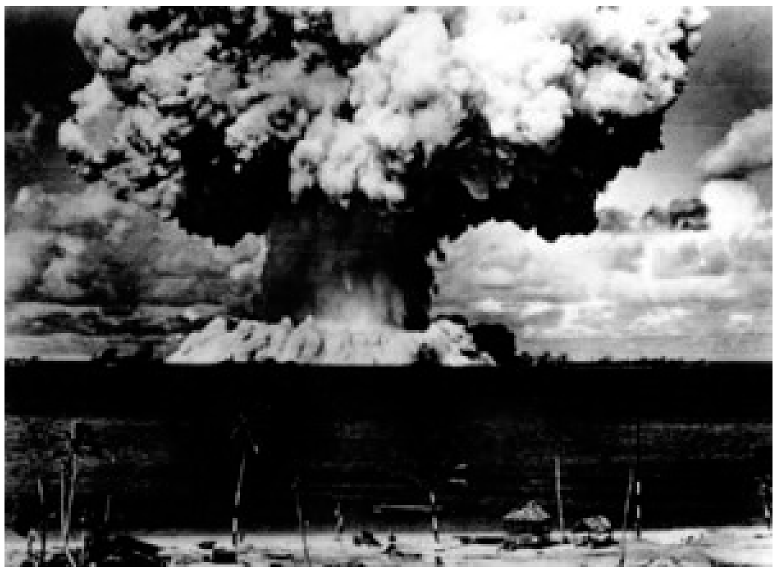


Figure 7. Able underwater test, July 1st, 1946, operation Crossroads.

Figure 8. Severe damage to the USS Skate, Able test, operation Crossroads, July 1st, 1946.

Figure 9. Fleet of 96 decommissioned and captured warships were assembled in the Bikini Lagoon for the Baker test.



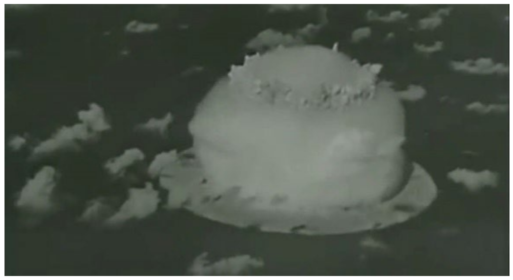


Figure 10. The Baker test was a 21 kT of TNT equivalent underwater test at the Bikini lagoon on July 25, 1946. The fleet of test ships is silhouetted against the water stem. An expected tidal wave or tsunami did not materialize.

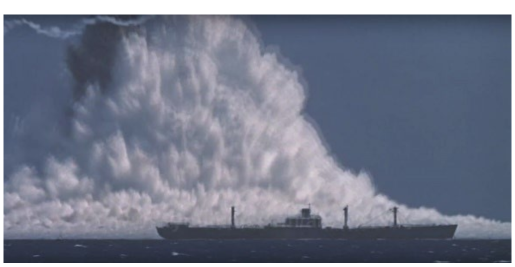


Figure 11. Underwater tests water surge rise than fall progression.

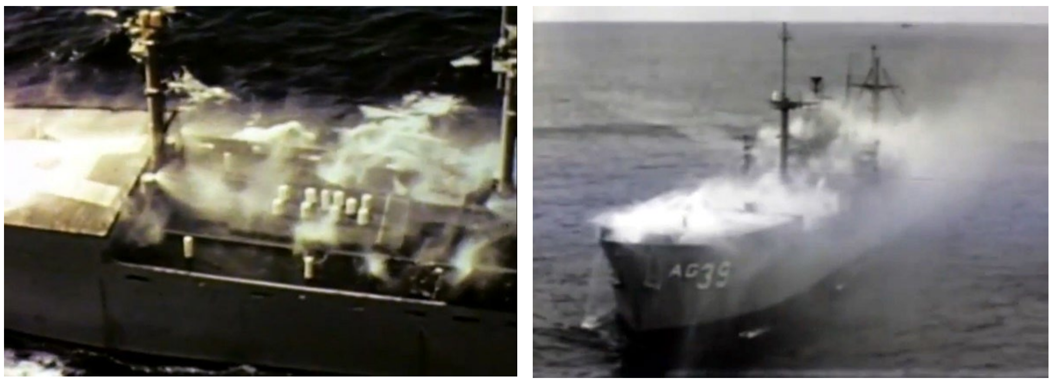


Figure 12. Pressurized sea-water ship decontamination of surviving ships after the Baker underwater test.

6.6 OPERATION SANDSTONE

In July 1947 the Marshall Islands and the rest of Micronesia became a UN strategic Trust Territory administered by the USA. In December, the Enewetak Atoll was selected for the second series of USA nuclear tests, and the Enewetak people were moved to the Ujelang Atoll. In March of 1948, on the verge of starvation, the Bikinians were taken off Rongerik Atoll and moved to Kwajalein, where they stayed for six months while a new home was being found for them. In April, Operation Sandstone begun at Enewetak and included three atomic tests. The Bikini community was moved to southern Kili, a single island with no protected lagoon or boats anchorage.

6.7 OPERATIONS GREENHOUSE AND IVY MIKE TEST

In April 1951, Operation Greenhouse started at Enewetak. Four atomic tests were conducted. In November 1952, operation Ivy started at Enewetak and included the first test of a thermonuclear or hydrogen device using liquid deuterium D_2 as a thermonuclear fuel. The Mike test vaporized an island and its yield was estimated at 10.4 MT of TNT equivalent, or 693 times the yield of the Hiroshima device.

Figure 13. Ivy Mike test fireball, October 31, 1952.

Figure 14. Ivy Mike test mushroom cloud, October 31, 1952.

The Ivy Mike test of October 31, 1952, at Enewetak Atoll was the world's first thermonuclear test. At the time, it was the largest nuclear test ever conducted. Yet it was not to be the largest test to be carried out in the Marshall Islands.

Ivy Mike had the largest fireball ever produced. At its maximum, it measured about 3.25 miles in diameter. Compared with the skyline of New York, with the Empire State Building as zero point, the Mike fireball would have extended downtown to Washington Square, and uptown to Central Park. The fireball alone would engulf about 25 percent of the Manhattan Island.

The height of the mushroom cloud at two minutes after the explosion reached 40,000 feet or the height of 32 Empire State Buildings.

Ten minutes later, the cloud reached its maximum height at around ten miles, and spread out along the base of the stratosphere to a width of about a hundred miles, while the stem itself was pushed upward, deep into the troposphere, to a height of about 25 miles.

The Mike yield at around 10.4 MT of TNT equivalent was four times the yield from all the high-explosives dropped by the entire American and British air forces on Germany and the European countries during World War II.

The resulting crater in the atoll was roughly a mile in diameter. It was illustrated that some 14 Pentagon Buildings could be accommodated in the crater which gradually sloped down to a maximum depth of 175 feet or the height of a 17-story building.

The lateral destructive blast effects resulted in complete annihilation within a radius of three miles. There was severe to moderate damage out to seven miles, and light damage extended as far as ten miles. For a city the size of Washington D.C., with the Capitol as zero point, there would be complete annihilation west to Arlington Cemetery; east to the Anacostia River; north to the Soldiers Home; and south to Holling Field.

6.8 OPERATION CASTLE, BRAVO TEST, FALLOUT EXPOSURE

In January of 1954, preparations commenced at the Bikini Atoll for Operation Castle, to test a series of megaton-range weapons, including the USA’s first deliverable hydrogen device using lithium deuteride, LiD powder as a fusion fuel.

On February 28, 1954 at 6 pm on the eve of the Bravo test, the weather reports indicated that the atmospheric conditions were getting less favorable. At midnight, just seven hours from the shot, it was reported there are less favorable winds at the 10,000 to 25,000 feet levels. Winds at 20,000 feet were headed for Rongelap to the east.

Figure 15. Bravo thermonuclear 43,000 lbs device was placed on a barge in the Bikini Atoll.

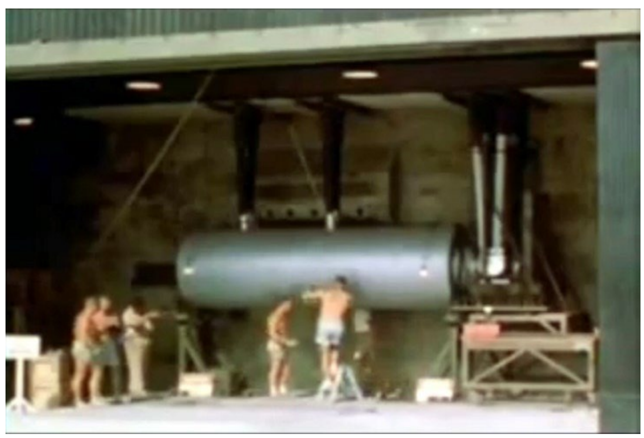


Figure 16. Exterior of the Castle Bravo device using lithium deuteride.

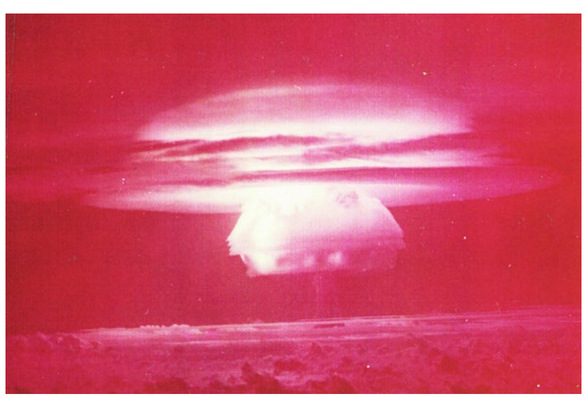


Figure 17. Bravo test, March 1st, 1946, Bikini Atoll.

On March 1st, 1954, the Bikini's weather outlook was downgraded to unfavorable and the Joint Task Force 7 directed several ships to move 20 miles to the south to remove them from the expected fallout zone. Despite weather reports showing that winds are blowing in the direction of the inhabited islands, the March 1, 1954 Bravo hydrogen test proceeded as planned at Bikini. At a yield of 15 MT of TNT equivalent, it was 1,000 times the yield of the Hiroshima device.

Within hours a gritty, white fallout ash, similar in appearance to snow, enveloped the islanders on Rongelap and Ailinginae Atolls. A few hours later, American weathermen were exposed to the snowstorm of fallout on Rongerik, and still later the people of Utrik and other islands experienced the fallout mist.

Figure 18. Military personnel being familiarized with nuclear explosions at a nuclear test wearing ultraviolet protection goggles and facing the explosion. No provisions were provided for shielding against neutron, x-rays and gamma radiation.

With a short time lag, the individuals exposed to the fallout experienced nausea, vomiting and itching skin and eyes. On March 3rd, 1954 the Rongelap islanders were evacuated 48 hours later, and Utrik was evacuated 72 hours after the Bravo test. Both groups were taken to Kwajalein for observation. Skin burns from the beta particles emission of the fission products in the fallout on the heavily exposed people began to develop, and later epilation occurred. The USA Atomic Energy Commission (USAEC) issued a press statement to the effect that Bravo was a routine atomic test, and that some Americans and Marshallese were unexpectedly exposed to some radioactivity.

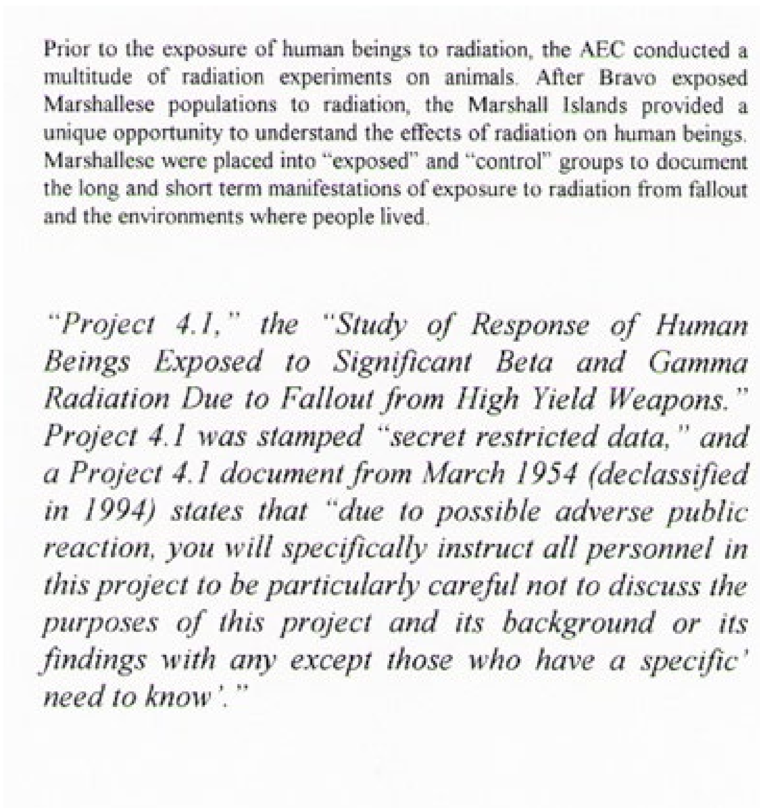
Figure 19. Decontamination of protective suits after the Bravo test.

Figure 20. Rongelap resident exposed to beta particles from fallout ash.

Figure 21. Skin burns from fallout fission products beta radiation.

6.9 PROJECT 4.1

On March 7, Project 4.1, the "Study of Response of Human Beings Exposed to Significant Beta and Gamma Radiation due to Fallout from High Yield Weapons," was launched establishing a medical group to monitor and evaluate the Rongelap and Utrik people. Project 4.1 was stamped "secret restricted data," and a project 4.1 document from March 1954, declassified in 1994, states that: "due to possible adverse public reaction, you will specifically instruct all personnel in this project to be particularly careful not to discuss the purposes of this project and its background or its findings with any except those who have a specific 'need to know'."



Prior to the exposure of human beings to radiation, the AEC conducted a multitude of radiation experiments on animals. After Bravo exposed Marshallese populations to radiation, the Marshall Islands provided a unique opportunity to understand the effects of radiation on human beings. Marshallese were placed into "exposed" and "control" groups to document the long and short term manifestations of exposure to radiation from fallout and the environments where people lived.

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Figure 22. Project 4.1 outline.

Prior to exposure of human beings to exposure, the USAEC conducted a multitude of radiation experiments on animals. After Bravo exposed the Marshallese population to radiation, the Marshall Islands provided a unique opportunity to understand the effects of radiation on human beings. The Marshallese were divided into exposed and control groups to document the long and short term manifestations of exposure to radiation from fallout and the environment where people lived.

In April, 1954 a Project 4.1 memo recommended that the exposed Rongelap people should have no radioactive exposure for the rest of their natural lives. On April 29, 1954 a USA Department of Defense report stated that the only other populated atoll which received fallout of any consequence at all was Ailuk. It was calculated that the yearly exposure would reach approximately 20 Röntgens (R). Balancing the effort required to move the 400 inhabitants against the fact that such an exposure would not be a medical problem it was decided not to evacuate the atoll.

In May, the Utrik Islanders were allowed to return home because their island was only slightly contaminated and considered safe for habitation.

6.10 OPERATION REDWING

In May 1956 Operation Redwing began at Enewetak and Bikini. A total of 17 nuclear tests, including several thermonuclear devices were detonated. In November, USA officials granted the Enewetak Islanders living on Ujelang $25,000 in cash and a $150,000 trust fund earning a 3 1/3 percent annual interest as compensation. The Bikini Islanders living on Kili were granted $25,000 in cash and a $300,000 trust fund yielding about $15 per person annually. Throughout the 1950s, both the Bikinians and Enewetakese faced food shortages and repeated bouts of near starvation, as their temporary islands proved difficult to live in and was inhospitable.

In July 1957 Rongelap was declared safe for rehabilitation in spite of slight lingering radiation. The Rongelap people, who have been living temporarily on Ejit Island, Majuro, returned to Rongelap. The Brookhaven National Laboratory, Upton, New York, scientists reported about Rongelap that even though the radioactive contamination of Rongelap Island is considered perfectly safe for human habitation, the levels of activity are higher than those found in other inhabited locations in the world.

6.11 OPERATION HARDTACK

In May 1958, Operation Hardtack began at Enewetak and Bikini, with 32 tests, including several thermonuclear devices. On August 18, 1958 the last nuclear detonation in the Marshall Islands took place, bringing to 66 the total of nuclear weapons tests at Bikini and Enewetak.

6.12 MARSHALL ISLANDS RADIOACTIVE FALLOUT

The most fallout contaminating event in the nuclear tests conducted at the Marshall Islands was the Castle-Bravo test on March 1st, 1954. The explosive yield from the Bravo event reached 15 MT of TNT equivalent and far exceeded the expected yield.

It was feared for a while that it could ignite the Earth's atmosphere turning it into a star; which evidently did not occur.

It led instead to an unanticipated high level radioactive contour of the fallout pattern over the inhabited islands of the Rongelap and Utirik atolls and areas to the east of the Bikini Atoll.

The test shot a fireball 20 miles into the stratosphere at a speed of 300 miles per hour. It generated 100 miles / hour winds that dispersed the fallout over 7,000 square miles of ocean. The fallout enveloped the islands of Ainlinginae, Jemo, Mejit, Rongelap, Rongerik, Taka, Utirik, and Wotho. The people on these islands thought that the falling ash was a mosquito pesticide or snow and collected it in rain barrels.

A famous news event of the period is about the Japanese fishing trawler, the Daigo Fukuryu Maru, or Fifth Lucky Dragon, which drifted unexpectedly into a large fallout area.

Its 457 tons fish catch was contaminated and part of it was inadvertently sold to consumers in Japan's markets. At least one of its crew did not survive the event, and the remaining 22 crew members suffered radiation sickness.

The crew of the USA Navy observation ship "Curtiss' was exposed to the fallout ash. Observers at an observation bunker affected by the unexpected larger yield were covered with the fallout and had to be evacuated by helicopter.

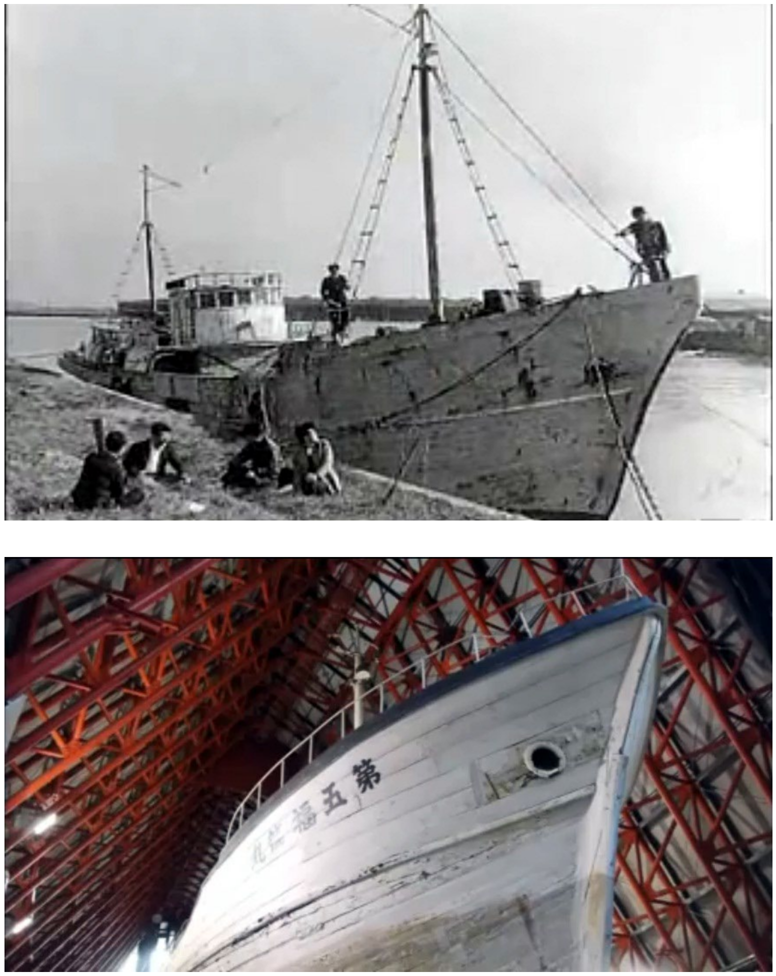


Figure 23. Japanese fishing boat, the "Fifth Lucky Dragon," "Daigo Fukuryu Maru," is preserved at a museum in Japan.

Figure 24. The crew of the USA's Navy observation ship "Curtiss" was exposed to the fallout from the "Bravo" test.

Figure 25. Personnel at the observation bunker at Bikini were exposed to the fallout by the Bravo test and were evacuated by helicopter.

Sixty-four people on Rongelap received significant exposure to radioactive fallout from the Bravo event and had to be evacuated for medical treatment. The Utirik community returned back about three months after the test. The Rongelap population spent the next three years living on Ejit Island in the Majuro atoll. They returned home in 1957.

6.13 OPERATIONS GREENHOUSE REDWING AND CASTLE

Operation Greenhouse was conducted in the spring of 1951, and included 4 tests. Another 57 tests were carried out in the Marshall Islands, 36 of them in the Enewetak Atoll and 21 on the Bikini Atoll. Among them was the Ivy Mike test, an experimental thermonuclear device which was exploded on Enewetak Atoll on October 31 1952. The Seminole detonation, a surface burst was part of operation redwing and was exploded on Enewetak Atoll on June 6, 1956. The 11 MT of TNT equivalent Romeo shot was fired from a barge near the Bikini Atoll on March 26, 1954, and was part of operation Castle.

Figure 26. The Ivy Mike, an experimental thermonuclear device test was conducted in the Enewetak atoll on October 31, 1952.

Figure 27. The Seminole test was a surface explosion on June 6, 1956, on the Enewetak atoll as part of operation Redwing.

Figure 28. The Romeo test released 11 Megatons of TNT-equivalent as part of operation Castle. It was fired from a barge near the Bikini Atoll on March 26, 1954.

Other tests included 35 atmospheric tests on Christmas Island and Johnston Island between April and November 1962.

When the Limited Test Ban Treaty took effect in 1963, 106 nuclear devices had been detonated in this area of the Pacific Ocean.

6.14 AFTERMATH

In 1963, thyroid nodules were reported among the Rongelap people exposed to the Bravo test in 1954. Also, a higher than normal incidence of growth retardation among young Rongelap Islanders was suspected.

In January 1966, the USA Congress approved an ex-gratia payment of $950,000, or about $11,000 per capita to the exposed Rongelap people for injuries resulting from their exposure in 1954.

In October 1969 the Bikini Atoll was declared safe for habitation by USA officials who thought that there was virtually no radiation left and could find no discernible effect on either plant or animal life.

In October 1972, because it was not satisfied with information provided by the USA Atomic Energy Commission (AEC), the Bikini Council voted not to return to Bikini as a community, but said it would not prevent individuals from returning. Several Bikini families moved back to Bikini into newly built homes.

A 1973 the AEC draft unpublished report concluded that Bravo fallout may have contaminated as many as 18 atolls and islands, including Kwajalein and Majuro.

In June 1975, during regular monitoring at Bikini, radiological tests showed higher levels of radioactivity than originally thought, and it appeared to be hotter or questionable as to safety, according to USA Department of Interior officials.

In August, AEC surveys suggested that some Bikini ground wells were too radioactive for safe use, and that the consumption of pandanus, breadfruit and coconut crabs needed to be prohibited.

In October, 1975, the Bikinians filed a suit in USA federal court demanding that a complete scientific survey of Bikini and other northern Marshall Islands be conducted.

6.15 RESETTLEMENT ACTIVITIES

By the year 1969, the islands were cleared of a substantial amount of the nuclear tests debris and scrub vegetation. The top 2 inches of Runit Island were removed and replaced with uncontaminated soil shipped all the way from Nevada and buried in the crater resulting from the Cactus test at the northwest tip of the island. Coconut and pandanus trees were planted to restore the native flora.

Resettlement of the Bikini Atoll started in 1969. However, "trouble bloomed in paradise." Ingestion of the radioisotope Cs^{137} and other fission products from eating locally grown food and drinking the local water was noted as a significant radiation exposure pathway, exceeding the plutonium pathway.

Chemically, cesium (Cs) is in the same column of the periodic table of the elements as potassium (K) and hence mimics it chemically when ingested by plants, animals as well as humans. The increased body burden of Cs^{137} in the bodies of the Bikini residents led to the relocation a second time of the population in 1978. They started returning back again by 2003.

Similar events occurred on Rongelap, where the residents were relocated a second time in 1985. The southern part of the Enewetak Atoll was resettled in 1980.

In 1996 the USA Congress approved a resettlement agreement that included an initiative aimed at the reduction of the levels of radiation exposure on the island using a cleanup strategy.

6.16 REMEDIATION EFFORT AND CONPENSATION

In July 1976, the USA Congress approved $20 million and military logistic support for a nuclear cleanup of the Enewetak Atoll. A Brookhaven National Laboratory report on Rongelap showed that 20 of 29, or 69 percent of the Rongelap children who were under 10 years old in 1954 had developed thyroid nodules. The people of Utrik, whose original exposure in 1954 of 14 cSv (rem) of radiation was less than one-twelfth that of Rongelap, suddenly showed a higher rate of thyroid nodules than the Rongelap people, suggesting a long latency period before health problems develop from chronic long term radiation exposure.

In May 1977 the nuclear cleanup at Enewetak Atoll began. About 700 USA Army personnel carried out the cleanup's first phase, which included scraping and collecting 100,000 cubic yards of radioactive soil and debris, and 125,000 cubic yards of uncontaminated debris and dumping them in a bomb crater on Runit Island that was sealed with a concrete cap.

In June 1977, a USA Department of Energy (USDOE) study reported that all living patterns involving Bikini Island exceeded Federal radiation guidelines for 30 year population doses. About 100 Bikinians continued living on Bikini. The USA Congress approved about $1 million in compensation for Rongelap and Utrik. Of these $100,000 each went to the Rongelap, Utrik and Bikini for building community facilities; $1,000 each to the 157 exposed Utrik people; and from $25,000 for people with thyroid nodules to $100,000 for the families of those who have passed away.

In May 1978, the USA Interior Department officials describe a discovered 75 percent increase in intake of Cs^{137} found in the bodies of the Bikini people as incredible. Plans were announced to move the people within 90 days.

In August 1978, a USDOE survey of the northern Marshall Islands revealed that in addition to Bikini, Enewetak, Rongelap, Utrik, and ten other atolls or islands received intermediate range fallout from one or more of the megaton-range tests. These included the inhabited atolls and islands of Ailuk, Likiep, Mejit, Ujelang and Wotho.

In September 1978, the now 139 people living on Bikini Atoll were evacuated once more by USA officials. The USA government funded a $6 million trust for the Bikini people.

In March 1980 the USA Defense Nuclear Agency announced that the Enewetak nuclear cleanup was complete. The estimated cost of the cleanup and rehabilitation was $218 million. Enewetak Islanders began returning home to the southern islands in the atoll.

6.17 CONTINUING LITIGATION

In 1981 the Bikinians filed a class action lawsuit against the USA government in USA courts seeking $450 million in compensation. Attorneys for the Marshall Islands Atomic Testing Litigation Project filed lawsuits on behalf of several thousand Marshall Islanders seeking about $4 billion in compensation from the USA for personal injuries from the nuclear testing.

In 1982 the USA established a second trust fund of $20 million for the Bikini people. Later, this was increased with an additional $90 million appropriation in the late 1980s.

In 1983 the Compact of Free Association was approved in a plebiscite by about 60 percent of the Marshal Islands voters. The Compact included a trust fund of $150 million intended to provide $270 million in compensation payments over the 15-year lifeime of the Compact. The share of Bikini was $75 million; Enewetak $48 million; Rongelap $37 million; Utrik $22 million; the Nuclear Claims Tribunal $45 million; $2 million annually for medical care for the four atolls and $53 million for a nationwide radiological survey and other activities.

In March 1986, examination of 7,000 people from the northern atolls and from three southern atolls showed that the prevalence rates of thyroid neoplasia, benign and malignant, are equal to or greater than those observed by the Brookhaven National Laboratory on Utirik Atoll where the radiation exposure is known.

In May 1986, the Rongelap people evacuated their atoll, moving to Mejatto, a small island in the northwestern section of Kwajalein Atoll. Rongelap leaders said that they feared that their continued residence on Rongelap will expose them to unwarranted levels of radiation.

In 1986 the USA Congress approved the Compact of Free Association. The Compact included an espousal provision, prohibiting Marshall Islanders from seeking future legal redress in USA courts and dismissing all current court cases in exchange for a $150 million compensation trust fund. In October 1986 the Compact between the USA and the Marshall Islands came into effect.

In August 1991, the Nuclear Claims Tribunal approved its first compensation awards, based on a list of health conditions presumed to be caused by radiation, and therefore eligible for compensation. Because of concerns that the $45 million available was not judged as adequate to pay all claims, the Tribunal limited its initial payments to 25 percent of the total awards.

In January 1994, an ongoing thyroid study revealed that even if only 50 percent of the survey results are verified, the incidence rate is still significantly higher, by a factor of 100, than the rate of thyroid cancer found anywhere else in the world. The USA Department of Energy (DOE) began releasing thousands of previously classified nuclear test era documents, many of which confirmed the wider extent of the fallout contamination in the Marshall Islands.

In December 1994 a five year study of 432 islands in the Marshall Islands showed that 15 atolls and single islands, or almost half of the nation were subjected to radioactive fallout from the USA nuclear weapons tests of the 1950s. However, the Nationwide Radiological Survey, funded by the USA and conducted by the Marshall Islands government, states that with the exception of islands in Bikini, Enewetak, Rongelap and Rongerik, the amount of radioactivity remaining in the environment has diminished to levels that are not of concern

In February 1995, Marshall Islands officials testified before President Bill Clinton's Advisory Committee on Human Radiation Experiments in Washington, D.C. charging that fallout exposed many more than the four atolls acknowledged by the USA government, and that islanders were purposefully resettled on contaminated islands so the USA could study the long-term effects of radiation exposure.

In October 1995, the USA Advisory Committee on Human Radiation Experiments issued its final report, including observations and recommendations on the Marshall Islands. The report recommended that at least two more atolls, Ailuk and Likiep, be included in a medical monitoring program, and that the DOE’s program be reviewed to determine if it is appropriate to add to the program populations of other atolls to the south and east of the Bravo blast whose inhabitants may have received exposures sufficient to cause excess thyroid abnormalities.

In December 1995, the Nuclear Claims Tribunal reported that it had awarded $43.2 million, nearly its entire fund, to 1,196 claimants for 1,311 reported illnesses.

In August 1996 the Nuclear Claims Tribunal projected that it will have $100 million in personal injury claims by 2001, when the Compact ended. Land claims for Bikini, Enewetak and other northern islands were also pending before the Tribunal. The Tribunal's claim fund, however, was limited to $45 million.

6.18 INTERNATIONAL ATOMIC ENERGY AGENCY (IAEA) RECOMMENDATIONS

In March 1998 the IAEA issued the recommendations of a study regarding the "Radiological Conditions at Bikini Atoll: Prospects for Resettlement."

In concluded that: "No further independent corroboration of the measurements and assessments of the radiological conditions at Bikini Atoll was deemed necessary. This conclusion was based on the excellent quality control of those measurements and assessments; the regular participation in intercomparison programs by the various scientific groups that carried out those measurements and assessments; and the good agreement among the data submitted."

Nevertheless, it was acknowledged that the Bikinian people have concerns about the actual radiological conditions in their homeland, and it was therefore considered that the Bikinians might be reassured about the actual radiological conditions at Bikini Atoll by a limited program of monitoring of radiation levels, which should involve some participation by members of the community.

Permanent resettlement of Bikini Island under the present radiological conditions without remedial measures was not recommended in view of the radiation doses that could potentially be received by inhabitants with a diet of entirely locally produced foodstuffs. This conclusion was reached on the basis that a diet made up entirely of locally produced food which would contain some amount of residual radionuclides could lead the hypothetical resettling population to be exposed to radiation from residual radionuclides in the island, mainly from Cs^{137}, resulting in annual effective dose levels of about 1.50 cSv (rem). If the effective dose of 0.24 cSv (rem) due to natural background radiation were added, this would result in an annual effective dose of about 1.74 cSv (rem). This level was judged to require intervention of some kind for radiation protection purposes.

In practice, doses caused by a diet of locally derived foodstuffs are unlikely to be actually incurred under the current conditions, as the present Marshallese diet contains, and would in the near future presumably continue to contain, a substantial proportion of imported food which is assumed to be free of residual radionuclides. Nevertheless, the hypothesis of a diet of solely locally produced food was adopted in the assessment for reasons of conservatism and simplicity, and also because the present level of imports of foodstuffs could decrease in the future.

6.19 JOHNSTON ATOLL NUCLEAR, BIOLOGICAL AND CHEMICAL WEAPONS TESTING

INTRODUCTION

Johnston Atoll is located 717 nautical miles southwest of Oahu,, Hawaii, and 450 nautical miles south of the French Frigate Shoals in the Northwest Hawaiian Islands. It is one of the most isolated atolls in the world. It rests on the core of an ancient volcanic island now buried under a limestone cap thousands of feet thick which resulted from 70 million years of reef growth on the slowly sinking island.

Today, the Johnston Atoll is a broad shallow platform of approximately 50 square miles with a marginal reef emergent only on the northwest. The atoll consists of four coral islands: Johnston Island, Sand Island, North Island, and East Island. At just over 625 acres, Johnston Island is the largest island. Johnston Island and Sand Island are natural islands, which have been expanded by coral dredging; North Island (Akau) and East Island (Hikina) are man-made islands formed from coral dredging. The four small islands of Johnston Atoll are home to over 200 species of fish, 32 species of coral, and 20 species of native and migratory birds.

HISTORY

Johnston Atoll was accidentally discovered on September 2, 1796 by Captain Joseph Pierpont of the American Brig "Sally." He published a notice of his ship's grounding in several American newspapers in 1797, giving an accurate position and noting the two original islands: Johnston and Sand, and the incomplete marginal reef. No traces or records of any earlier visitations or occupations by Polynesians or Europeans during their voyages of discovery exist. Lieutenantt William Smith of the HMS Cornwallis named the larger island for his ship's captain, Charles J. Johnston, after sighting it briefly on December 14, 1807.

The Guano Act of 1856 granted Americans the privilege of removing guano, the accumulation of sea bird excrement used as fertilizer, from nearly 30 central Pacific islands claimed by the USA. For several years guano was removed from Johnston and Sand Islands before the operation was abandoned in the late 1800's. During the late 1800s, the Atoll was claimed by both the Kingdom of Hawaii and the USA. This claim was settled when Hawaii became a USA Territory.

In 1923 the Biological Survey of the USA Department of Agriculture and the Bishop Museum visited the islands with a scientific expedition to study the bird and marine life. Their findings resulted in Executive Order 4467 of President Calvin Coolidge designating the islands as a bird refuge. In 1934 by Executive Order 6935, President Franklin D. Roosevelt placed the atoll under the auspices of the USA Navy while retaining the earlier provisions for refuge designation and protection.

In 1934, Johnston Atoll was transferred to and managed by the USA Navy. The Navy development began in earnest in 1936 with reef blasting, dredging, land filling and grading and construction on the islands. The atoll was briefly shelled by Japanese naval units shortly after the Pearl Harbor attack but combat soon shifted west and the island's role changed from an outpost to an aircraft and submarine stopover and refueling base.

In 1999, the host base management responsibilities for Johnston Atoll (JA) transferred from the Defense Threat Reduction Agency (DTRA) to the Air Force. The 15th Contracting Squadron at Hickam Air Force Base managed the tenants of Johnston Atoll. The USA Army operated the Johnston Atoll Chemical Agent Disposal System, (JACADS) on the atoll as a tenant unit of the 15th Air Base Wing, Hickam Air Force Base, Hawaii.

BIOLOGICAL WEAPONS

Biological weapons or Bioweapons are more destructive as strategic weapons than nuclear or chemical weapons. A chemical weapon is a toxic poison that kills upon contact with the skin. Bioweapons are microscopic microorganisms, bacteria or viruses, that invade the body, multiply inside it and ultimately destroy it while infecting other individuals. Chemical weapons can only be used tactically affecting a limited number of people, and they do not multiply through an infectious process.

Some biological weapons like anthrax are not contagious. Smallpox is contagious spreading rapidly on a large scale.

Accidental releases of bioweapons can linger in the environment indefinitely. At Omutninsk, Russia, a small leak in a pipe dripped a suspension of the Tularemia bacterium in the ground. Rodents in the surrounding woods were chronically infected with the Schu-4 military strain of Tularemia, a bacterium that causes a form of pneumonia.

It was obtained through intelligence sources from the USA by the Russians. Tularemia used the rodents as a new host. Attempts at eradicating them were unfruitful. The rodents spread the Shu-4 among themselves in the woods. The American-Russian Tularemia remains endemic around the Kirov region in Russia.

Some scientists contend that biological weapons to be uncontrollable, liable to infect their users, or unworkable in any practical sense. Others counter that Yersinia Pestis, plague, or Black Death, an airborne contagious organism wiped out one third of the human population of Europe around 1348.

Natural plague being curable with antibiotics, the Russians had developed a genetically engineered strain that is multi-drug resistant to different antibiotics. The disease could amplify itself in an ever expanding circle of infection that no nuclear weapon can achieve.

The most potent bioweapons are a mixture of dry powders or biodusts such as talcum powder, pollen, dry blood, ground silk or wool or silica gels that acquire an electric charge, disperse in the air, become invisible, and lodge themselves into the human lung.

Even if the biological agent is curable by an antibiotic or an antiviral, huge amounts would have to be stockpiled as a defense against it. If 84 grams of an antibiotic or antiviral are needed per person, for a small city of 100,000 people, an immediate delivery of:

$$84 \times 100,000 = 8.4 \times 10^{+6} \text{ grams} = 8.4 \text{ metric tonnes}$$

would be needed.

Protecting large cities, and the whole population of a country becomes a daunting task. Triage becomes inevitable favoring the ruling political elites, health care providers, emergency responders and the police and military forces for survival over the populace at large.

THE BIOLOGICAL WEAPONS CONVENTION

The USA ended its offensive bioweapons program in 1969, but maintains a defensive capability. It signed with 140 nations in 1972 the "Biological and Toxin Weapons Convention," banning the development, use and stockpiling of biological weapons. Some nations like Israel did not sign the Convention. In addition Pakistan, India, China, Israel, Iran, Iraq, Syria and Lybia had significant bioweapons programs at some time or the other.

Some others in Russia believed that the USA had not ended its bioweapons program, calling it: "The great American lie," believing that it turned it into a "black" weapons program, and continued their programs such as Russia under the "Biopreparat" system established in 1973 and consisting of 40 research and production facilities developing both weapons and their vaccines and medicines, after signing the bioweapons convention.

As late as 1991, Russia was on the verge of producing the Marburg Variant U (For Nikolai Ustinov, a Russian scientist killed while working on the virus), in addition to the smallpox virus, plague and anthrax, for use as a strategic and operational biological weapon on Multiple Independently targeted reentry Vehicles (MIRV) Inter Continental Ballistic Missile (ICBM), the S18.

Special cooling systems were designed inside each of the ten MIRVED warheads that would keep the virus alive during the heat of reentry through the Earth's atmosphere. The bio-warheads would be parachuted over a city breaking apart at a certain altitude. Each warhead would burst into more than one hundred oval bomblets the size of a cantaloupe. These fly a distance then split in overlapping patterns releasing a plume of particles that becomes invisible.

One to five microscopic particles of this hemorrhagic fever virus variant in the lung of a mammal would cause the mammal to crash, bleed and die. In comparison to anthrax, it takes about 8,000 spores lodged in the lungs to guarantee death. The particles of the Marburg Variant U were coated to protect them in the air from oxygen so that they can drift for a long distance of many miles.

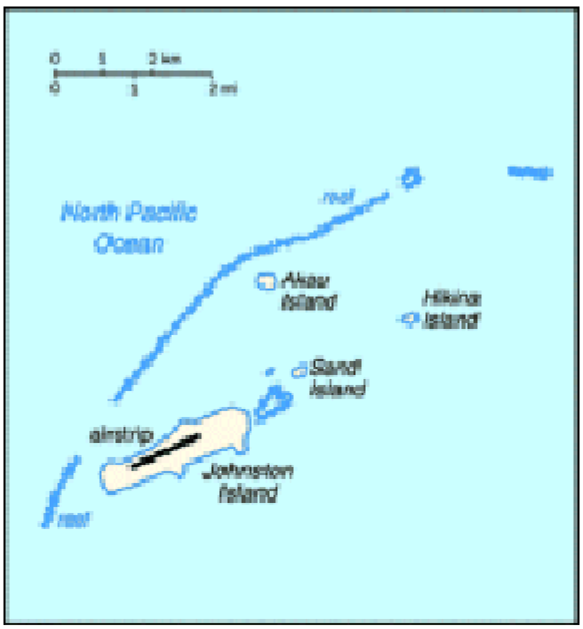


Figure 29. Jonhston Atoll, and Sand, Akau and Hikina islands.

NUCLEAR AND BIOLOGICAL TESTING

In the late 1950's and early 1960's a series of high altitude nuclear tests brought attention to the Johnston Atoll. A series of dredge and fill projects completed in 1964 brought the size of Johnston Island up to 625 acres from its original 46, increased Sand Island from 10 to 22 acres, and added two manmade islands, North (Akau) and East (Hikina) of 25 and 18 acres.

Beginning in 1964 a series of large open-air biological weapon tests was conducted downwind of Johnston Atoll. The American strategic bioweapons tests involved a number of ships positioned around Johnston Atoll, upwind from a number of barges loaded with goats and rhesus monkey test subjects which were exposed to agents that were dispensed from aircraft.

Figure 30. Jonhston Island proving grounds facilities.

Real lethal biological agents were used. The strategic tests were as elaborate and expensive as the nuclear tests. They involved as many naval vessels as to constitute the world's fifth navy in size. The ships were positioned around the Johnston Atoll upwind from a number of barges loaded with hundreds of rhesus monkeys.

At sunset, as the sun touched the horizon, a Marine Phantom IV jet would carry on a line-source laydown, by flying low heading on a straight line parallel to the island's beach. A single pod under its wings would release a weaponized biological weapon powder. The particles are given an electrostatic charge so that they repel each other and float in the air like smoke particles. Like smoke, the powder would disappear out of sight.

The jet would release a specified amount of powder per mile. The whole process takes a few minutes. The jet would appear on radar, but the dispensed biological weapon would be invisible. The plume of particles, one to five microns in diameter, would move with the wind over the sea sweeping the sea surface to a distance of eighteen to twenty miles. In the path of the particles were stationed at intervals separated by miles the barges containing the rhesus monkeys. They were manned by Navy crews wearing biohazard space suits. When taken back to the Johnston Atoll, half the monkeys died and half survived.

The choice of sunset as a spray time is dictated by the choice of a wind of ten to twelve miles per hour with a temperature inversion so that the plume would hang in the air without drifting up. A brain virus biological agent used was the Venezuelan Equine Encephalitis or VEE. This is grown in weapons-grade concentrations in live chicken embryos much like the influenza vaccine is grown in eggs. The sickened embryos are harvested, they are dry-frozen, then ground into a fine powder.

The pink colored dried blood of healthy chicken embryos is used as a fine creamy fluffy simulant for testing of the dispersal properties. It may be similar to the yellow simulant, possibly pollen that was used by then Secretary of State Colin Luther Powell as a demonstration at his speech on February 5, 2003 at the United Nations as he was making a convincing case for the invasion of Iraq. The unfortunate action sullied an otherwise impeccable record and reputation and may have cost him the possibility of a presidential candidacy through the loss of his credibility.

The ground dry frozen harvested sickened embryos may be the basis of some reported "Freeze dried embryo dispersion" method.

Figure 31. Secretary of State Colin Luther Powell convincingly gesturing in making the case for the invasion of Iraq at the United Nations, showing a yellow simulant in a tube; possibly pollen, ground silk or wool, or dried chicken blood, February 5th, 2003. He engaged his reputation in convincing the General Assembly of the United Nations that Iraq's WMD poses a threat to the world. He will later regret his speech, calling it "a blot on my record", and claiming to have been deceived himself.

Another reason for choosing sunset time is that a bioweapon is destroyed by the ultraviolet radiation in sunlight. Like nuclear radiation, bioweapons decay with a given half-life, necessitating their coating with protective layers. Those that are electrostatically-charged would lose their charge, especially in humid atmospheres. Anthrax has a long half-life, whereas Tularemia has only a few minutes half-life in sunlight, necessitating its release only at night.

Intense heat destroys biological and chemical agents. That is why Earth-penetrating nuclear weapons were contemplated to destroy the presumed, yet unexisting underground stockpiles of biological and chemical weapons in the second Iraq war.

NUCLEAR TESTING

The Air Force retained operational control of the Johnston Atoll until 1962, with the exception of 4 months in 1958 when Joint Task Force 7 held operational control. From 1962 to 1963, Joint Task Force 8 and the Atomic Energy Commission jointly held operational control of Johnston Atoll for the purpose of conducting high-altitude atmospheric nuclear testing operations.

The Joint Task Force 8 retained operational control of Johnston Atoll from 1963 to 1970 as the Limited Test Ban Treaty came into force identifying Johnston Atoll as the principal overseas readiness-to-test base. In 1970, the Johnston Atoll was again transferred to the Air Force. Host-management responsibility for Johnston Atoll was given by the Deputy Secretary of Defense in July 1973 to DSWA (formerly the Defense Nuclear Agency), which continued to perform that mission.

In 1963, the Congressionally mandated Safeguard C provision to the Limited Test Ban Treaty, and subsequent Nuclear Testing Treaties, formed the basis for maintaining the Johnston Atoll as a readiness-to-test site should the resumption of atmospheric nuclear testing be deemed essential to the USA's national security.

In November 1993, the USA Congress zero-funded the Johnston Atoll Safeguard C mission and defined the military mission as storage and destruction of chemical weapons.

DEACTIVATION OF JOHNSTON ISLAND

On July 31, 2001 the USA Army Chemical Activity Pacific retired its colors on Johnston Island. The unit's deactivation marked an end to 30 years of storing and handling chemical weapons stockpiles, and participating in the destruction of those weapons since 1990. Johnston Island, 825 miles southwest of Hawaii, was the only site where soldiers were entirely responsible for the storage, security and transport of the deadly chemical agents. Department of Defense contractors run eight other sites throughout the USA.

The island, only 2½ miles long and a half-mile wide, was home to a military police company and chemical company, along with a headquarters unit. Every soldier assigned to the island during the 30 years when chemicals were stored there, received special training in handling and emergency responses to chemical agents.

The unit safeguarded and disposed of deadly sarin and VX nerve agents and assisted the Johnston Atoll Chemical Disposal System, a contract civilian group assigned to destroy the chemical agents. The two units destroyed more than 400,000 rockets, bombs, projectiles, mortars and mines. Two thousand tons of nerve and blister agent were also destroyed. The last of the chemical stockpile was destroyed in November 2000. There were no incidents or accidents in the unit's 30-year history.

The last soldier left Johnston Island by ship on August 17, 2001, but some Department of Defense (DOD) contract civilians would remain. The Johnston Atoll Chemical Disposal System continued to be dismantled and dispose of secondary hazardous waste from the chemical weapons destruction. That operation ended in 2004.

CONVERSION INTO A NATURE PARK

There were about 960 civilian and 250 military personnel assigned to the island. The Johnston Atoll mission was to support the USA Army chemical weapon storage and destruction program. Closed to the public, the atoll is an unincorporated territory of the USA administered by the USA Defense Threat Reduction Agency (DTRA), formerly the Defense Nuclear Agency (DNA), and managed cooperatively by DNA and the Fish and Wildlife Service of the US Department of the Interior as part of the National Wildlife Refuge system. The Johnston Atoll has also been used by the military since the mid-1930s, serving as a refueling point for aircraft and submarines during World War II and as a base for airlift operations during the Korean War. It was also the site of several air atomic tests during the early 1960s.

NUCLEAR REMEDIATION

Under direction from the Department of Defense at the time of the transfer, DTRA remained responsible for completing the plutonium cleanup project on the atoll, with a goal of achieving a safe level for humans and the environment. The atoll became contaminated with plutonium through two aborted missile launches during high altitude nuclear weapons testing conducted in 1962.

On February 1, 2000, DTRA sent a letter to the Environmental Protection Agency (EPA), the USA Fish and Wildlife Service (USF&WS), and the Air Force, requesting their review and concurrence with DTRA's proposed standard of a specific activity of 40 piocuries per gram (pCi/g) of plutonium in the soil as a final radiological cleanup standard.

The cleanup level for Enewetak Atoll, also in the Pacific, was 60 pCi/g for agricultural areas and 40 pCi/g for residential areas.

The cleanup level for Rocky Flats, which is near Denver, Colorado, was between 35 and 600 pCi/g.

CHEMICAL WEAPONS STORAGE

Chemical weapons have been stored on Johnston Island since 1971. The weapons stored at Johnston Island included rockets, projectiles, mines, mortars, and ton containers, containing both nerve and mustard agents.

The chemical munitions stockpile stored at Johnston Atoll originated from four locations. The Army leased 41 acres in 1971 to store chemical weapons formerly held in Okinawa, Japan, which were transferred to the atoll from Okinawa during Operation Red Hat in 1971. In 1972, the Air Force moved Agent Orange stocks to Johnston Atoll. These stocks were destroyed in 1977. In November 1990, chemical weapon stocks from the Federal Republic of Germany were transferred to Johnston Atoll for destruction in Operation Steel Box. In 1991, range-recovered chemical munitions were brought from the Solomon Islands were they were also being tested.

CHEMICAL WEAPONS DISPOSAL

In 1981, the Army began planning for the Johnston Atoll Chemical Agent Disposal System (JACADS). Before destruction operations began in 1990, JACADS stored approximately 6.6 percent of the total USA stockpile.

Table 1. Stockpile of chemical agents munitions.

Item	Quantity	Weight [lbs]
HD-Blister		
155mm Projectiles	5,670	66,339.0
105mm Projectiles	46	136.6
M60 Projectiles	45,108	133,970.7
4.2 Mortars	43,600	261,600.0
Ton Containers	68	116,294.0
GB-Nerve		
M55 Rockets	58,353	624,377.1
155mm Projectiles	107,197	696,780.5
105mm Projectiles	49,360	80,456.8
8" Projectiles	13,020	188,790.0
MC-1 Bombs	3,047	670,340.0
MK 94 Bombs	2,570	277,560.0
Ton Containers	66	101,158.0
VX-Nerve		
M55 Rockets	13,889	141,769.8
155mm Projectiles	42,682	256,092.0
8" Projectiles	14,519	210,525.5
Land Mines	13,302	139,671.0
Ton Containers	66	97,360.0

Construction began in 1986. It was the world's first full-scale facility built to destroy chemical weapons. The design was based on technologies used for years by the Army and industry. Following completion of construction and facility characterization, JACADS began Operational Verification Testing (OVT) in June 1990. From 1990 until 1993, the Army conducted four planned periods of Operational Verification Testing (OVT), required by Public Law 100-456. OVT was completed in March 1993, having demonstrated that the reverse assembly incineration technology was safe and that JACADS operations met all environmental parameters. The OVT process enabled the Army to gain critical insight into the factors that establish a safe and effective rate of destruction for all munitions and agent types. Only after this critical testing period, did the Army proceed with full-scale disposal operations at JACADS. Transition to full-scale operations started in May 1993. The facility actually did not begin full-scale operations until August 1993.

Approaching hurricanes in both 1993 and 1994 necessitated the facility to shut down and the evacuation of more than 1,100 soldiers, Department of the Army civilians, and Army contractors from Johnston Island to Hawaii. During each of these instances, JACADS production was disrupted for a period of time. As a result of the hurricane striking Johnston Island in August 1994, JACADS production was disrupted for approximately 70 days. This time was required to repair damaged installation infrastructure needed to sustain the presence of the work force and to provide power and water supply critical to JACADS processing.

On January 31, 2000, the Ocean going tug “Sea Valiant” pulling a barge: the “Malalo” entered the waters of Johnston Atoll and docked at Johnston Island. After a short period of unloading construction materials, the crew of the tug began to load into the hold of the barge, projectile casings and One-Ton Containers from the main pier area. The operation, once started, ran continuously 24-hours a day, loading round after round onto the vessel, for the better part of the next 6 days, loading these former chemical warfare agent munitions and containers. The tug and barge departed fully loaded with over 400 tons of 800,000 pounds of metal bound for Japan on February 6, 2000. This was part of the final disposal operation to get the remains of what once were chemical munitions off the island. These metal hulls of what were once chemical munitions or containers that stored chemical agent in the case of the One-Ton Containers, had all been processed through the Johnston Atoll Chemical Agent Disposal System (JACADS) facility and demilitarized to 5X level in the previous HD and GB campaigns.

On March 7, 2000, the Chemical Ammunition Company (CAC) shipped the last VX filled M121A1, 155 millimeter projectile from the “Red Hat” storage area to the JACADS facility. This completed the shipment of all 42,682 projectile in 43 Load and Transport (L&T), missions over an 85 day period that started with the first L&T that was conducted on 17 December 1999. On March 10, 2000, the JACADS plant processed and thermally decontaminated the last 155-mm projectile casings through its Metal Parts Furnace (MPF). This event brought an end to the 155 VX Stockpile Campaign.

The JACADS facility then began retooling its equipment and conducting changeover operations to proceed with the next munitions campaign which was the M426 8-inch VX filled projectiles. This retooling changeover was expected to take place through April 2000, followed by pre-operational checks of the operating system with inert training projectiles to validate the process, prior to the 8-inch campaign itself, beginning to process the stockpile projectiles in May 2000.

JACADS disposed of all of its stockpiled M55 nerve agent rockets, one-ton containers filled with mustard and GB nerve agent, one class of mustard-filled projectiles and nerve agent bombs. All rockets, projectiles, bombs and ton containers filled with GB have been safely destroyed at JACADS.

Once all of the munitions were destroyed, the facility was dismantled in 2003. The Army departed the atoll. The Air Force then returned the atoll to the US Forest and Wildlife Service to continue its national wildlife refuge operations.

As a twist of sorts on the “Spear Points to Plow Point” or “Swords to Plowshares” sayings, which could be modified in this case to say “Chemical Munitions to Driving Projectiles,” the scrap metal recovered from the disposal of the munitions was sold to smelters in Japan to be melted down and reformed to become automobiles to be most probably exported and returned back to the USA.

6.20 KYSHTYM REPROCESSING PLANT ACCIDENT

Figure 32. Kyshtym reprocessing plant site in the Urals. Source: DPA

On September 29, 1957, a storage tank containing about 80 tons of high-level radioactive liquid waste underwent a chemical explosion or a criticality excursion at the Mayak fuel recycling plant in the southern Urals, 15 kms east of the Russian city of Kyshtym.

The blast resulted in a fallout plume 300 kms in length and 40 kms in width which diffused to the northeast and did not reach Europe.

About 15,000 people were evacuated, and the houses located in a 25 kms radius surrounding the release location were leveled off and the evacuees were not allowed to return back. The fuel reprocessing at the plant, which produced the material for the Soviet Union's first atomic bomb, was not discontinued.

Information about the incident leaked out in the 1970s and its occurrence was admitted in 1989. A 150 km^2 area remains closed to the public.

6.21 HANFORD SITE, WASHINGTON, USA

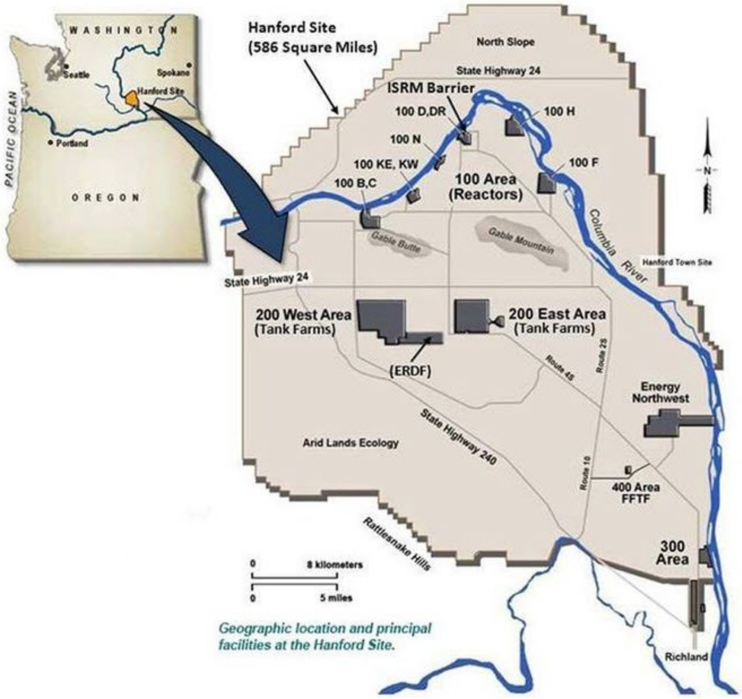


Figure 33. Hanford reservation site by the Columbia River, Washington, USA.

Figure 34. Decommissioned B Reactor at the Hanford reservation site is open for visitors as a historic national landmark, Washington, USA.

Figure 35. Reactor site with associated auxiliary buildings and electrical switchyard.

Figure 36. The Hanford reactors used the Columbia River for reactor cooling.

A large proportion of the Pu and T used in the USA nuclear arsenal was produced at the Hanford site reactors and reprocessing plants on the Columbia River in the USA state of Washington. The Pu used in the first implosion device Trinity test in July 1945 and in the Fat Man device dropped on Nagasaki on August 9, 1945. The other site where these isotopes were produced was at Savannah River, South Carolina.

The contamination at the Hanford site involves 52 buildings and 240 square miles. About 204,000 m^3 of high-level waste remain on site which is 2/3 of the total for the USA.

Discharges of about 216 x 10^6 liters of liquid waste and cooling water have occurred out of leaky tanks. About 100,000 spent fuel rods weighing 2,300 tons are stored on site

An experiment designated as “Green Run” involved the intentional release of a radioactive plume from the T-plant; largest Pu factory at the time. Fallout from the experiment reached California.

Figure 37. Exterior of Purex reprocessing canyon showing access through covered tunnels at the right hand side. Fuel from reactors was brought in in underground tunnels in railroad cars at the right side. There are two tunnels: One is approximately 360 feet long and the other is approximately 1,700 feet long.

Figure 38. Interior of Purex Pu reprocessing plant canyon, Washington, USA.

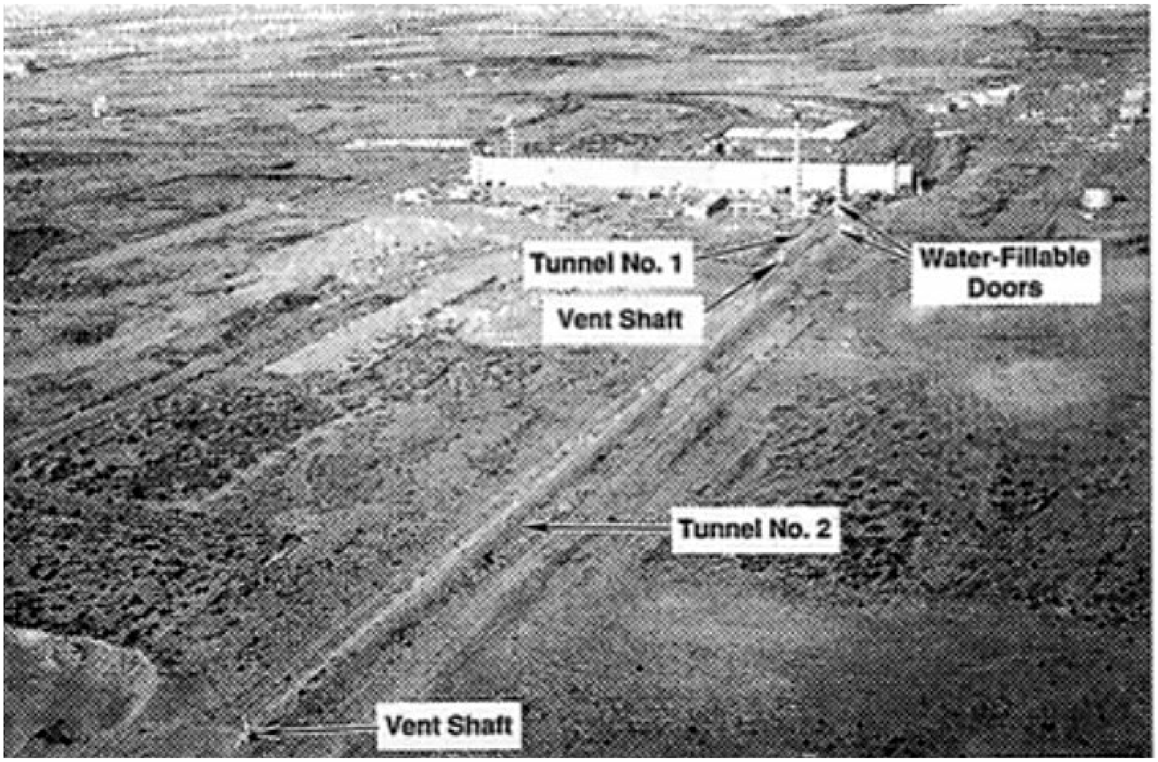


Figure 39. Purex plant tunnels configuration with water-fillable doors and ventilation shafts.

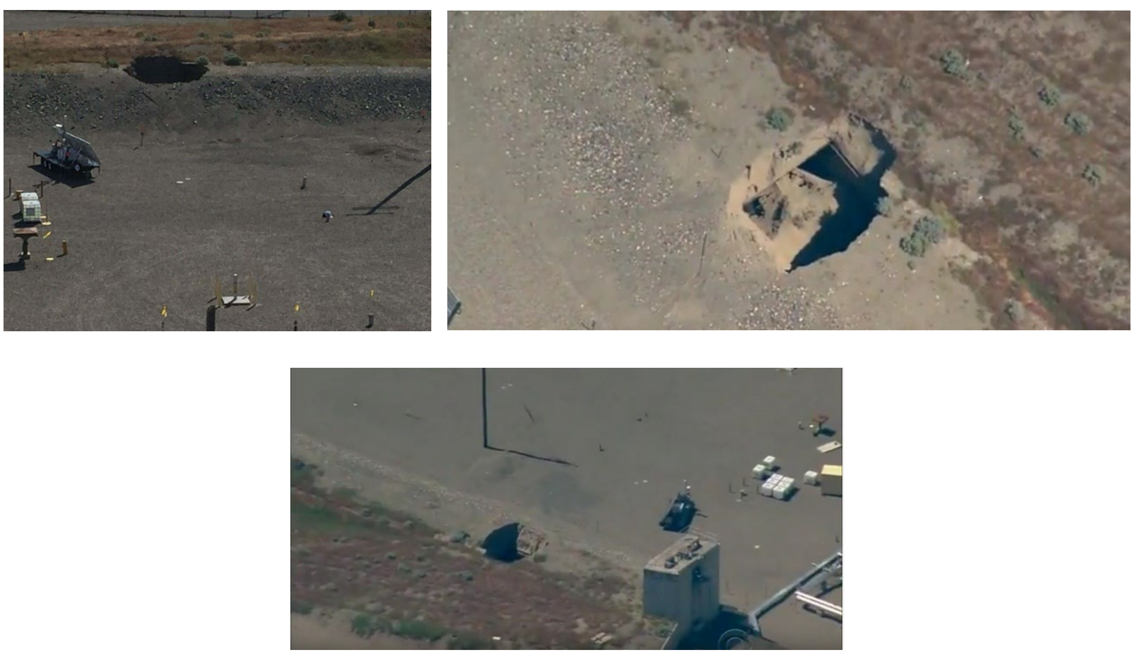


Figure 40. The tunnels were used beginning in the 1950s to store contaminated equipment. The 20 foot wide by 20 foot long cave-in is in an area where the two tunnels join together, possibly as a result of an area earthquake or a quarry blast northwest of the site. A road is being constructed in the foreground.

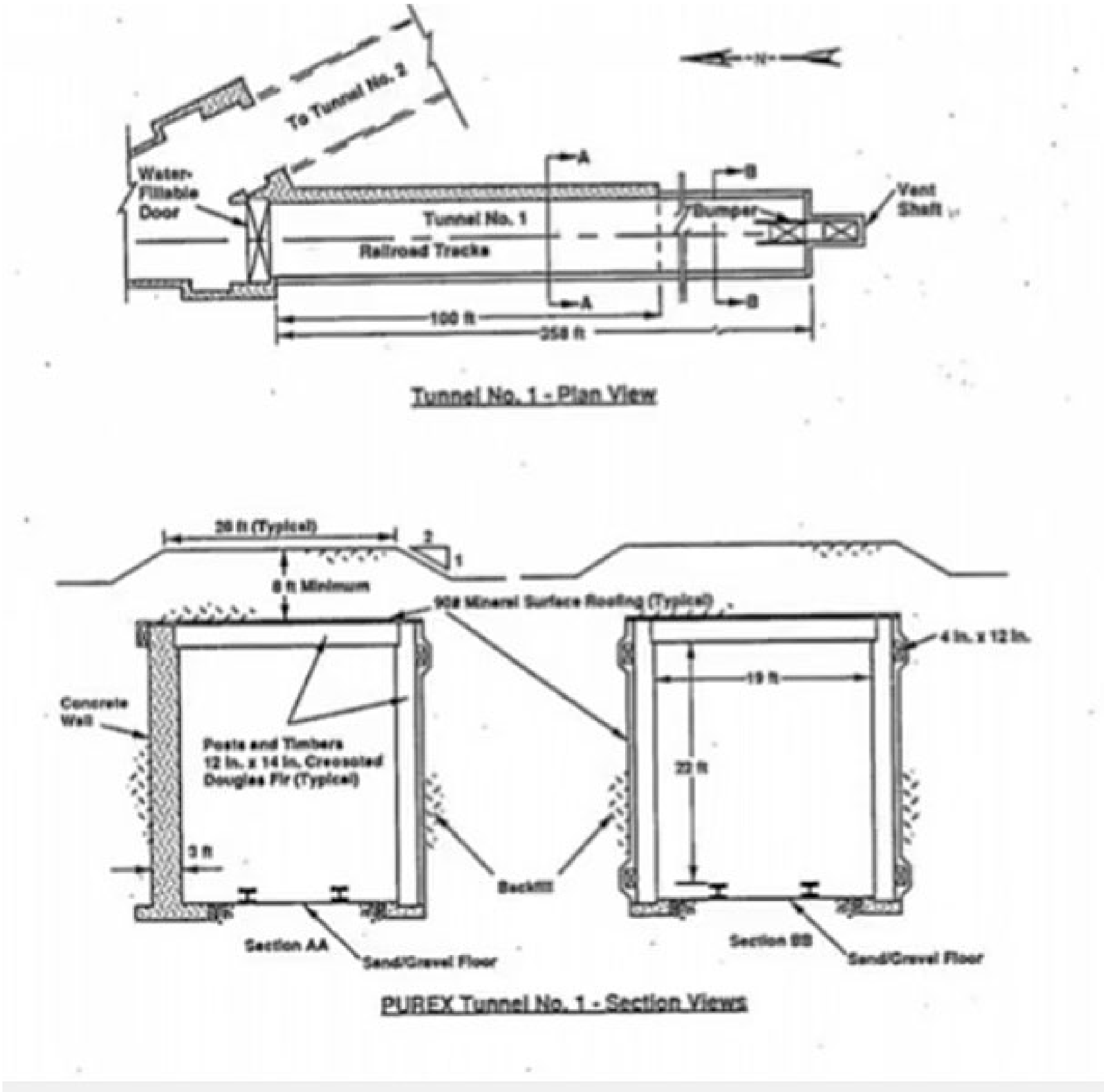


Figure 41. Tunnel 1 configuration with Douglas fir wooden posts and timbers, railroad tracks, water-filled doors and vent shaft.

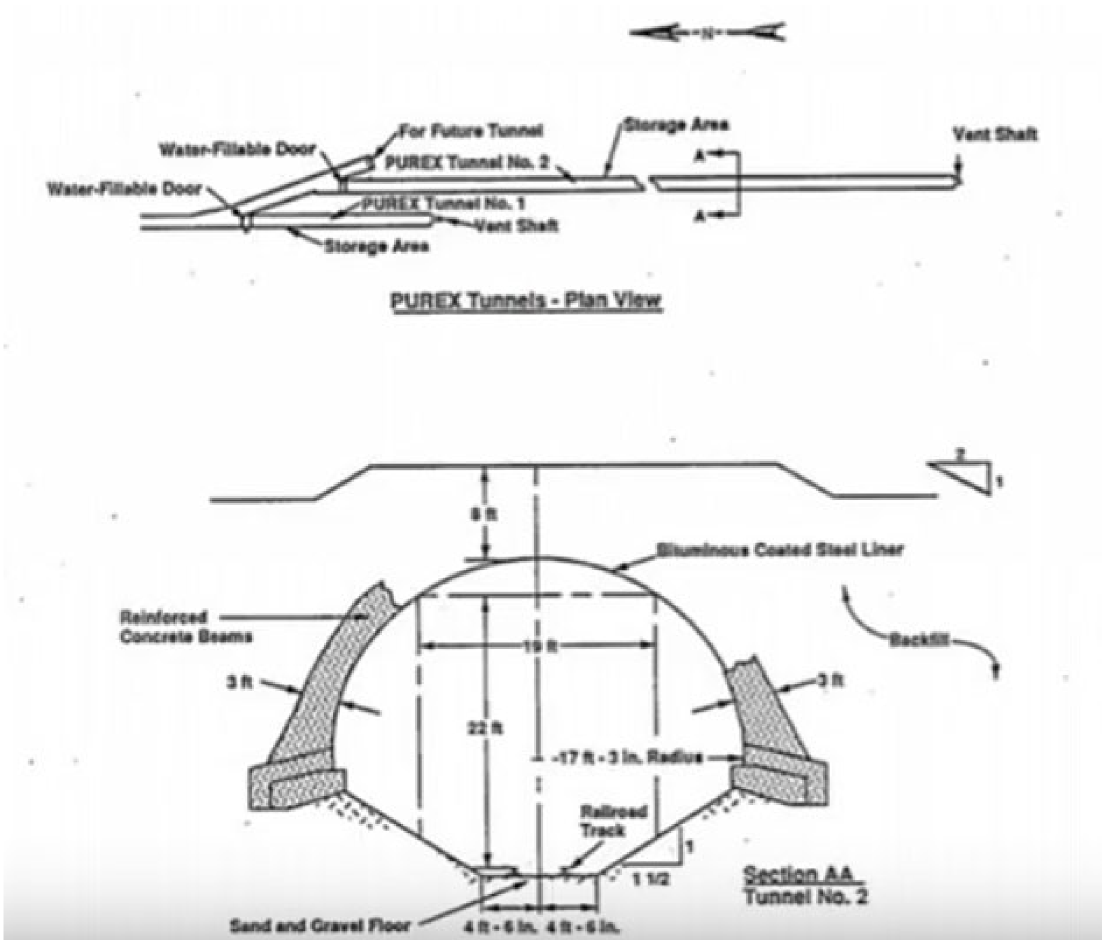


Figure 42. Tunnel 2 configuration with bituminous-coated steel liner and reinforced concrete beams.

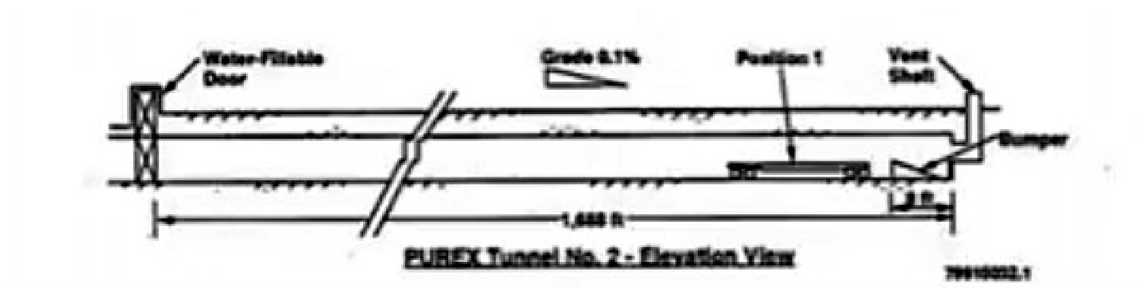
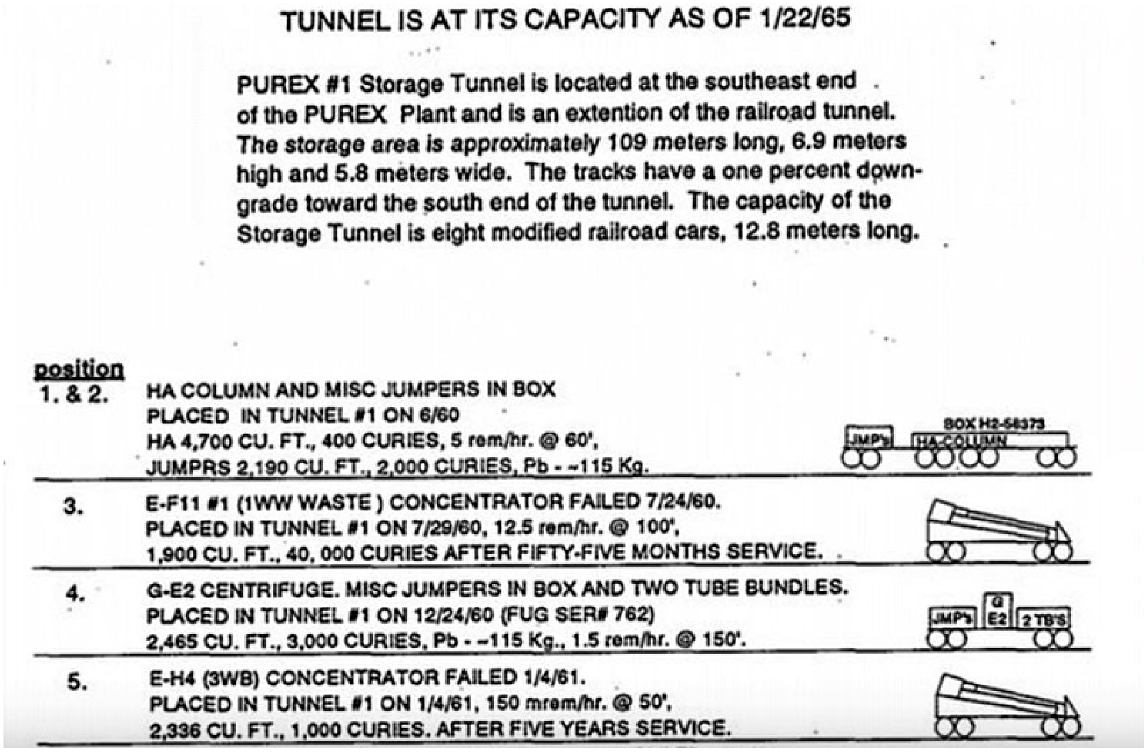


Figure 43. Tunnel 2 was built with a one percent slope, equipped with water fillable doors, vent shafts and is used to store unused contaminated equipment on railroad cars.


TUNNEL IS AT ITS CAPACITY AS OF 1/22/65

PUREX #1 Storage Tunnel is located at the southeast end of the PUREX Plant and is an extention of the railroad tunnel. The storage area is approximately 109 meters long, 6.9 meters high and 5.8 meters wide. The tracks have a one percent down-grade toward the south end of the tunnel. The capacity of the Storage Tunnel is eight modified railroad cars, 12.8 meters long.

position		
1. & 2.	HA COLUMN AND MISC JUMPERS IN BOX PLACED IN TUNNEL #1 ON 6/60 HA 4,700 CU. FT., 400 CURIES, 5 rem/hr. @ 60', JUMPRS 2,190 CU. FT., 2,000 CURIES, Pb - ~115 Kg.	JMP's / BOX H2-58373 / HA COLUMN
3.	E-F11 #1 (1WW WASTE) CONCENTRATOR FAILED 7/24/60. PLACED IN TUNNEL #1 ON 7/29/60, 12.5 rem/hr. @ 100', 1,900 CU. FT., 40, 000 CURIES AFTER FIFTY-FIVE MONTHS SERVICE.	
4.	G-E2 CENTRIFUGE. MISC JUMPERS IN BOX AND TWO TUBE BUNDLES. PLACED IN TUNNEL #1 ON 12/24/60 (FUG SER# 762) 2,465 CU. FT., 3,000 CURIES, Pb - ~115 Kg., 1.5 rem/hr. @ 150'.	JMP's / G E2 / 2 TB'S
5.	E-H4 (3WB) CONCENTRATOR FAILED 1/4/61. PLACED IN TUNNEL #1 ON 1/4/61, 150 mrem/hr. @ 50', 2,336 CU. FT., 1,000 CURIES. AFTER FIVE YEARS SERVICE.	

Figure 44. Purex Tunnel 1 storage of contaminated equipment such as concentrators, centrifuges and dissolvers on railroad cars displays radiation dose rates of 0.16 – 25 rem / hr.

During the Cold War, the project included nine nuclear reactors and five large plutonium processing complexes, which produced plutonium for most of the 60,000 weapons in the USA nuclear arsenal. The high level chemicals storage tanks at the site has been leaking in the vicinity of the Columbia River.

Figure 45. Double-walled high level waste tank farm at the Hanford reservation site, Washington, USA.

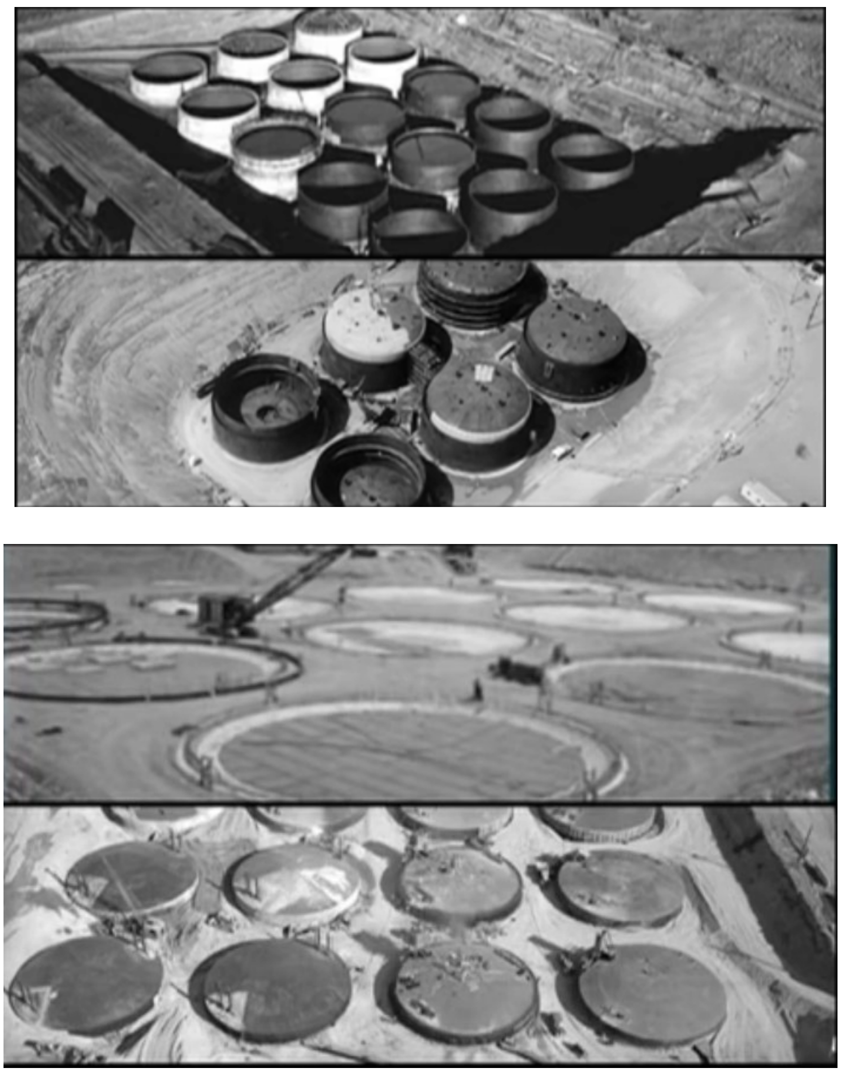


Figure 46. Underground 177 storage tanks at Hanford.

Figure 47. Waste treatment plant under construction at Hanford for the eventual glass vitrification of the waste.

Figure 48. Removal and burial of contaminated structures at Hanford.

Hanford's Pu and Tritium production reactors were decommissioned at the end of the Cold War, but the decades of manufacturing left behind 53 million USA gallons of high-level radioactive waste, an additional 25 million cubic feet of solid radioactive waste, 200 square miles of contaminated groundwater beneath the site and occasional discoveries of undocumented contaminations. The Hanford site represents two-thirds of the nation's high-level radioactive waste by volume. Hanford is the most contaminated nuclear site in the USA and is the focus of the nation's largest environmental cleanup. The government spends $2 billion per year on Hanford cleanup, which is one-third of its entire budget for nuclear cleanup nationally. The cleanup is expected to last decades.

A significant chemical tank leak occurred in 2013, when thousands of 3,000-3,500 gallons of radioactive waste are estimated to have leaked from the site. The problem occurred at the double-wall storage tank AY-102, which has a capacity to hold one million gallons of waste, and which has been leaking since 2011. At the time, the leak was small, and the waste would dry up almost right after spilling out between the inner and outer walls, leaving a salt-like substance behind. Over time the small leak got bigger.

Tank AY-102 is just one of 28 double-shell tanks at Hanford; there are 177 underground tanks total; holding nuclear byproducts from nearly four decades of plutonium production on the Hanford Nuclear Site, located near Richland, Washington. The outer shell of AY-102 does not have the exhaust or filtration system needed to keep the exhausted gases created by the waste in check. Workers have been ordered to wear full respiratory safety

On May 9 2017, a 20 by 20 feet roof collapse occurred in an underground tunnel previously used to bring the fuel from the production reactors to the Purex (Pu uranium extraction) facility separation plant as a result of soil subsistence from nearby work. "The USA Department of Energy (DOE) Richland Operations Office activated the Hanford Emergency Operations Center at 8:26 a.m., after an alert was declared at the 200 East Area. There are concerns about subsidence in the soil covering railroad tunnels near a former chemical processing facility. The tunnels contain contaminated materials."

In the 1950s and 1960s two tunnels were constructed next to a former chemical processing plant, the Plutonium Uranium Extraction Plant, or PUREX, located in an industrial area near the center of the Hanford Site called the 200 East Area. The tunnels were constructed of wood and concrete and covered with approximately 8 feet of soil. The tunnels were constructed to hold rail cars that were loaded with contaminated equipment and moved into the tunnels during the Cold War.

A 20-foot-wide hole in the roof of one of the tunnels was observed, leading to the precautionary sheltering of employees and notifications to area counties and states. After no contamination was detected, the shelter in place order was lifted and employees were sent home from work early as a precaution.

The approximately 360-foot-long tunnel where the partial collapse occurred contains 8 rail cars loaded with contaminated equipment. That tunnel feeds into a longer tunnel that extends hundreds more feet and contains 28 rail cars loaded with contaminated equipment. The hole opened up in the shorter tunnel near where it joins the longer tunnel. The tunnels were sealed in the mid-1990s and are checked periodically.

Plutonium as a metal is pyrophoric and gets airborne with the heat of the oxidation reaction. Elemental plutonium would have oxidized long ago. Vitrification is the choice for high level waste treatment. It was being implemented at the Fernald, Ohio plant as early as 1991 and it is the choice for Hanford for treating its waste. A problem is getting the waste out of the underground tanks.

At the Savannah River Site (SRS), the tank cars ran in the open on the surface between the reactors and the reprocessing canyons. The canyons at Savannah River were kept at negative pressure even after they were shut down circa 1990. Exhaust fans are deployed downstream of two football field size, 30 foot deep, underground filter beds. It was safe to walk on the surface of those beds, which are 10 feet below grade. At SRS, all of the flow was from the offices down to the hottest points in the dissolving cells. If the same reasoning applied at Hanford, the tunnels would be at elevated pressure relative to the Purex reprocessing canyon.

6.22 CHERNOBYL ACCIDENT SITE

Figure 49. Testing for radioactive contamination at the Chernobyl accident site.

On April 26, 1986 at the Chernobyl power plant near Pripyat, in what was then the USSR and is now the Ukraine, a steam explosion resulting from a criticality excursion in unit 4 destroyed the roof, exposing the melting core and hurling radiation into the airto the open air.

The authorities initially covered up the incident. On the morning after the explosion, the area residents were asked to remain indoors and to keep their windows shut.

The next day, all the 50,000 residents of the town of Pripyat were evacuated being told they would be able to return home after three days, which they never were allowed to do.

The radioactive plume reached large parts of Europe. An exclusion zone was set as an area of 30 kilometers in radius around the site.

The International Atomic Energy Agency, IAEA asserted in 2006 that fewer than 50 people died from initial exposure to radiation from the reactor. At the scene of the accident, the radiation exposure is 700 times higher than the permissible levels, and the neighboring town of Pripyat remains uninhabitable primarily because of soil contamination with the Cs^{137} isotope.

6.23 NUCLEAR BOMBER CRASH, PALOMARES, ALBORAN SEA, SPAIN, JANUARY 17, 1966

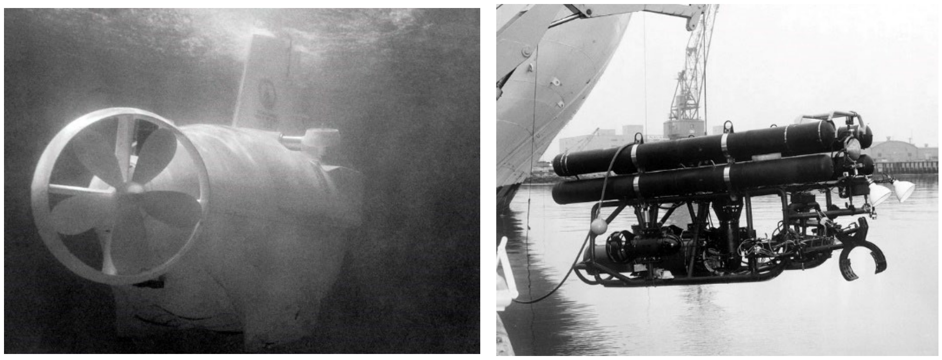


Figure 50. Barrels containing contaminated soil being shipped to the USA from Palomares, Spain. About 3.2 kgs of Pu were dispersed. Alvin submersible vehicle and robotic submarine were used in retrieval of sunken device.

There have been 32 so-called "broken arrow" accidents involving the loss of nuclear devices since 1950. These devices were dropped by mistake or jettisoned during an emergency, then later recovered. Airplanes armed with nuclear weapons were kept in the sky at all times from 1960 to 1968 under the Mutually Assured Destruction, MAD doctrine, in an operation known as Chrome Dome. Operation Chrome Dome was ended in 1968, and planes carrying nuclear devices no longer fly around on regular training exercises.

Three USA bombs have gone missing altogether in swamps, fields and oceans across the planet. One Mark 15 thermonuclear bomb by Tybee Island, Georgia on February 5 1958, was jettisoned to reduce the plane's weight for a safer landing. One B43 thermonuclear bomb in The Philippine Sea on December 5, 1965. A bomber plane, pilot and nuclear weapon slipped off the side of the aircraft carrier USS Ticonderoga 50 miles or 80 kms off the coast of Okinawa, Japan in 1965. An A4E Skyhawk was being rolled to a plane elevator, while loaded with a B-43 nuclear device. One B28FI thermonuclear bomb, second stage at Thule Air Base, Greenland on 22 May 1968. A cabin fire forced the crew to eject, leaving the plane to crash with its nuclear payload.

All these devices have inherent safety features preventing them from accidental explosion. The trigger primary capsule or "tip" made out of plutonium is added to the weapon at the last minute, when it was needed. A "one point safety" option of making sure nuclear devices would go off without being activated is implemented. The conventional explosives in a bomb might go off, but they would not detonate the fissile material because it is squeezed out in an uneven way and squirt out before it can be compressed.

On January 17, 1966, a USA B52 bomber and a refueling tanker plane collided over the Spanish coast near Almeria and the fishing village of Palomares on the Mediterranean sea. The bomber, on a routine patrol flight, was carrying four B28 1.1 Mt each thermonuclear devices. Three of them fell to the ground near the Andalusian village of Palomares and their contents of Pu and tritium were dispersed. The fourth 1.1 Mt of TNT equivalent device was retrieved from the bottom of the ocean on April 7, 1966 using submersible.

An eight-week clean-up operation was organized by the USA to remove several thousand tons of contaminated soil and ship them to the USA for storage. Half a kg of Pu is believed to remain unaccounted for.

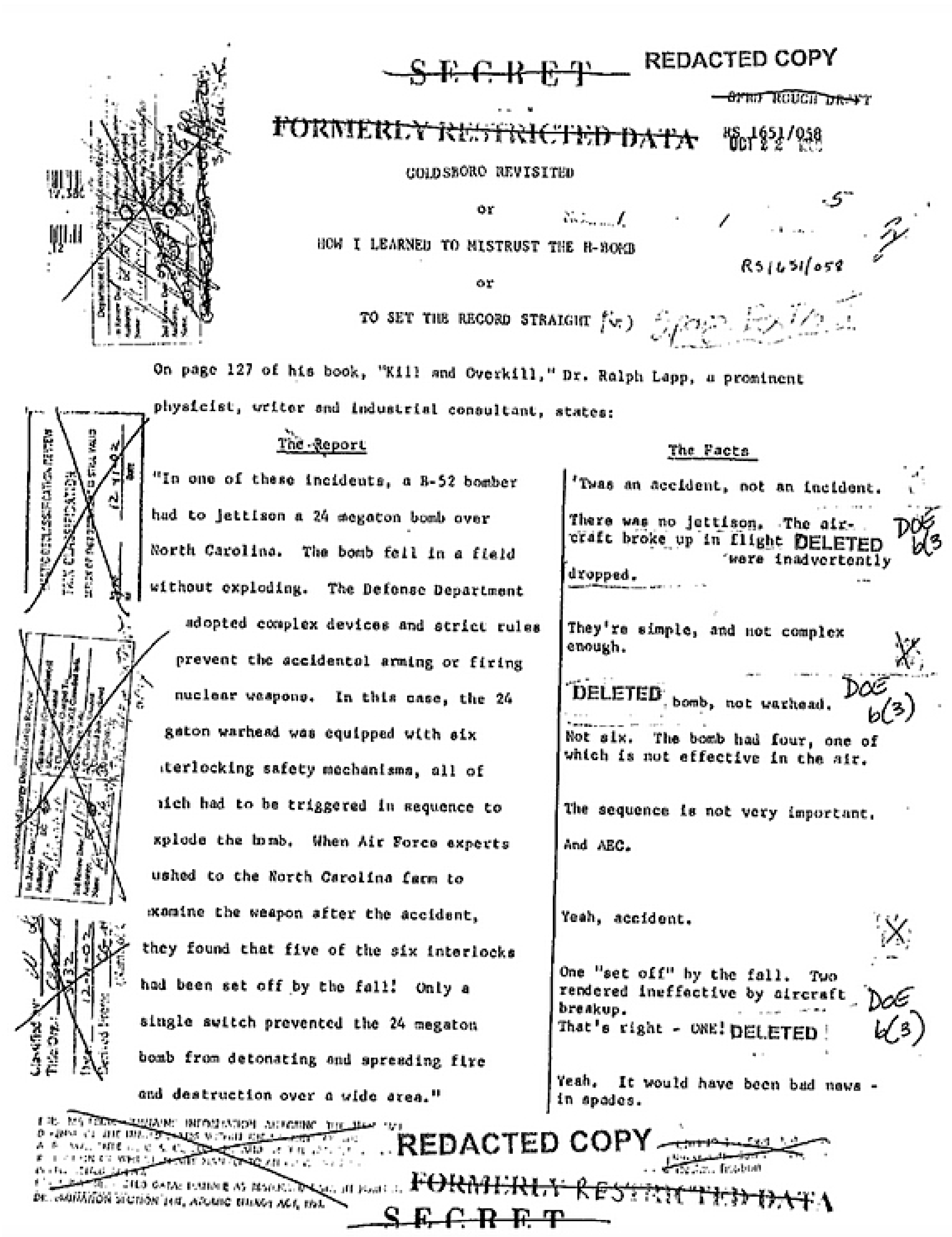
The Soviet Union, USSR amassed a stockpile of 45 thousand weapons as of 1986. Their accidents involved weaponry in nuclear submarines. On April 8, 1970, a fire started spreading through the air conditioning system of a Soviet K-8 nuclear submarine in the Bay of Biscay, a treacherous stretch of water in the northeast Atlantic Ocean off the coasts of Spain and France, notorious for its violent storms. Four nuclear torpedoes were onboard when it sank. In 1974, a Soviet K-129 submarine sank in the Pacific Ocean northwest of Hawaii, along with three nuclear missiles. The USA mounted a secret attempt to retrieve them in Project Azorian. In 1989, a Soviet nuclear submarine, the K-278 Komsomolets, sank in the Barents Sea off the coast of Norway. It was also nuclear-powered, and carrying two nuclear torpedoes. Its wreck is lying under one mile or 1.7 km of Arctic water.

6.24 GOLDSBORO, NORTH CAROLINA B52 BOMBER CRASH

Figure 51. Extraction of two Mk-39 Mod 2, 24 Mt thermonuclear devices from a B52 bomber crash at Eureka, North Carolina, on January 23, 1961.

In January 1961, a B-52G bomber aircraft broke apart in mid-flight crashed near Goldsboro, North Carolina. Later examination revealed that three out of four safeguards had failed. A fuel leak in the right wing occurred during aerial refueling from a fuel tanker. A crew of five ejected and landed safely. Another ejected but did not survive and two died in the crash. Two thermonuclear devices were inadvertently dropped before the crash and one landed with its parachute extended. According to Wikipedia: “Three of the four arming mechanisms on one of the bombs activated, causing it to execute many of the steps needed to arm itself, such as charging the firing capacitors and, critically, deployment of a 100-foot-diameter (30 m) retard parachute. The parachute allowed that bomb to hit the ground with little damage.” The parachute was caught in a tree.

According to Wikipedia: “Excavation of the second bomb was abandoned as a result of uncontrollable ground-water flooding. Most of the thermonuclear stage, containing U and Pu, was left in place, but the pit or core of the bomb had been dislodged and was removed. The United States Army Corps of Engineers purchased a 400 feet (120 m) circular easement over the buried component. The University of North Carolina at Chapel Hill determined the buried depth of the secondary component to be 180 feet (55m), plus or minus 10 feet (3.0 m).” Most parts were recovered, but one part containing uranium remains stuck under more than 50ft or 15m of mud. The USAF purchased the land around it to deter people from digging.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~~FORMERLY RESTRICTED DATA~~ RS 1651/058

GOLDSBORO REVISITED

or

HOW I LEARNED TO MISTRUST THE H-BOMB

or

TO SET THE RECORD STRAIGHT

R5 1651/058

On page 127 of his book, "Kill and Overkill," Dr. Ralph Lapp, a prominent physicist, writer and industrial consultant, states:

The Report	The Facts
"In one of these incidents, a B-52 bomber	'Twas an accident, not an incident.
had to jettison a 24 megaton bomb over North Carolina. The bomb fell in a field without exploding.	There was no jettison. The aircraft broke up in flight DELETED were inadvertently dropped.
The Defense Department adopted complex devices and strict rules prevent the accidental arming or firing nuclear weapons.	They're simple, and not complex enough.
In this case, the 24 megaton warhead	DELETED bomb, not warhead.
was equipped with six interlocking safety mechanisms, all of which had to be triggered in sequence to	Not six. The bomb had four, one of which is not effective in the air.
explode the bomb.	The sequence is not very important.
When Air Force experts	And AEC.
rushed to the North Carolina farm to examine the weapon after the accident,	Yeah, accident.
they found that five of the six interlocks had been set off by the fall!	One "set off" by the fall. Two rendered ineffective by aircraft breakup.
Only a single switch prevented the 24 megaton	That's right - ONE! DELETED
bomb from detonating and spreading fire and destruction over a wide area."	Yeah. It would have been bad news - in spades.

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Figure 52. Redacted copy of report about by Ralph Lapp's recount of the Goldsboro incident.

Apparently, there exists a policy of no nuclear devices are allowed to be flown over the contiguous USA.

6.25 TYBEE ISLAND, WASSAW SOUND, GEORGIA DEVICE

A 1.7 Mt thermonuclear device was jettisoned to reduce the plane's weight for a safer landing. near Tybee Island, Georgia in 1958. A Mark 15 Modification 0 was lost on the night of February 5, 1958, when a B-47 Stratojet bomber carrying the 7,600-pound, 3,400 kgs hydrogen bomb on a simulated combat mission off the coast of Georgia collided with an F-86 Saber jet fighter at 36,000 feet of altitude.

The collision destroyed the fighter and severely damaged a wing of the bomber, leaving one of its engines partially dislodged. The fighter pilot ejected to safety.

The bomber's pilot, Maj. Howard Richardson was instructed by the Homestead Air Force Base in Florida. to jettison the H-bomb before attempting a landing on an unfinished runway..

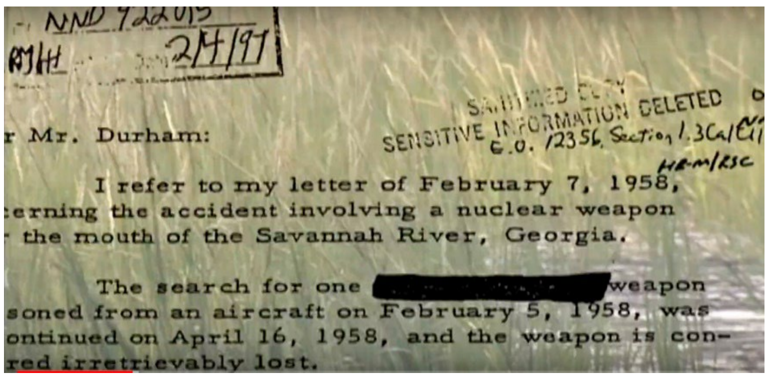
Richardson dropped the bomb into the shallow waters of Wassaw Sound, near the mouth of the Savannah River, where he believed the bomb would be swiftly recovered 2.5 miles offshore instead of the 20 miles mandated distance in such a situation. The crew did not see an explosion when the bomb struck the sea and they managed to land the B-47 safely at the nearest base.

For the following six weeks, the Air Force looked for the bomb without success. Underwater divers scoured the depths, troops tromped through nearby salt marshes, and a blimp hovered over the area attempting to spot a hole or crater in the beach or swamp. Researches were finally abandoned and the device is still lost.

Figure 53. Tybee Island, Georgia, USA.

Figure 54. B-54 stratojet strategic bomber.

Figure 55. Damaged wing of B-54.



NND 922015

SENSITIVE INFORMATION DELETED

E.O. 12356, Section 1.3(a)

r Mr. Durham:

I refer to my letter of February 7, 1958,
erning the accident involving a nuclear weapon
the mouth of the Savannah River, Georgia.

The search for one [redacted] weapon
soned from an aircraft on February 5, 1958, was
ontinued on April 16, 1958, and the weapon is con-
red irretrievably lost.

Figure 56. Report of accident on February 5, 1948.

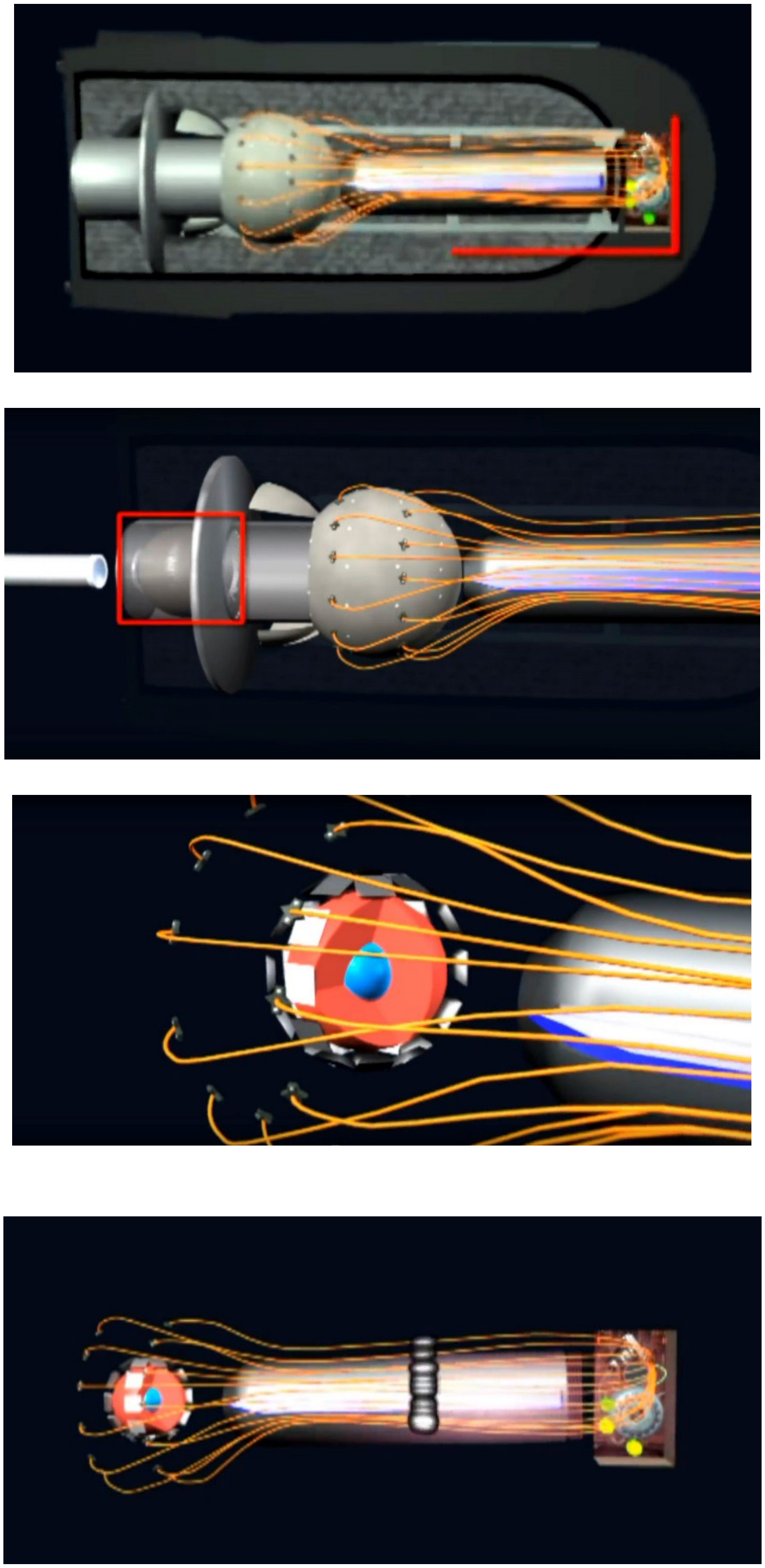
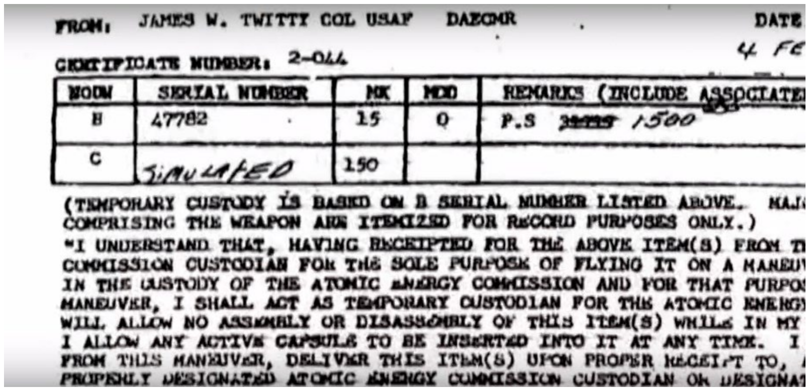


Figure 57. Primary of Mark 15 mod 0 device consisted of a Pu pit with a Be core and secondary used U^{235}. A accelerator neutron source initiated the reaction.



FROM: JAMES W. TWITTY COL USAF DAECMR DATE

4 FE

CERTIFICATE NUMBER: 2-044

NOUN	SERIAL NUMBER	MK	MOD	REMARKS (INCLUDE ASSOCIATE
B	47782	15	0	P.S 1500
C	SIMULATED	150		

(TEMPORARY CUSTODY IS BASED ON B SERIAL NUMBER LISTED ABOVE. MAJ
COMPRISING THE WEAPON ARE ITEMIZED FOR RECORD PURPOSES ONLY.)
"I UNDERSTAND THAT, HAVING RECEIPTED FOR THE ABOVE ITEM(S) FROM T
COMMISSION CUSTODIAN FOR THE SOLE PURPOSE OF FLYING IT ON A MANEU
IN THE CUSTODY OF THE ATOMIC ENERGY COMMISSION AND FOR THAT PURPO
MANEUVER, I SHALL ACT AS TEMPORARY CUSTODIAN FOR THE ATOMIC ENERG
WILL ALLOW NO ASSEMBLY OR DISASSEMBLY OF THIS ITEM(S) WHILE IN MY
I ALLOW ANY ACTIVE CAPSULE TO BE INSERTED INTO IT AT ANY TIME. I
FROM THIS MANEUVER, DELIVER THIS ITEM(S) UPON PROPER RECEIPT TO,
PROPERLY DESIGNATED ATOMIC ENERGY COMMISSION CUSTODIAN OR DESIGNAT

Figure 58. Mark 15 Mod 0 ammunition report.

On January 21, 1968, a plane crash over the Tule base in Greenland occurred. The American B-52G bomber, carrying four thermonuclear bombs on board, caught fire in the air and collapsed on the ice of the North Star Bay. The radioactive components were scattered over a large area, and then completely went under water. In 2008, the British corporation BBC published a series of articles based on declassified documents, according to which only three bombs were found, the fourth has not been found so far.

6.26 CONTAMINATED NUCLEAR TESTING SITES

Several nuclear testing sites remain contaminated in Kazakhstan, Nevada, USA, the Mururoa and Fangataufa atoll in the South Pacific, Rajasthan Desert, India and the Sahara Desert in Algeria from the above ground and underground before the test ban treaty. Over its history as a Russian nuclear test site, Novaya Zemlya hosted 224 nuclear detonations with a total explosive energy equivalent to 265 megatons of TNT. The USA Nevada Test Site history has 921 tests underground and 100 above ground open-air atmospheric detonations.

Figure 59. Soviet Union's nuclear test site at Semipalatinsk in Kazakhstan.

The Semipalatinsk site in Kazakhstan, now known as Semey, was the main nuclear test site of the former Soviet Union. About 506 nuclear tests were carried out during the Cold War.

The site has been closed with the USA contributing $600 million in the decontamination effort in 18,500 km^2 or 7,142 square miles. The USA invested $100 million in securing the special nuclear materials at the site and shipping them to the USA. The Kazakhstan government had hoped to return the site available for agricultural use.

Figure 60. Nuclear artillery shell fired at the Nevada test site, 1953.

The Nevada Test Site encompasses 1,350 square miles in the continental USA. Beginning in 1951, on the orders of President Harry Truman, and during the Cold War period, 105-119 nuclear weapons were exploded aboveground at the Nevada Proving Ground northwest of Las Vegas. After 1962, another 828 nuclear tests were exploded underground in tunnel chambers and deep, vertical shafts. The last nuclear weapons test on American soil occurred at the Nevada Test Site on September 23, 1992. The site was decommissioned in 1992.

French nuclear testing was initially conducted in the Sahara Desert in Algeria when it was one of its colonies, before it gained its independence in 1962. The first French nuclear device was named: "Gerboise Bleue, after a blue desert rodent. It was detonated on the morning of February 13, 1960 in the Reggane district of Algeria.

Its yield was 70 kT of TNT equivalent; a larger yield than the first nuclear tests of the UK, USSR and USA combined. Three more devices followed turning France into a nuclear club member.

Figure 61. Fenced-in French nuclear test site at the Reggane district in the Sahara Desert in Algeria. The three letters at the bottom are remaining from the word: “Danger.” The top word is “Khatar,” the Arabic word for “Danger.”

In 2010, the French paper: “Le Parisian” published secret documents from the French Defense Ministry revealing that 300 soldiers were purposefully exposed to radiation during the last test. The French government provided €10 million in compensation for those affected by the 210 nuclear bomb tests it has carried out.

Algerian groups complain that France never carried out a decontamination program and demand compensation.

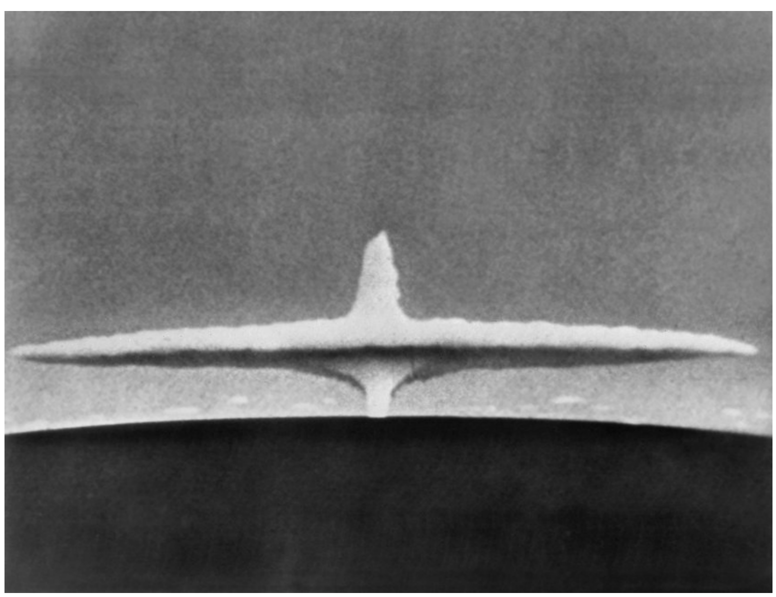


Figure 62. France atmospheric testing at the Muroroa and Fangataufa Atolls in the South Pacific in the 1960s.

France carried out nuclear testing in the 1960s at the Mururoa and Fangataufa atolls in the South Pacific. It conducted 41 atmospheric tests and 147 underground tests. The New Zealand government protested the testing and sent ships to the atoll in the 1970s in support of a nuclear free pacific region. The test site was abandoned in 1996, but remains under French control.

Figure 63. Indian nuclear test site in the Thar Desert in Rajasthan.

India joined the nuclear club on May 18, 1974. In the Thar Desert in Rajasthan, near the border with Pakistan.

India used the expertise acquired from a CANDU Canadian power reactor to build its own Pu production reactor. The first Indian nuclear device was called: "Smiling Buddha" and was detonated 107 meters underground.

In 1998 another five weapons tests were conducted at the same site. India has not signed the nuclear Non Proliferation Treaty, NPT but has pledged a non-first use nuclear posture.

6.27 URANIUM MINING

Uranium mining sites use settling and treatment ponds that would remain contaminated with the tailings and waste from the mining and milling operations. This also applies to rare earths elements which are associated with the presence of U and Th, gold and even shale oil mining sites.

Figure 64. Uranium mine settling ponds, Gera, Germany. (Photo: Gerhard Launer).

6.28 ENVIRONMENTAL REMEDIATION OPTIONS

A number of straightforward environmental remediation strategies at Bikini Island have been considered, which, if properly implemented, would achieve very satisfactory results from the point of view of radiation protection. It was therefore concluded that provided that certain remedial measures are taken, the Bikini Island could be permanently re-inhabited.

Several possible remediation strategies were considered with the result that the following were selected as a basis for further assessment:

1. The periodic application of potassium (K) based fertilizer to all areas of Bikini Island where edible crops may be grown, supported by the removal of soil from around and beneath the dwelling areas and its replacement by crushed coral. This is known as the *potassium fertilizer remediation strategy.*

2. The complete removal of the topsoil from Bikini Island, called the *soil scraping remediation strategy.*

While no definite recommendations were given on which strategy to follow, it was considered that the strategy using potassium fertilizer is the preferred approach. In this connection, it was noted that the soils of Bikini Atoll are extremely deficient in potassium and extensive field trials have demonstrated that the application of potassium rapidly reduces the concentration of Cs^{137} in food crops since potassium is taken up by the plants in preference to cesium. The reduction of Cs^{137} in the food crops is sustained for about four to five years, after which the values slowly begin to increase again. However, repeated application of fertilizer forms an effective strategy in reducing the estimated doses to the potential inhabitants of Bikini Island. Furthermore, the supporting strategy of removing soil from dwelling areas would eliminate most of the external and internal exposures from direct soil ingestion or inhalation.

The results expected from the potassium fertilizer remediation strategy are consistent with international guidance on interventions to avoid dose in chronic exposure situations and, therefore, this strategy would provide a radiologically safe environment permitting early resettlement.

6.29 RESULTING EFFECTIVE DOSES

Depending on assumptions made concerning diet, the annual calculated mean effective doses would be reduced from about 1.5 cSv or rem (if the dose due to natural background radiation were added, this would result in an annual effective dose of about 1.74 cSv or rem), for a high calorie diet of totally local foodstuffs, to about 0.04 cSv (rem) (if the dose due to natural background radiation were added, this would result in an annual effective dose of about 0.28 cSv or rem) for a diet of high calorie local and imported foods (Table 2).

Table 2. Mean per capita yearly effective dose based on different modes of food intake.

Diet Option	Mean annual per capita Effective Dose [cSv/(person.year)] [rem/(person.year)]	Mean annual per capita Effective Dose including background dose [rem/(person.year)]
High calorie diet of totally local foodstuffs.	1.500	1.740
High calorie diet of both local and imported food.	0.040	0.280

Even for the more conservative assumption of a high calorie diet of totally locally produced foodstuffs, the resulting doses will be far below acceptable generic action levels for intervention. The doses will be somewhat higher than those due to natural background radiation that were incurred by the inhabitants of Bikini Island before the evacuation and prior to when the nuclear weapon tests took place, and also somewhat higher than global average natural background doses, but lower than typical elevated levels of natural background doses around the world.

The alternative soil scraping remediation strategy which is the alternative preferred by the Bikinians would be very effective in avoiding doses caused by the residual radionuclides, but it could entail serious adverse environmental and social consequences.

The consequences may be serious because the fertile topsoil supports the tree crops, which are the major local food resource. The replacement of the soil with topsoil from elsewhere would be an enormous undertaking which is likely to be prohibitively expensive. The content of natural radionuclides in any continental soil used as replacement soil would most probably exceed that of the present soil.

No remedial actions should be proposed at this stage for the islands of Bikini Atoll other than the Bikini Island. The other islands have historically been nonresidential and used only for occasional visits and for fishing.

On the assumption that the proposed remediation strategy is undertaken, it was further recommended that regular measurements of activity in local foodstuffs should be made to assess the effectiveness of the measures taken. A simple, local whole body monitor and training in its use should be provided as a further means of enabling potential inhabitants to satisfy themselves that there is no significant uptake of Cs^{137} into their bodies.

6.30 ENVIRONMENTAL PROTECTION AGENCY (EPA) 0.015 cSv, rem STANDARD

Most of the scientific studies conducted on Bikini Atoll and throughout the Marshall Islands prior to the late 1990s, including the IAEA Study, considered that a safe level of radiation to be 0.100 cSv or rem above background levels of radiation.

This level of radiation is considered safe in many segments of the scientific community, the USA Environmental Protection Agency has adopted a more conservative standard of 0.015 cSv (rem) above background for cleanups under the Superfund Project.

When the people of the Marshall Islands gained knowledge about the EPA's 0.015 cSv (rem) standard, the 0.100 cSv (rem) standard, regardless of its scientific merits, became irrelevant.

If 0.015 cSv (rem) above background is the standard that the USA cleans up its former nuclear test sites with, then the Marshallese expect it to be the standard for radiological cleanups in the Marshall Islands. What makes this a conflict is that most of the scientists doing the data collection in the Marshall Islands, and most of the other regulatory agencies in the USA and the world, subscribe to the 0.100 cSv (rem) standard.

The islanders want unrestricted use of their islands, which they thought the 0.015 cSv (rem) standard ultimately provided while the 0.100 cSv (rem) standard does not.

Accordingly, the Nuclear Claims Tribunal, the body set up in 1985 under the Compact of Free Association with the USA to hear lawsuits resulting from damages arising from the USA nuclear testing, adopted the EPA's 0.015 cSv (rem) standard in determining cleanup costs for those atolls subjected to fallout from the nuclear testing.

6.31 THE COMPREHENSIVE ENVIRONMENTAL RESPONSE, COMPENSATION AND LIABILITY ACT (CERCLA), OR SUPERFUND

The EPA has developed a comprehensive set of standards and implementation protocols, under several environmental statutes, that are designed to protect members of the public from hazardous chemicals and radioactive materials in the environment. The statute most applicable to the issues of concern here is the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA), also referred to as “Superfund.”

The main objectives of Superfund are to assure cleanup of sites contaminated with hazardous material to acceptable levels and the return of the property to a condition suitable for unrestricted use. The statute is also concerned with ensuring that those individuals and organizations responsible for the contamination are held accountable for the costly cleanup of the sites.

Though the EPA makes use of average doses for some purposes, when establishing requirements for cleanup, it places primary reliance on the doses and risks associated with the reasonable maximum exposure of individuals. According to the EPA, the actions at Superfund sites should be based on an estimate of the Reasonable Maximum Exposure (RME) expected to occur under both current and future land use conditions.

The reasonable maximum exposure is defined here as the highest exposure that is reasonably expected to occur at a site. The intent of the RME is to estimate a conservative exposure case, well above the average, that is still within the range of possible exposures.

The EPA provided information about individual exposure and risk. Individual risk descriptors are intended to address questions dealing with risks borne by individuals within a population. These questions can consider:

1. Characterization of the people at the highest risk.
2. The risk levels are they are subjected to.
3. Their activities, where do they live, and other factors that might be placing them at higher risk.
4. The average risk for individuals in the population.

The high-end of the risk distribution is, conceptually, above the 90th percentile of the actual, either measured or estimated distribution. The conceptual range is not meant to precisely define the limits of this descriptor, but should be used by the assessor as a target range for characterizing "high-end risk."

Given the general EPA guidelines, it can be concluded that, although the dose assessment of 0.100 cSv (rem) is useful for characterizing the doses to an average member of the population, it does not fully address the high end doses and potential health risks, which the 0.015 cSv (rem) per capita per year addresses.

6.32 REMEDIATION ACTIONS

External exposure to gamma rays and the resumption of human activity, which could cause the radioactive nuclides in the surface soil to be re-suspended in the air and thus inhaled, were studied. It was concluded that ingestion of the radionuclides was the most significant exposure pathway, with external exposure to gamma radiation being the second significant factor.

The dose from ingestion of radionuclides contributed from 70 to 90 percent of the dose to the islands residents. This is mostly through the uptake of $Cesium^{137}$ from the foods grown on the island such as coconut, breadfruit, papayas, and pandanus.

Cesium lies under potassium in the periodic table of the elements, and hence possesses similar chemical properties. Plants absorb potassium from the soil, and if the soil is lacking in it, they end up absorbing Cs^{137} instead.

It was discovered that the uptake of Cs^{137} for plants grown in the Marshall Islands soils is different than in plants grown in European and North American soils. The uptake of Cs^{137} in continental soils is much lower than in the Marshall Islands soils. The soil uptake is measured in terms of the soil-to-plant transfer factor:

$$T_{soil-plant} = \frac{A'_{plant}}{A'_{soil}},$$

where: Specific activity $A' = \lambda N' = \lambda \frac{\gamma .1. A_v}{M} [\frac{Bq}{gm}]$,

Decay constant of isotope $\lambda = \frac{\ln 2}{T_{1/2}} = \frac{0.6931}{T_{1/2}} [\sec^{-1}]$,

Half life $T_{1/2}$ [sec], (1)

Avogadro's Number $A_v = 0.6 \times 10^{24} [\frac{nuclei}{mole}]$,

Molecular weight of radioactive isotope [*amu*],

Weight percent of isotope in soil or plant: γ [*percent*].

which is the ratio of the specific activity in Becquerels per 1 gm of dry weight of the plant to the specific activity in Becquerels per gm of dry weight of the soil.

The soil to plant transfer ratio for Cs^{137} for tropical fruit grown on the Bikini Island ranges between 2 to 40. For crops grown on continental soils this factor ranges between the much smaller values of 0.005 to 0.5.

The different compositions of the soils cause this difference. Island coral soils have little clay and possess low concentrations of potassium. Without clay for the Cs^{137} to bind to, and with plants starving for potassium, the plants uptake the Cs^{137} as a replacement for potassium.

This problem suggests its own solution. The simple approach is to remove the soil that is mostly contaminated with Cs^{137}. However this surface soil layer contains the nutrients needed for plants growth and controls the water retained in the soil. This approach would lead to severe environmental effects and would require a total revegetation of the islands.

The most promising approach to deal with the Cs^{137} contents in the soils has been to use as a remediation technique the application of large amounts of potassium fertilizer to food crops, and to remove soil on a limited scale in the housing and dwelling areas. It was observed that the added potassium fertilizer reduces the Cs^{137} uptake by nearly 90 percent. This in turn lowers the associated radiation ingestion dose to about 5-10 percent of the pretreatment level. The potassium fertilizer also adds to the productivity of the plants. A still unsolved problem is that the process works effectively over a four to five years period, and then decreases in effectiveness. A change in the ph acidity value could be affecting the solubility and uptake of different plant nutrients, and needs to be investigated.

6.33 SOIL DISPOSAL

A cleanup and rehabilitation program on the Enewetak atoll emphasized contamination by the heavy radionuclides such as the plutonium isotopes, and scraped off about 76,400 m^3 of surface soil from 6 islands. This contaminated soil was sealed off in a crater on the atoll' Runit Island. The nuclear detonation Cactus created a crater 30 feet deep and 350 feet wide at the northern tip of Runit Island in the Enewetak Atoll. It took a length of 3 years at a cost of 120 x 10^6 dollars. The "dome," as it is called, is constructed of 358 concrete panels of 18 inches thickness.

Figure 65. Concrete dome 18 inches in thickness entombs 111,000 cubic yards of contaminated soil and debris on Runit Island. As a prank by bored service-personnel, a red painted barrel on its top makes it visible as a nipple from aircraft flying overhead.

Figure 66. Twin craters created by the Cactus and Lacrosse tests on the Runit island. The left crater was used to isolate contaminated soil, now designated as the Nuclear Dome.

Two twin craters were created by the Cactus and Lacrosse tests. The larger crater is the site of the nuclear dome.

Soil disposal involves the removal surface soil to about 25 cms around the village areas, and replacing it with crushed coral. The result of this effort is that the per capita radiation dose from Cs^{137} in the service and village areas was reduced by a factor more than 20 times to less than 0.001 cSv (rem)/year. As a comparison, the average per capita radiation dose in the USA is 0.046 cSv (rem)/year from natural terrestrial gamma radiation.

For the returning islanders, it is hoped that the situation will improve with the passage of time, since rainfall transports Cs^{137} away from the root zone of plants into the groundwater.

6.34 OTHER REMEDIATION APPROACHES

Digging up contaminated soils and hauling it to landfills is neither economical nor totally environmentally friendly, since the disposal sites must continue to be monitored. Environmental biotechnology can offer a way of dealing with radionuclides contamination. One can use microorganisms to treat pollution through bioremediation, or use plants to treat it by phytoremediation.

Transgenic plants like grass can be assigned a genetic marker or biomarker that fluoresces under the effect of ultraviolet light with different colors depending on the heavy metal contaminant present. Having located the contaminated area, transgenic bacteria or plants can then be used to eliminate the contamination. At Oak Ridge National Laboratory (ORNL) in the USA, a green fluorescent jellyfish gene has been attached to a bacterial gene that detects the Trinitrotoluene (TNT) high explosive contamination, and could be used as a mine detection plant. Neal Stewart at the University of North Carolina placed the same fluorescent gene in what would be an explosive detection plant. Sunflower plants have been used at the Chernobyl accident site in the Ukraine to absorb the cesium soil contamination. Ferns have been found to soak arsenic contamination from soil and water and are suggested for the treatment of arsenic contaminated water supplies in the USA. Brazil nuts plants are known to concentrate significant amounts of thorium from the soil. Without going too far ahead, the same transgenic plants that could be used to detect contaminants could be bioengineered to clean them up as well.

Research at the Natural and Accelerated Bioremediation Research (NABIR) program administered by the USA's Environmental Protection Agency (EPA) primarily focuses on naturally occurring microorganisms for the transformation of metals and radionuclides. Anna Palmisano, the program manager suggests that transgenic microorganisms may not be needed because naturally occurring metal reducing organisms already exist at the contaminated sites. Non-native and bioengineered microbes could compete against native organisms. The public would also object to the use of non-native and bioengineered microbes. For these reasons using methods of biomolecular science and engineering the radiation resistant bacterium Deinococcus Radiodurans is being made to be resistant to mercury. Such basic research could find specialized applications to clean up depleted uranium or Cs^{137} contamination as well as nuclear wastes. The rapid reproduction rates of naturally occurring bacteria allow the possibility of using them as a starting point for a process of "guided evolution." This would involve manipulating their environment, buffers, bioreactor hardware, monitoring equipment and nutrients until an efficient bioremediation bacterium appears. The design of the bioreactors could for instance involve the use of an electrostatic charge to attract the bacteria to a matrix of fixed film surfaces.

6.35 DOSE MONITORING

Dose monitoring depends on whole body counting systems that ensure that the doses to the exposed individuals remain at below the acceptable safety standards. Whole body counting systems measure the gamma rays coming from radionuclides such as Co^{60}, K^{40} and Cs^{137}, deposited in the body and internal organs. The total amount of a radionuclide is converted into a dose estimate. In the Marshall Islands experience, the main pathway of exposure to residual fallout was through the ingestion of Cs^{137}. The exposure to the radioactive release in the vicinity of the Chernobyl accident should similarly be expected to be primarily from Cs^{137}, particularly in the vicinity of the damaged plant.

Another monitoring method is the sensitive measurement technique of plutonium urinalysis. It is also a technique and can be used to monitor uranium contamination wherever depleted munitions were used around populated areas. Urine is collected from a person over a 24 hours period and turned into a powder that is analyzed by counting the number of plutonium nuclei in a given sample. Every person in the world possesses a small amount of plutonium in their body, resulting from the atmospheric nuclear testing in the 1950s and 1960s.

Accelerator mass spectroscopy is a hundred times more sensitive than any other techniques used in USA occupational monitoring programs. Figure 68 shows an accelerator mass spectrometer. Accelerator Spectrometry is used in nuclear isotopic forensics, risk assessment, counter terrorism and dose reconstruction for nuclear workers. The mass spectroscopy technique is the only technique meeting the American National Standard Institute (ANSI) quality performance criteria in both precision and bias at all test levels.

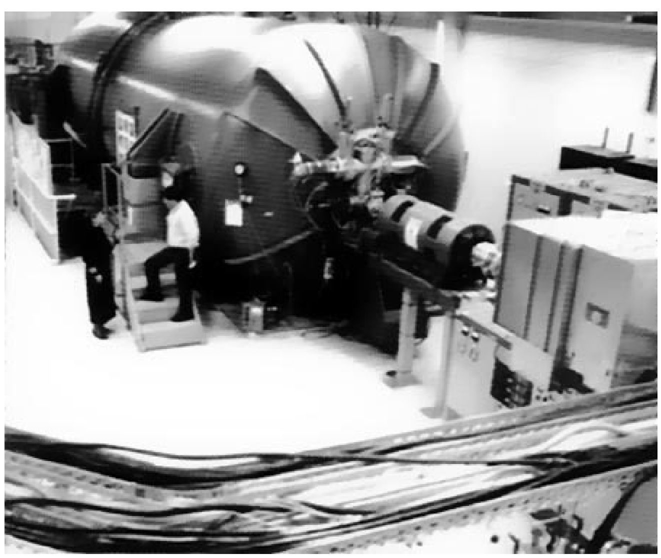


Figure 67. Accelerator Spectrometry is used in nuclear isotopic forensics, risk assessment, counter terrorism and dose reconstruction for nuclear workers.

6.36 OCEAN EVENTS

In addition to land contamination, a significant oceanic contamination occurred. Until 1992, the Soviet Union and Russia had been dumping radioactive waste, including some nuclear submarine reactors containing fuel at sea. This took place even though the Soviet Union USSR had ratified the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, unofficially known as the London Dumping Convention, in 1975.

In particular, the Soviet Union dumped thirteen nuclear submarine reactors, six of which contained spent or damaged nuclear fuel, in the Kara Sea. Waste dumped at sea by the Soviet Union includes some 17,000 containers of radioactive waste, 19 ships containing radioactive waste; 735 other pieces of radioactively contaminated heavy machinery, and the K-27 nuclear submarine with its two reactors loaded with nuclear fuel.

Seven USSR/RU nuclear submarines sank, one of them was scuttled, four were sunk, two were raised and decommissioned, with the USA having two that sank in the Atlantic Ocean, the USS Scorpion and the USS Tresher.

Russian design of submarines have an emergency capsule for the crew. Similar safety design is also present on Russian helicopters who have ejection seats for the crew. Reactor accidents that resulted in core damage and release of radioactivity from nuclear-powered submarines include:

K-8, 1960: suffered a loss-of-coolant accident; substantial radioactivity released.

K-14, 1961: the reactor compartment was replaced due to unspecified "breakdown of reactor protection systems".

K-19, 1961: suffered a loss-of-coolant accident resulting in 8 deaths and more than 30 other people being over-exposed to radiation. The events on board the submarine are dramatized by the film K-19: The Widowmaker.

K-11, 1965: both reactors were damaged during refueling while lifting the reactor vessel heads; reactor compartments scuttled off the east coast of Novaya Zemlya in the Kara Sea in 1966.

K-27, 1968: experienced reactor core damage to one of its liquid metal (lead-bismuth) cooled VT-1 reactors, resulting in 9 fatalities and 83 other injuries; scuttled in the Kara Sea in 1982.

K-140, 1968: the reactor was damaged following an uncontrolled, automatic increase in power during shipyard work.

K-429, 1970: an uncontrolled start-up of the ship's reactor led to a fire and the release of radioactivity.

K-116, 1970: suffered a loss-of-coolant accident in the port reactor; substantial radioactivity released.

K-64, 1972: the first Alfa-class liquid-metal cooled reactor failed; reactor compartment scrapped.

K-222, 1980: the Papa-class submarine had a reactor accident during maintenance in the shipyard while the ship's naval crew had left for lunch.

K-123, 1982: the Alfa-class submarine reactor core damaged by liquid-metal coolant leak; the sub was forced out of commission for eight years.

K-431, 1985: a reactor accident while refueling resulted in 10 fatalities and 49 other people suffered radiation injuries.
K-219, 1986: suffered an explosion and fire in a missile tube, eventually leading to a reactor accident; a 20-year-old enlisted seaman, Sergei Preminin, sacrificed his life to secure one of the onboard reactors. The submarine sank three days later.
K-192, 1989 (reclassified from K-131): suffered a loss-of-coolant accident due to a break in the starboard reactor loop.

6.37 DISCUSSION

The work on the Marshall Islands continues to characterize the radiological conditions and determination of the transport, uptake and cycling of the radionuclides throughout the ecosystem. The radiological risk and doses continue being estimated. The experience and techniques attained there will be helpful when eventually the remediation of other contaminated sites worldwide will be undertaken.

APPENDIX

USA AND RUSSIAN FISSION AND FISSION-FUSION TESTING OVERVIEW

Greenhouse George. Total yield: 225 kT of TNT equivalent.

This was detonated on May 9, 1951 at 09:30 local time atop a 200-ft tower on the Ebireru / Ruby Island at the Eniwetok Atoll.

Greenhouse George was a test of a pure fission device, and the highest yield weapon tested up to that time. It was a cylindrical implosion U^{235} device, reportedly based on a cylindrical geometry design suggested by physicist George Gamow that he calls" "Squeezing the cat's tail," and named 'George' after his first name.

An experiment called the Cylinder Device was added to George to test the possibility of the ignition of a thermonuclear reaction by a fission explosion. The cylindrical implosion design allowed the fusion fuel to be directly heated by a central fission pit without the shielding effects of a high explosive layer, and avoided the disruption by the expanding explosive lenses detonation gases.

A DT mixture external to the large fission pit core was ignited by the thermal flux, and produced detectable fusion neutrons. This was the first ignition of a thermonuclear reaction by a fission device.

Author Richard Rhodes, in his book, "Dark Sun," estimates the fusion energy yield as 25 kT of TNT equivalent out of a 225 kT of TNT equivalent total yield or just 25 / 225 = 0.11 or 11 percent. The mass of fusion fuel given of less than an ounce is suggested as a factor of 12 too small for this yield. Other sources characterize the fusion yield as "small."

This approach provided no prospect for development into a high yield thermonuclear weapon. This test provided useful data for evaluating the eventually adopted the Ulam-Teller configuration which had been devised two months earlier as a combination of George Gamow's 'Squeezing the cat's tail' idea, Stanislav Ulam's 'Spitting into a spittoon' idea, and Edward Teller's 'Naja fertility necklace' idea.

Greenhouse Item: Total yield: 45.5 kT of TNT equivalent.

Detonated on May 25, 1951 at 06:17 local time atop a 300-ft tower on the Engebi / Janet Island at Eniwetok Atoll.

First test of a fusion-boosted fission device. A deuterium-tritium mixture in the U^{235} core boosted the fission yield by 100 percent over its expected unboosted yield. This innovation was eventually incorporated into most or all strategic weapons, but the fusion yield was negligible and overall yield was still limited by the capabilities of fission designs.

Ivy Mike experimental device: Total yield: 10.4 mT of TNT equivalent.

Detonated on November 1st, 1952, at 07:14:59.4 +/- 0.2 sec local time at ground level on the Elugelab / Flora Island at the Enewetak atoll.

This was the first test of the Ulam-Teller configuration. The Mike device used liquid deuterium D_2, as the fusion fuel. It was a massive cryogenic laboratory experiment installed on the Elugelab Island in the Enewetak Atoll. It consisting of a cylinder about 20 feet or 243.625 inches or 6.19 m in height, 6 ft 8 in. width, and weighing 164,000 lb including the attached diagnostic instruments. It is reported to weigh 140,000 lb without the cryogenic unit which meant the casing itself. It was housed in an open hangar-like structure 88 ft x 46 ft, and 61 ft high, where assembly started in September of 1952.

The Mike device consisted of a massive steel cylinder with rounded ends, a TX-5 implosion device at one end acted as the primary, and a giant stainless steel dewar or thermos flask holding several hundred liters of liquid deuterium D_2 surrounded by a massive natural uranium pusher/tamper constituting the secondary fusion stage, referred to as the Sausage.

The welded steel casing was lined with a layer of lead. A layer of polyethylene several centimeters thick was attached to the lead with copper nails. This layer of plastic generated the plasma pressure during the implosion.

The Sausage consisted of a triple-walled stainless steel dewar. The inner-most wall contained the liquid D_2. Between this wall and the middle wall was a vacuum to provide heat insulation. Between the middle wall and the outer wall, was another vacuum, and a liquid nitrogen-cooled Cu thermal radiation shield.

To reduce the thermal radiation leakage further, the uranium pusher, which was oxidized to a purple-black color, making it an excellent thermal radiator, was lined with gold leaf.

Along the axis of the dewar, suspended in the liquid deuterium D_2 was a plutonium Pu rod that acted as the spark-plug to ignite the fusion reaction once the compression shock wave arrived at the center. It did not run the entire length of the dewar, but was supported at each end by axial columns. The spark plug was a boosted fission-fusion device, it was hollow and was charged with a few grams of DT gas, which liquefied once the dewar was charged with liquid deuterium.

The Mike device had a conservative design. The external casing was made of steel and was about a 10-12 in thick to maximize the confinement of the radiation-induced plasma pressure inside it. The interior diameter was about 60 inches. A very wide radiation channel was provided around the secondary stage to minimize the thermal gradients, and to make success less dependent on a sophisticated analysis. Due to the low density of liquid

D_2, and the necessity of thermal insulation, the secondary itself was quite voluminous which, when combined with the wide channel between the secondary and the casing led to the 80 inch diameter. The massive casing accounted for most of Mike's weight at about 85 percent.

The TX-5 device was an experimental version of the implosion system that was also deployed as the Mk-5 fission device. It used a 92 point ignition system with 92 detonators and explosive lenses to create a spherically imploding shock wave. This allows the formation of the implosion shock wave with a thinner layer of explosive than earlier designs.

The TX-5 was designed to use different fission pits to allow variable yields. The highest reported yield for a TX-5 test was Greenhouse Easy at 47 kT of TNT equivalent on April 20, 1951, with a 2,700 lb device. The smaller mass compared with earlier designs kept the temperature higher and allowed thermal radiation to escape more quickly from the primary, thus enhancing the radiation implosion process. If the Easy configuration were used in the Mike shot, then the secondary fusion-secondary / fission-primary yield ratio would be 50:1. The deployed Mk-5 had an external diameter of 43.75 in, the TX-5 would have been substantially smaller since it lacked the Mk-5 device casing.

Three fuels were considered for use in the Mike device: liquid deuterium D_2, liquid deuterated ammonia ND_3, and solid lithium deuteride LiD. The reason for choosing liquid deuterium for this first test was due to two factors: the physics was simpler to study and analyze, and extensive studies had already been conducted over the previous decade on the use of pure deuterium fuel.

The desirability of using lithium^6 deuteride Li^6D as a fuel was considered, but sufficient Li^6 could not be produced in time for the November 1952 target date since the construction of the first lithium enrichment plant had just begun at Oak ridge, Tennessee using the Column Exchange COLEX process creating a mercury amalgam with Li^6, at the time of the test.

Liquid deuterium produces energy through the fusion catalyzed DD reaction:

$$
\begin{aligned}
&{}_1D^2 + {}_1D^2 \rightarrow {}_0n^1 + {}_2He^3 + 3.268\,MeV\,(neutron\,branch)\\
&{}_1D^2 + {}_1D^2 \rightarrow {}_1H^1 + {}_1T^3 + 4.03\,MeV\,(proton\,branch)\\
&{}_1D^2 + {}_1T^3 \rightarrow {}_0n^1 + {}_2He^4 + 17.588\,MeV\\
&{}_1D^2 + {}_2He^3 \rightarrow {}_1H^1 + {}_2He^4 + 18.34\,MeV\\
\hline
&6\,{}_1D^2 \rightarrow 2\,{}_0n^1 + 2\,{}_1H^1 + 2\,{}_2He^4 + 43.226\,MeV
\end{aligned}
\tag{1}
$$

For the Mike device to function successfully, densities and temperatures in the fusion secondary sufficient to ignite the two DD reaction neutron and proton branches were needed. This required densities hundreds of times normal such as 75 gm/cm^3, and temperatures in the tens of millions of kelvins around 30×10^6 K.

Since the reaction cross section of the DT reaction is about 100 times higher than the combined value of the DD reactions, the tritium produced in the neutron branch is burned as fast as it is produced through the DT reaction, contributing most of the energy early in the reaction. The DHe^3 reaction, on the other hand, requires temperatures exceeding 200 x 10^6 K before its cross section becomes large enough to contribute significantly. Whether sufficient temperatures are reached and quantities of He^3 are produced to make it a major contributor depends on the combustion efficiency or the percentage of the fuel burned.

In the case of the semi-catalyzed DD reaction where He^3 is not burned:

$$
\begin{aligned}
&{}_1D^2 + {}_1D^2 \rightarrow {}_0n^1 + {}_2He^3 + 3.268\,MeV\,(neutron\,branch) \\
&{}_1D^2 + {}_1D^2 \rightarrow {}_1H^1 + {}_1T^3 + 4.03\,MeV\,(proton\,branch) \\
&{}_1D^2 + {}_1T^3 \rightarrow {}_0n^1 + {}_2He^4 + 17.588MeV \qquad (2) \\
\hline
&5\,{}_1D^2 \rightarrow 2\,{}_0n^1 + {}_1H^1 + {}_2He^4 + {}_2He^3 + 24.886\,MeV
\end{aligned}
$$

The semi-catalyzed DD reaction corresponds to the combustion of 25 percent of the deuterium fuel or less, with the energy output as 57 kT / kg of deuterium. If the DHe^3 reaction contributes to the maximum extent through the full catalyzed DD reaction, the yield would be 82.4 kT / kg of deuterium. The maximum temperature generated by an efficient burn reaches 350 x 10^6 million K.

Of the 10.4 mT of TNT equivalent total yield, the fission fraction for Mike was quite high at about 76 percent or 10.4 x 0.76 = 7.9 mT TNT of TNT equivalent. The total fusion yield was just 10.4 – 7.9 = 2.5 mT of TNT equivalent, which corresponds to the efficient thermonuclear combustion of 29.1 kg of deuterium or 172 liters, or the inefficient combustion of 41.6 kg or 249 liters.

The total fission yield of 7.9 mT of TNT equivalent resulted from the fission of 465 kg of uranium. All but some 50 kT of TNT equivalent of this 7.9 mT of TNT equivalent was due to fast fissions of the uranium secondary stage tamper by the DT fast 14.06 MeV fusion neutrons, a factor of 3.3 times energy amplification.

The amount of deuterium actually present in the Mike device was just about 1,000 liters, which is the amount of liquid deuterium handled by Operation Ivy. It was probably substantially less than 1,000 liters since excess liquid D_2 was brought along in case leakage or other losses occurred.

Prior to the test, the Mike's yield was estimated at 1-10 mT of TNT equivalent, with a most likely yield of 5 mT of TNT equivalent, but with a remote possibility of yields in the range of 50-90 mT of TNT equivalent.

The main uncertainties would have been the efficiency of the fusion burn, and the efficiency with which the tamper captured the fast DT neutrons. Both of these factors are strongly influenced by the success of the compression process. The fusion efficiency involved novel and complex physics which could not be calculated reliably even if the degree of compression was known. The physics for determining the efficiency of neutron capture on the other hand were well understood and could be calculated if the conditions could be predicted.

The upper limit estimate provides some insight into the mass of the uranium fusion tamper. The 90 mT of TNT equivalent figure was calculated by assuming complete fusion and fission of all materials in the secondary. If 1,000 liters of deuterium were burned with complete efficiency, the yield would be 13.9 mT of TNT equivalent. Fission must account for 76.1 mT of TNT equivalent, corresponding to a uranium tamper mass of 4,475 kg. Lower amounts of deuterium would lead to higher tamper estimates with a ratio of 0.82 kg of U for each liter of liquid D_2.

The detonation of Mike completely obliterated the Elugelab Island, leaving an underwater crater 6240-feet in width and 164 ft deep in the atoll where an island had once been. The Mike device created a fireball 3 miles in width; the mushroom cloud rose to 57,000 ft within 90 seconds, and topped out in 5 minutes at 135,000 ft at the top of the stratosphere with a stem eight miles across. The cloud eventually spread to 1,000 miles in width, with a stem 30 miles across. About 80 million tons of soil were sucked up into the atmosphere by the fireball.

TX-16 liquid D_2 / EC-16, (Emergency Capability) weaponized cancelled devices: 7 mT of TNT equivalent.

The Mike design was converted into a deliverable weapon. Solid lithium deuteride LiD was not essential initially for constructing a usable weapon. The weaponized design, designated as the TX-16, went into engineering development in June 1952, 5 months before the Ivy Mike test.

The TX-16 design eliminated the cryogenic refrigerator, reduced the weight of the tamper, drastically reduced the dimensions and mass of the casing, used a lighter and less powerful primary, and pared the weight in other areas. The expected yield was reduced to 7 mT of TNT equivalent. The device was about 60 inches in diameter, 25 ft long, and weighed 30,000 lb. This weapon design would have been filled with liquid deuterium at a cryogenic filling station before take-off, a reservoir in the weapon held sufficient liquid hydrogen to replace boil-off losses during flight. Components for about five of these weapons were built in late 1953, and had reached deployment by the time of the Castle tests.

A unit of the TX-16, code named Jughead, was slated for a proof test detonation on March 22, 1954 as part of the Castle series, prior to its expected deployment as the EC-16 for “Emergency Capability” gravity bomb in May 1954. The excellent results with the solid-fueled Shrimp device in the Castle Bravo test on March 1st, 1954 resulted in the cancellation of this test, and then of the entire EC-16 program on April 2nd, 1954.

Russian Joe 4 / RDS-6s Sloika, Layer-Cake design: Total yield: 400 kT of TNT equivalent.

Detonated on August 12, 1953, atop a tower at Semipalatinsk in Kazakhstan

This was the fifth Soviet test, and first Soviet test of a weapon with a substantial yield enhancement from fusion reactions. The American “Joe” designation refers to the Russian leader Joseph Stalin.

The RDS-6s device did not employ the Teller-Ulam configuration, instead it used the “Sloika,” or “Layer Cake” in Russian, design suggested by Andrei Sakharov and Vitalii Ginzburg. A Sloika is a layered Russian pastry, rather like the French layered Napoleon pastry, and has thus been translated as "Layer Cake". The design was first introduced in the USA by Edward Teller who called it "Alarm Clock," but it was not pursued in favor of the Ulam-Teller configuration.

This design is based on a combination of what Sakharov has called the "First and Second Ideas”. The First Idea, developed by Sakharov, calls for using a layer of fusion fuel, such as D and T in his original concept, around a fission primary, with an outermost layer of U^{238} acting as a fusion tamper. The U^{238} tamper confines the fusion fuel so that the radiation-driven shock wave from the fission core can efficiently compress and heat the fusion fuel to the ignition point, while the low conductivity of the fusion tamper prevents heat loss and at the same time yields additional energy from fast fission by the fast DT and DD fusion-generated neutrons. The “Second Idea,” contributed by Ginzburg used Li^6D with some tritium as the fusion fuel. Being a solid, LiD is a convenient material for designing a deliverable device, and it was thought that it also produces additional tritium from fission neutrons through the tritium breeding reaction:

$$ {}_3Li^6 + {}_0n^1(\text{thermal}) \rightarrow {}_2He^4(2.05\text{ MeV}) + {}_1T^3(2.73\text{ MeV}) + 4.78\text{ MeV} \qquad (3) $$

The use of Li^6 was later discovered to be unnecessary with equivalent performance achievable with natural Li without need for enrichment in Li^6. The same situation occurred in the USA Castle Bravo test. The Russian adoption of the USA initial approach of using Li^6D may have resulted either from a similar state of knowledge or from the acquisition of intelligence information from the USA, or vice versa.

The Sloika design is an energy amplifier of a fission - fusion - fission three amplification stages to the U^{238} Depleted Uranium (DU) tamper, with the fusion fuel acting in effect as a neutron energy amplifier. Larger devices can be conceptualized by placing additional successive layers of Li^6D and U around the device. The device tested in 1953 may have consisted of two layers.

A small U^{235} fission device acted as the trigger with a yield of about 40 kT of TNT equivalent. The total yield was 400 kT of TNT equivalent, and 15-20 percent of the energy was released by fusion, and 90 percent due directly or indirectly to the fission reactions.

A few weeks before the conduction of the test, it was realized that despite the sparse population of the area around Semipalatinsk, a serious fallout hazard still existed for tens of thousands of people. The options were to carry out a mass evacuation or delay the test until an air-dropped system could be arranged, which would take at least six months. Rather than delay the test, a hasty evacuation was conducted.

This was so because the Sloika Layer Cake design was not available as a usable weapon until after February 1954, a time at which the USA had actually deployed the EC-14 device, a megaton-range solid LiD fueled Ulam-Teller configuration in the Castle Union series of tests.

Castle Union, Bravo Test: Total yield: 14.8 mT of TNT-equivalent.

Detonated on March 1st, 1954, at 06:45 local time on the reef 2,950 ft off of the Nam / Charlie Island, Bikini Atoll.

The Shrimp device detonated in the Bravo test was the first test of the Ulam-Teller configuration fueled with LiD as a solid fuel. This became the standard design for all subsequent thermonuclear devices including the Russian designs. The Shrimp device was a cylinder 179.5 in long, and 53.9 in wide, weighing 23,500 lb. The Li in Shrimp was enriched to a level of 30-40 percent in Li^6. The predicted yield of this device was only 6 mT of TNT equivalent with a range of 4-6 mT of TNT equivalent.

An unexpected result from the contemporary lack of knowledge about the cross section of the Li^7 isotope in the fast neutrons energy region was the production of a large amount of tritium through the interaction of fast neutrons with Li^7:

$$_3\mathrm{Li}^7 + {_0}\mathrm{n}^1(\mathrm{fast}) \rightarrow {_2}\mathrm{He}^4 + {_0}\mathrm{n}^1 + {_1}\mathrm{T}^3 - 2.47\ MeV \qquad (4)$$

The produced tritium would immediately interact with deuterium through the exothermic DT reaction:

$$_1D^2 + {_1}T^3 \rightarrow {_0}n^1 + {_2}He^4 + 17.588 MeV \qquad (5)$$

with the produced fast neutrons available for further depleted uranium fission. The use of natural lithium instead of enriched lithium would have sufficed.

This boosted the yield to about 247 percent of the initially predicted value of about 6 mT of TNT equivalent to 6 x 2.47 = 14.8 mT of TNT equivalent, making it the largest device ever tested by the USA, destroying much of the measuring equipment at the observation sites and forcing the evacuation of the observation personnel by helicopter from their bunkers. The fission yield was 10.4 mT of TNT equivalent, the fusion yield was 14.8 -10.4 = 4.4 mT of TNT equivalent for a fusion/fission ratio of 4.4 /10.4 = 0.42 or 42 percent.

The explosion created a 6,000-ft wide crater, 240-ft deep in the atoll reef. The mushroom cloud top rose to 114,000 ft.

The Bravo test created the worst radiological exposure event in USA history. Due to failure to postpone the test following unfavorable changes in the weather, combined with the unexpectedly high yield, the Marshallese Islanders on Rongerik, Rongelap, Ailinginae, and Utirik atolls were blanketed with the fallout plume. They were evacuated on March 3, 1954, but 64 Marshallese received doses of 175 Roentgen (R).

The crew of the USA Navy "Curtiss" observation ship were confined to their quarters to avoid exposure to the widespread fallout. The Japanese fishing trawler Daigo Fukuryu Maru, or Fifth Lucky Dragon, was also heavily contaminated, with the 23 crewmen receiving exposures of 300 R. One crew member later died from complications.

The entire Bikini Atoll was contaminated to varying degrees, and many operation Castle personnel were subsequently over-exposed as a result. After this test the exclusion zone around the Castle tests was increased to 570,000 square miles, a circle 850 miles in diameter. This is equal to about 1 percent of the entire Earth's land area.

The two-stage Shrimp device design was used as the basis for the deliverable Mk-21 weapon device. The weaponization effort began on March 26, 1954, only three weeks after the Bravo test. By mid-April 1954, the military characteristics were defined. On July 1, 1954, an expedited schedule for deployment was approved.

The use of the final depleted uranium fast fission stage was eliminated. After a number of efforts to reduce the weight, the design was stabilized in mid-July 1955 with a projected yield of 4 mT of TNT equivalent, subsequently tested at 4.5 mT of TNT equivalent in the Redwing Navajo test with a fusion yield fraction of 95 percent on July 11, 1956. Quantity production began in December 1955 and ended in July 1956 with 275 units being produced. The Mk 21 warhead weighed about 15,000 lb; was 12.5 ft long, and 56 in. in diameter. During June-November 1957 it was converted to the Mk-36 design.

Castle Romeo Test: Total yield: 11 mT of TNT equivalent.

Detonated on March 27, 1954 on a barge in the Bikini Atoll lagoon near the Bravo test site at 06:30:00.4, local time.

The Runt I device, the second in the Castle series, was another solid-fueled LiD two stage design. This device was 224.9 in. long, 61.4 in. in diameter, and weighed 39,600 lb. The fuel for Runt was natural LiD, a major advantage considering the high cost of enrichment of Li into Li^6. It exceeded its predicted yield by an even larger margin than Bravo, with a most probable yield of 4 mT of TNT equivalent out of a 1.5-7 mT of TNT equivalent range. This is consistent with the higher proportion of Li^7, compared with Bravo. The fusion yield was 7 mT TNT, for a fusion fraction of 36 percent.

The Runt I and Runt II devices were design tests for the EC-17 and EC-24 devices respectively. These two weapons were very similar. They were externally identical, with similar internal configurations, but with different primaries. They were the most powerful weapons ever built by the USA, with predicted yields of 15-20 mT TNT, and were also the largest and heaviest devices ever deployed by the USA. The Mk 17/24 as the deployed versions were eventually designated was 24 ft. 8 in. long, with a 61.4 in. diameter, and a weight of 41,400-42,000 lb. About 30,000 lb of this was the 3.5 in. steel casing.

Although the initial work on these devices dates at least to February 1953, they went into development engineering in October 1953. The EC-17 and EC-24 devices became the second and third models of thermonuclear devices to enter the USA arsenal. From April to September in 1954, five EC-17 and ten EC-24 devices were stockpiled. These were removed in October 1954, modified for better safety features and with drogue parachutes for a slower air-drop fall, and returned to duty as the Mk 17 Mod 0 and the Mk 24 Mod 0 in November 1954. These devices went through two subsequent modifications, and stockpiles reached 200 Mk 17s and 105 Mk 24s during the October 1954 - November 1955 production phase. The Mk 24s were retired in September-October 1956; and the Mk 17s were retired between November 1956 and August 1957.

Castle Union Test: Total yield: 6.9 mT of TNT equivalent.

Detonated on March 26, 1954 at 06:10:00.7 local time on barge in the Bikini Atoll lagoon off the Yurochi Island.

This was the fourth test in the Bravo series of tests. The third test, Koon, failed when the fusion stage did not ignite. This was the test of the EC-14 Alarm Clock device, which was unrelated to Edward Teller's earlier Alarm Clock concept, which was the first hydrogen device to enter the USA arsenal and the first Teller-Ulam device ever to be deployed.

This was a solid fueled two stage device using 95 percent enriched Li^6. It also exceeded expectations. The predicted yield was 3-4 mT of TNT equivalent with a range of 1-6 mT of TNT equivalent. The fission yield was 5 mT of TNT equivalent for a fusion fission fraction of 28 percent. The tested device had a length of 151 in., a diameter of 61.4 in, and weighed 27,700 lb.

The TX-14 Alarm Clock design went into development engineering in August 1952, and procurement was approved in mid-September, 6 weeks before the Mike device had even been tested. The first EC-14 weapons were produced in Feb. 1954, two months prior to testing the design. The design was simple but had very poor safety features. A total of 5 were deployed, this low figure can probably be attributed to the scarcity of Li^6 at the time. Safety could presumably have been improved through retrofitting, but the high cost of these weapons probably led to their rapid retirement. It was also later discovered that there was no need to use Li^6 which can be substituted for with natural Li.

These designs were removed from the USA arsenal in October 1954 with the deployment of the EC-17. The Mk 14, its final deployed designation, had a diameter of 61.4 in., a length of 18 ft. 6 in., and weighed 28,954 lbs. After refitting with a drogue parachute its weight increased to 29,851 lbs.

Castle Yankee: Total yield: 13.5 mT of TNT equivalent.

Detonated on May 5 1954, at 06:10:00.1 local time on a barge in the Bikini Atoll lagoon, above the Union crater.

The Runt II device was very similar to Runt I, mostly differing in the design of the primaries. The fuel for Runt II was natural LiD without Li^6 enrichment. It also exceeded its predicted yield, with a most probable yield of 8 mT of TNT equivalent out of a 6-10 mT of TNT equivalent range. This device was 225 in. long, 61 in. in diameter, and weighed 39,600 lb. The fission yield was 7 mT TNT for a fission/fusion fraction of 48 percent.

Russian Test No. 19: Total yield: 1.6 mT TNT.

Detonated on November 22, 1955. This was the first Soviet test of an Ulam-Teller configuration and Sakharov Third Idea weapon. It used radiation implosion to detonate a solid LiD-fueled capsule. This was the world's first air-dropped thermonuclear device test. After this test the Soviet Union used radiation implosion devices as the basis for their strategic arsenal. Exploded underneath an inversion layer, the refracted shock caused unexpected collateral damage, killing three people.

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