Chapter 6

ENVIRONMENTAL REMEDIATION OF RADIOACTIVE CONTAMINATION

11/25/2010

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 Islands of Hawaii.

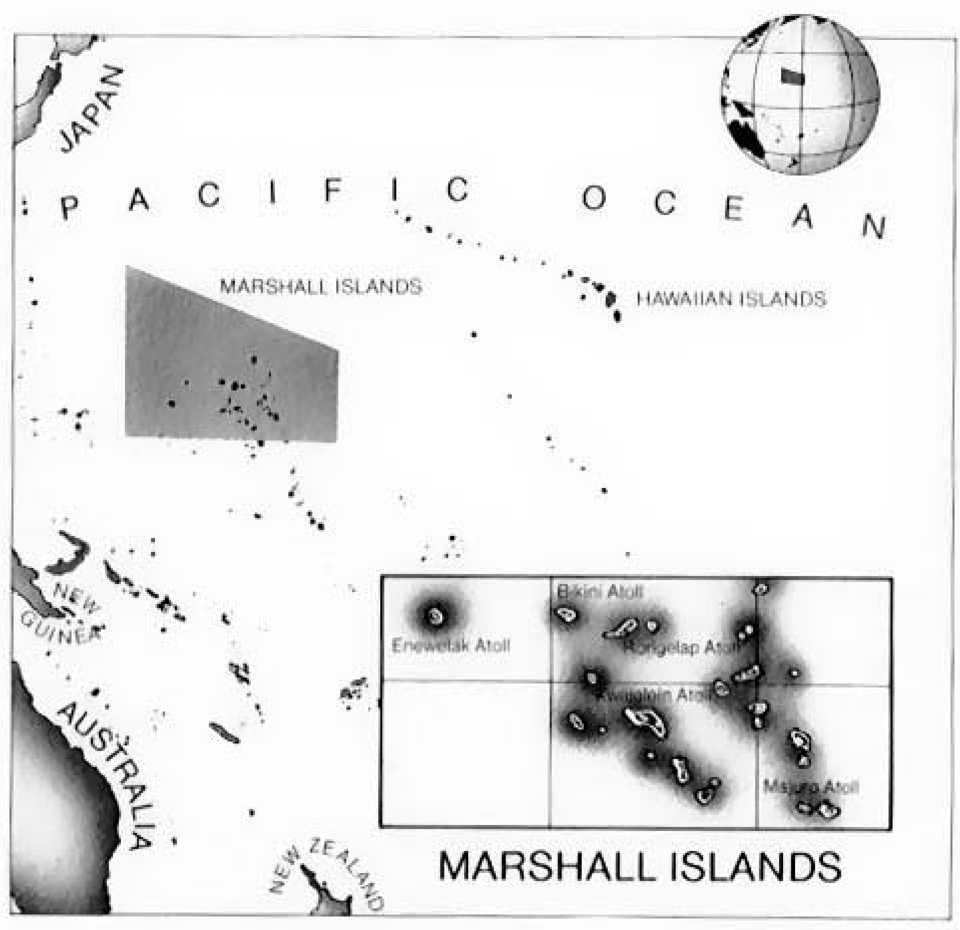

Figure 1. Location of the Marshall Islands in the Pacific Ocean.

The Republic of the Marshall Islands consists of 34 atolls covering an area of about 1.3 x 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 as shown in Fig. 1. 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.

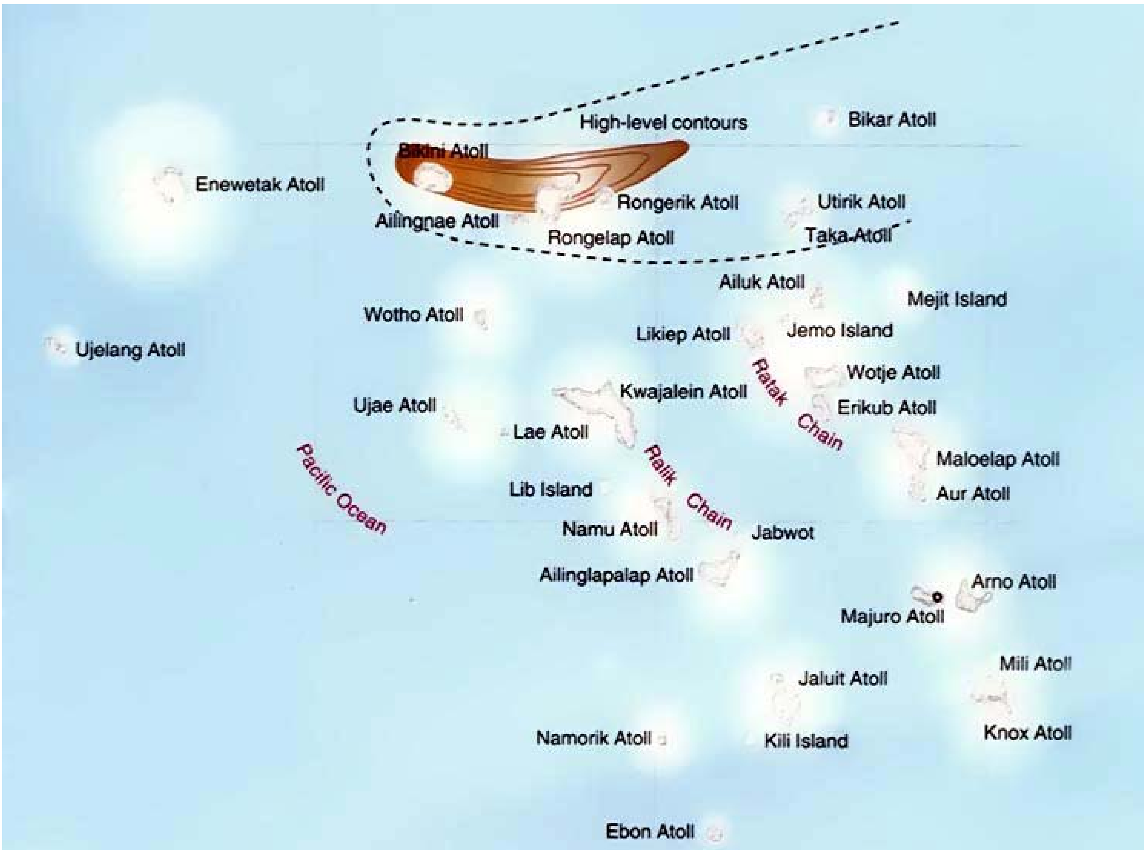

Figure 2. Fallout dose contours originating from the Bikini Atoll in the Marshall Islands from the Castle-Bravo test on March 1st, 1954.

Inspired by the news-making nuclear testing at the Bikini Atoll in the same week; on July 5, 1946, the French fashion designer Louis Reard unveiled a daring two-piece 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 and the use of depleted uranium munitions in Kosovo, Bosnia, Kuwait, Saudi Arabia, Iraq and Afghanistan, and those circumstances 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 about 7,200 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.

The seven-kilometer "Shrimp" shot in operation Castle-Bravo, detonated at the Bikini Atoll on March 1, 1954, was a 15 megatons thermonuclear device releasing 1,000 times the energy of the Hiroshima device. The destructive power unleashed by the explosion was more than twice as high as the experts had predicted and dug a crater two kilometers in diameter into the island. A mushroom cloud rose 40 kilometers into the sky.

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

6.3 THE MARSHALL ISLANDS

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

Most Bikinians reside on Kili, a single island, not an atoll, with no sheltered lagoon and 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. 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 United States 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 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 warming 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 atolls.

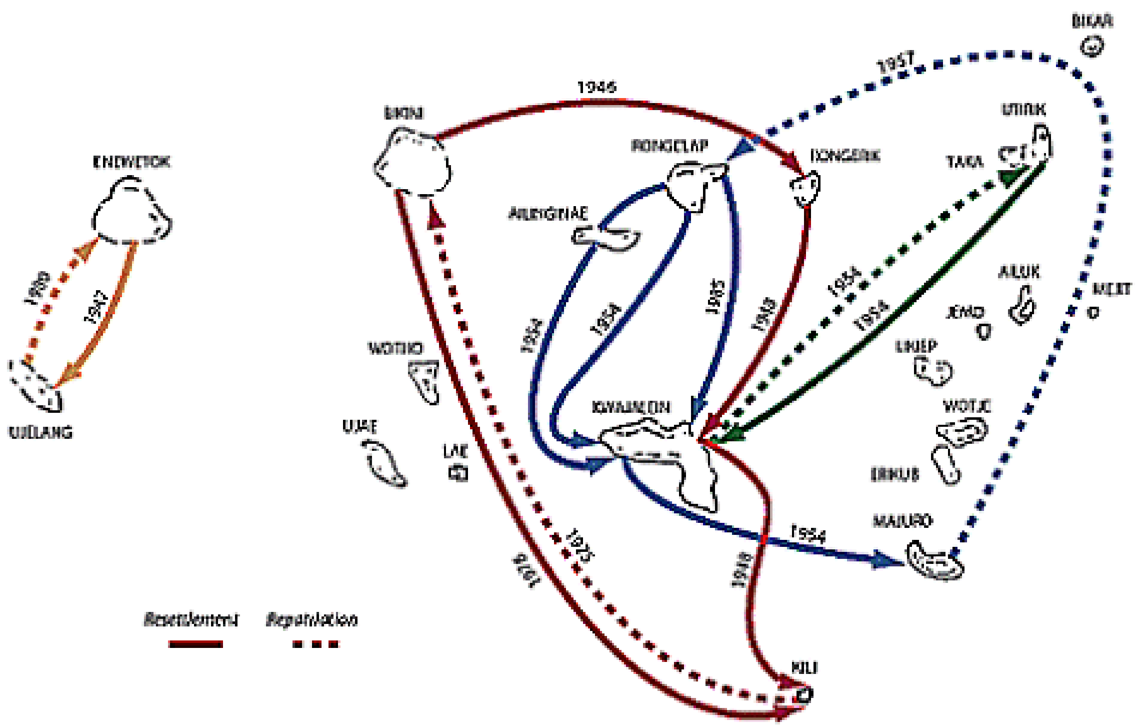

Figure 3. Relocation and resettlement paths of the Marshall Islands population.

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 craft and were relocated to the Rongelik Island, 140 miles east of Bikini.

6.5 OPERATION CROSSROADS, 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 naval fleet if a nuclear blast is directed at it. Of the naval ships, 73 were placed near ground zero as targets.

On June 30, 1946 at 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 bomb ever used, 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 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. 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 (Fig. 4).

In July, Operation Crossroads was launched with the Able (Fig. 5) and Baker (Fig. 6) nuclear tests at the Bikini Atoll. Both tests used Hiroshima size fission devices. Baker, an underwater test, targeted a fleet of decommissioned World War II ships positioned in Bikini's lagoon (Fig. 7).

Figure 4. Admiral and Mrs. Langley inaugurating operation Crossroads cutting an atomic cake and wearing an atomic hat.

Figure 5. Able underwater test, July 1^{st}, 1946, operation Crossroads.

Figure 6. 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 did not materialize.

Figure 7. Damage to USS Skate, Able test, operation Crossroads, July 1st, 1946.

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 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 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 as a thermonuclear fuel. The Mike test vaporized an island and its yield was estimated at 10.4 Mt, or 693 times the yield of the Hiroshima device (Figs. 8, 9).

Figure 8. Ivy Mike test fireball, October 31, 1952.

Figure 9. 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 island of Manhattan.

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 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 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, Li^6D powder as a fusion fuel.

On February 28, 1954 at 6 pm on the eve of the Bravo test (Fig. 10), 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 10. 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, it was 1,000 times the yield of the Hiroshima device.

Within hours a gritty, white fallout ash 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 11. Military personnel being familiarized with nuclear explosions at a nuclear test wearing ultraviolet protection goggles and facing the explosion.

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 emission of 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 (Figs. 11-13).

Figure 12. Rongelap resident exposed to beta particles from fallout ash.

Figure 13. 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 exposure of human beings to exposure, the USAEC 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 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 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 Roentgens. Balancing the effort required to move the 400 inhabitants against the fact that such a dose 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 inhospitable.

In July 1957 Rongelap was declared safe for rehabilitation in spite of slight lingering radiation. The Rongelap people, who have been living temporarily in Ejit Island, Majuro, returned to Rongelap. Brookhaven National Laboratory, Upton, New York, scientists report 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 was 15 Mt of TNT equivalent and exceeded the expected yield and it was feared that it could ignite the Earth's atmosphere turning it into a star. It led instead to unanticipated radioactive fallout over the inhabited islands of the Rongelap and Utirik atolls and areas to the east of the Bikini Atoll. The high level contours of the fallout pattern are shown in Fig. 2.

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 and collected it in rain barrels.

A famous news event of the period is about the Japanese fishing trawler, *Fukuryu Maru*, or 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.

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, and is shown in Fig. 14. The Seminole detonation, a surface burst was part of operation redwing and was exploded on Enewetak Atoll on June 6, 1956, and is shown in Fig. 15. The 11 megaton of TNT equivalent Romeo shot was fired from a barge near the Bikini Atoll on March 26, 1954, and was part of operation Castle, as shown in Fig.16.

Figure 14. The Ivy Mike, an experimental thermonuclear device test was conducted in the Enewetak atoll on October 31, 1952.

Figure 15. The Seminole test was a surface explosion on June 6, 1956, on the Enewetak atoll as part of operation Redwing.

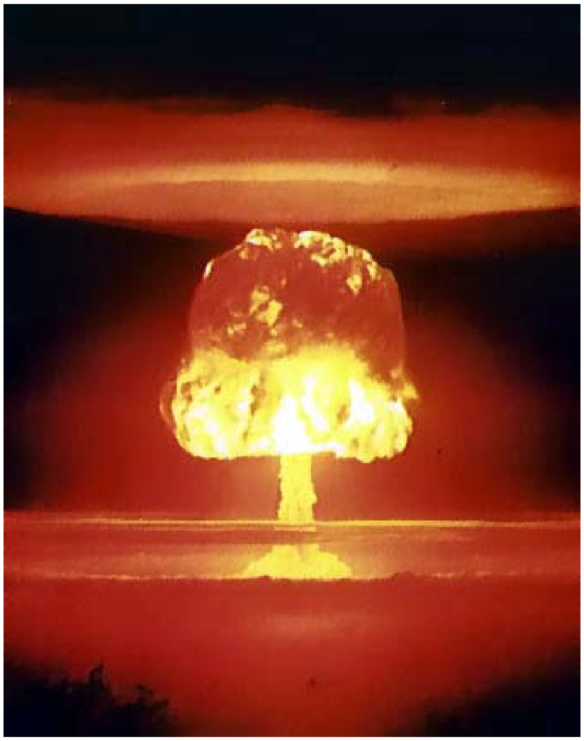

Figure 16. The Romeo test released 11 Megatons of TNT equivalent as part of operation Castle. It was fired from a barge near the Bikini Atoll on March 26, 1954.

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 nodes or tumors 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 rehabitation 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 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 move back to Bikini into newly built homes.

A 1973 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. Cesium (Cs) is in the same column of the periodic table of the elements as potassium (K) and hence mimics it chemically. 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 rads 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 low level 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 cap of cement.

In June 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 tumors to $100,000 for the families of those who have died.

In May 1978, the USA Interior Department officials describe a discovered 75 percent increase in intake of Cs^{137} found in the bodies of Bikini people as incredible. Plans are 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 and Utrik, 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 law suit 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 life 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 dose 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 dangerous 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 this 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.

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 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."

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 15 mSv. If the dose due to natural background radiation were added, this would result in an annual effective dose of about 17.4 mSv. 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

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, 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 (Fig. 17). 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 manmade 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. Lt. William Smith of HMS Cornwallis named the larger island for his ship's captain, Charles J. Johnston, after sighting it briefly on Decernber 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 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 strategic weapons than nuclear or chemical weapons. A chemical weapon is a poison that kills upon contact with the skin. Bioweapons are microscopic microorganisms, bacteria or viruses, that invade the body, multiply inside it and destroy it. 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 Tularemia in the ground. Rodents in the surrounding woods were chronically infected with the Schu-4 military strain of Tularemia, a bacteria that causes a form of pneumonia. It was obtained through intelligence sources from the USA by the Soviets. 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.

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 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 in 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 elites, health care providers, emergency responders and the police and military forces for survival.

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 and China have significant bioweapons programs.

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 system 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 biowarheads 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 become 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 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.

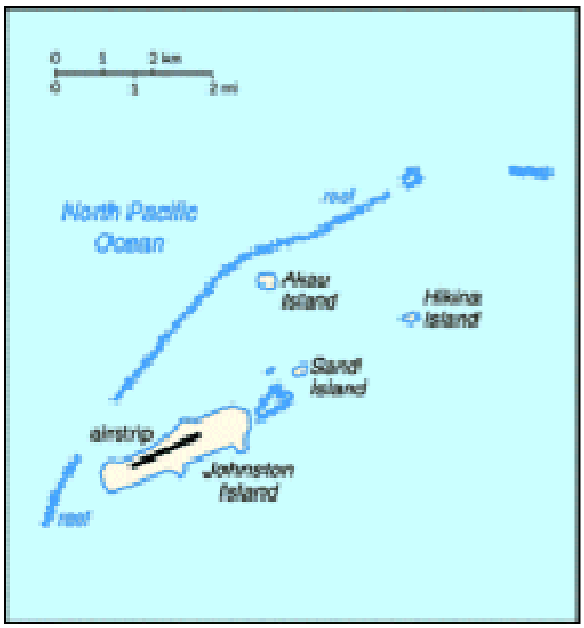

Figure 17. Jonhston Atoll, and Sand, Akau and Hikina islands.

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 (Fig. 18).

Beginning in 1964 a series of large open-air biological weapon tests was conducted downwind of Johnston Atoll. The American strategic bioweapon 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 18. Jonhston Island 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. 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 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 turned 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 Powell as a demonstration at his speech on February 5, 2003 at the United Nations as he was making a case for the invasion of Iraq. The ground dry frozen harvested sickened embryos may be the basis of some "Freeze dried embryo dispersion" method.

Figure 19. Secretary of State Colin Powell 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.

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. Anthrax has a long half-life, Tularemia has only a few minutes half-life in sunlight, necessitating its release at night.

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

NUCLEAR TESTING

The Air Force retained operational control of 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.

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, 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 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 was scheduled to end in 2004.

CONVERSION INTO A 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. 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 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 proposed cleanup level for Rocky Flats, which is near Denver CO, will be 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, 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 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. As a twist on the “Spear Points to Plow Point” saying, which could be modified in this case to say “from Chemical Munitions to Driving a Chemical Projectile” this scrap metal has been sold to Japan to be melted down and reformed to in all probability become automobiles to be most probability exported back to the USA.

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 a 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 wasthe 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.

6.20 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, Bikini Island could be permanently reinhabited.

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.

6.21 RESULTING EFFECTIVE DOSES

Depending on assumptions made concerning diet, the annual calculated mean effective doses would be reduced from about 15 mSv (if the dose due to natural background radiation were added, this would result in an annual effective dose of about 17.4 mSv), for a high calorie diet of totally local foodstuffs, to about 0.4 mSv (if the dose due to natural background radiation were added, this would result in an annual effective dose of about 2.8 mSv) 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 [mSv/(person.year)]	Mean annual per capita Effective Dose including background dose [mSv/(person.year)]
High calorie diet of totally local foodstuffs.	15	17.4
High calorie diet of both local and imported food.	0.4	2.8

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.

6.22 ENVIRONMENTAL PROTECTION AGENCY (EPA) 15 MREM 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 100 mrem 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 15 millirems above background for cleanups under the Superfund Project.

When the people of the Marshall Islands gained knowledge about the EPA's 15 mrem standard, the 100 mrem standard, regardless of its scientific merits, became irrelevant.

If 15 mrem 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 100 mrem standard. The islanders want unrestricted use of their islands, which they thought the 15 mrem standard ultimately provided while the 100 mrem 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 15 mrem standard in determining cleanup costs for those atolls subjected to fallout from the nuclear testing.

6.23 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 100 mrem 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 15 mrem per capita per year addresses.

6.24 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 resuspended 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:

$$T_{soil-plant} = \frac{(\lambda N)_{plant}}{(\lambda N)_{soil}}, \qquad (1)$$
$$\lambda = \frac{\ln 2}{T_{1/2}}$$

which is the ratio in Becquerels of the activity per kilogram of dry weight of the plant to the activity in Becquerels per kilogram 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.

6.25 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 as shown in Fig. 20. 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 120×10^6 dollars. The "dome," as it is called, is constructed of 358 concrete panels of 18 inches thickness.

Figure 20. Concrete dome 18 inches in thickness entombs 111,000 cubic yards of contaminated soil and debris on Runit Island. As a prank, a red painted barrel on its top makes it visible as a nipple from aircraft flying overhead.

Figure 21. 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.

The twin craters created by the Cactus and Lacrosse tests are shown in Fig. 21. The larger crater is the site of the nuclear dome shown in Fig. 20.

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 1 mrem/year. As a comparison, the average per capita radiation dose in the USA is 46 mrem/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.

6.26 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 being 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 in 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.

6.27 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 nuclear testing in the fifties and sixties.

Accelerator mass spectroscopy is a hundred times more sensitive than any other techniques used in USA occupational monitoring programs. Figure 22 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.

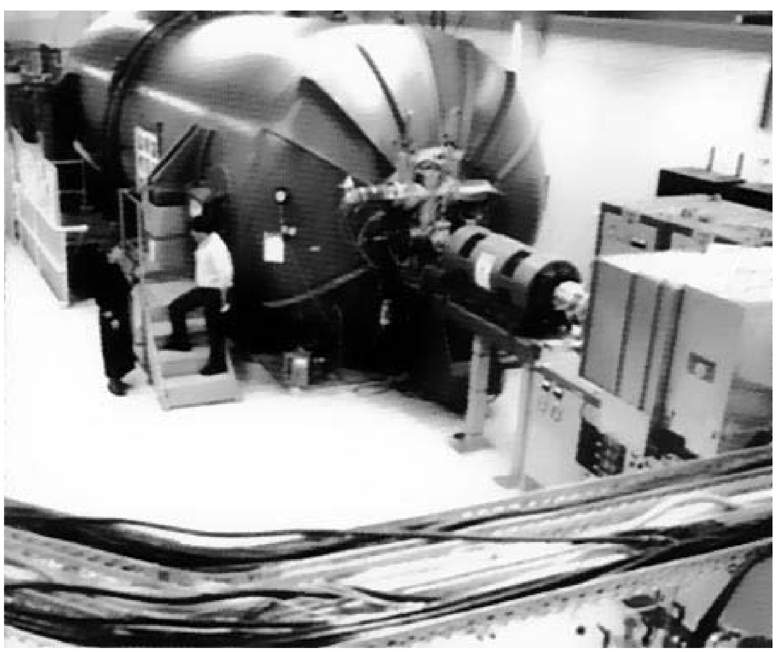

Figure 22. Accelerator Spectrometry is used in nuclear isotopic forensics, risk assessment, counter terrorism and dose reconstruction for nuclear workers.

6.28 CONCLUSIONS

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.

REFERENCES

1. Ann Parker, “Island Paradise Regained,” Science and Technology Review, p.10, February, 2003.
2. Peter Goin, “Nuclear Landscapes,” The Johns Hopkins University Press, Baltimore and London, 1991.
3. Glenn Alcalay, “Marshall Islands Field Report: Cultural Impact of the U.S. Atomic Testing Program,” Anthropology Dept., Livingston College, Rutgers University, New Brunswick, N.J. 08903, April 7, 1981.
4. Robert Conard, M.D., “A Twenty Year Review of Medical Findings in a Marshallese Population Accidentally Exposed to Radioactive Fallout,” Upton, NY: Brookhaven National Laboratory, 1975.
5. Brown M. Dobyns, M.D. Ph.D., “A Study of the Physiological Function and Histological Changes in Thyroid Irradiated with Radioactive Iodine. Prepared for the Department of Energy,” Cleveland, Ohio: Case Western Reserve University, September 30, 1981.
6. Neal O. Hines, “Proving Ground: An Account of the Radiobiological Studies in the Pacific, 1946-1961,” Seattle: University of Washington Press, 1962.
7. Lawrence Livermore Laboratory, “Dose Assessment at Bikini Atoll,” UCRL-51879, Pt. 5, prepared for the Department of Energy, June 8, 1977.