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The Devastating Consequences of Nuclear Testing

Effects of Nuclear Weapons Testing on Health and the Environment

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A Report by
International Campaign
to Abolish Nuclear Weapons
and IPPNW Germany

It is time to finally bring justice to
the survivors of nuclear weapons testing
and end the madness that endangers
humanity's survival and the future
of our living planet.

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Introduction: The devastating consequences of nuclear testing

Effects of nuclear weapons testing on health and the environment

Dear Reader,

In July 1946, less than a year after the atomic bombs were dropped on Hiroshima and Nagasaki, and knowing their catastrophic consequences, the first nuclear weapons tests were conducted on Bikini Atoll in the Marshall Islands. The inhabitants of Bikini were told before their relocation that the tests would bring eternal peace to mankind. But for them, it meant the loss of their home, disease and death. Since then, the world has lived through an era of nuclear arms races and the constant threat of doom.

The reviews that follow here by Arjun Makhijani and Tilman Ruff of the effects of nuclear weapons testing in the major nuclear weapons testing areas give readers a sense of the scale of the catastrophe. It is staggering, although the full extent of the damage has been poorly researched and much relevant data continues to be kept secret.

In the Pacific, tests took place in French Polynesia and Kiribati, in addition to the Marshall Islands. Nuclear weapons have also been tested in other regions of the world, mostly in colonies, former colonies, or in the territories of ethnic minorities.

Atmospheric tests have also been conducted in Semipalatinsk, Kazakhstan; on traditional Western Shoshone land in Nevada, USA, in Aboriginal lands in the Australian outback, on indigenous Nenetz' land in the Russian Arctic, in desert communities in Algeria, in the Uighur region of China, and elsewhere. Residents were often evacuated late or not at all, and were not informed of the effects of the tests.

Radioactive fallout was carried in dust and rain, contaminating drinking water and locally produced food with radioactive elements. As a result, local people were not only externally exposed to increased radiation; internal exposure also occurred. Many became ill and died from cancer and other radiation-related illnesses, and, in some cases, even from acute radiation sickness. Women and girls are most affected due to their higher sensitivity to radiation. According to data from the International Agency for Research on Cancer for 1998–2002, women in French Polynesia suffered the highest rates of thyroid cancer and myeloid leukemia worldwide, two forms of cancer strongly associated with radiation exposure. Infertility, miscarriages and births of babies with congenital physical malformations, often severe, and mental retardation occurred. The tests also resulted in psychological traumatization and social uprooting; for example, the rate of suicide in the areas surrounding the test site Semipalatinsk in Kazakhstan was more than twice that of the rest of the Soviet Union.

Underground nuclear tests resulted in the deposition of large amounts of radioactivity underground, some of which will take thousands or millions of years to decay. The massive explosions have shaken the stability of surrounding structures, increasing the likelihood of release into groundwater, the sea or the atmosphere. Rising sea levels due to climate change and an increase in extreme weather events such as cyclones are exacerbating the problem. One example is Runit Dome in the Marshall Islands, where tens of thousands of cubic meters of radioactive waste – including nuclear waste from the USA – was dumped into a crater created by nuclear weapons testing and covered with a concrete dome. However, the underside of the crater is not sealed and is in contact with the rising ocean.

The radioactivity released by above-ground nuclear tests has spread through the atmosphere across the globe, resulting in about 430,000 additional cancer deaths due to cumulative radiation doses by the year 2000 alone. In the long term, at least 2 million additional cancer deaths can be expected due to the longevity of many radioactive isotopes.

An important aspect in the history of nuclear weapons testing is the associated racism, which is not only evident in the selection of test regions far away from the capitals of the nuclear testing states. In many cases, different radiation protection standards were applied to residents of the affected areas and to others, such as members of the military and technicians and scientists involved in carrying out the tests. For example, a 1957 British report on a nuclear weapons test on Kiribati stated:

> *“The radiation dosage ... is about 15 times higher than that which would be permitted by the International Commission on Radiological Protection ... but only a very slight health hazard would arise, and that only to primitive people.”*[1]

Residents of nuclear weapons test sites were included in medical studies without their consent to study the effects of radioactive contamination on the human body. When the residents of Rongelap Atoll were taken back to their island, a representative of the U.S. Atomic Energy Commission said:

> *“This island is by far the most radioactively contaminated place on earth, and it will be very interesting to see what the uptake of radioactivity is when people live in this environment.”*[2]

Samples were taken from the blood, bone marrow and internal organs of the people of Rongelap. Some were compelled to undergo experimental surgery or received injections with radioactive substances. In Australia, bones of deceased people – especially children – were taken from hospitals for years to be examined in the United States without the knowledge and consent of the affected families. There are harrowing reports of families denied access to their dead children.

The quest for technical superiority and ever newer and more powerful weapons, which is one of the causes of the nuclear arms race, is not only racist but also patriarchal and sexist. For example, an advertisement for an aircraft capable of carrying nuclear weapons says “Speak softly and carry a big stick”; craters created by the French atomic bomb tests in the Pacific atolls were named with women’s names, for example Tamara, Phoebe or Ganymede. Edward Teller, known as the “father” of the hydrogen bomb famously sent the telegram “It’s a boy” to signal the success of the first thermonuclear test in 1952.[3]

The cruel consequences of nuclear weapons testing on people and the environment, and the racism and sexism that underlie them, show that the nuclear age is by no means an age of peace. The radioactive legacy of testing will remain a constant threat to the lives and health of our and future generations for many thousands of years.

For this reason, the Treaty on the Prohibition of Nuclear Weapons (TPNW), which entered into force in 2021, is of particular importance. Among other provisions, it prohibits the possession, testing and use of nuclear weapons, helping to make this world a safer place. It also provides, for the first time, an international framework to assist victims of nuclear weapons use and testing and to clean up contaminated environments. It is essential that all countries join this landmark treaty without delay.

Because it is time to finally bring justice to the survivors of nuclear weapons testing and end the madness that endangers humanity’s survival and the future of our living planet.

We wish you an intriguing read!

Angelika Claußen, Inga Blum and Juliane Hauschulz

1 Nic Maclellan. Grappling with the bomb. Britain's Pacific H-bomb tests. Acton ACT: ANU Press, 2017,

https://press.anu.edu.au/publications?search=Grappling+with+the+bomb&sort=

2 Adam Horowitz, Nuclear Savage. The Islands of Secret Project 4.1, November 2011, https://www.nuclearsavage.com/film-info

3 American Heritage Magazine Vol. 56 Issue 3 2005, https://www.americanheritage.com/we-knew-if-we-succeeded-we-could-one-blow-destroy-city

This report is the collection of texts prepared by Arjun Makhijani and Tilman Ruff for the International Campaign to Abolish Nuclear Weapons (ICAN). You can find these texts, along with others, on the website www.nucleartestimpacts.org. We thank ICAN for their kind permission to compile and publish them.

List of abbreviations

BEIR	Biological Effects of Ionizing Radiation
Bq – Bequerel	Describes the activity of a radioactive material and indicates the number of atomic nuclei that decay per second. Subunits, sorted in ascending order: mBq – Milibecquerel kBq – Kilobecquerel MBq – Megabecquerel GBq – Gigabecquerel TBq – Terabecquerel
CTBT	Comprehensive Test Ban Treaty, not yet in force. Prohibits all types of nuclear weapons testing and all other forms of nuclear explosions.
Gy – Gray	Gray indicates the dose of energy caused by ionizing radiation. 1 Gy = 1 J/kg
IAEA	International Atomic Energy Agency
kt – kilotons **Mt – megatons**	Common unit for the explosive effect of an atomic explosion Means the corresponding quantity (Mt/kt) of TNT equivalent and thus relates the explosion energy to the chemical explosive TNT.
NCI	National Cancer Institute, governmental cancer research center in the U.S.
NTS	Nevada Test Site, American test site in the U.S. state of Nevada
PTBT	Partial Nuclear Test Ban Treaty, bans all nuclear weapons testing in the atmosphere, underwater and in space.
RAF	Royal Air Force, the air forces of Great Britain and Northern Ireland
Sv – Sievert	Sievert is the unit for measuring radiation doses. In Germany, the limit of 0.001 Sv (1 milisievert – mSv) per year is officially considered safe.
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation

In March 2009, the French government finally offered to compensate survivors of nuclear testing. But the eligibility requirements for compensation are too restrictive and the entire compensation scheme too difficult to access – especially for the local Tuareg population.

French nuclear weapons tests in Algeria

Arjun Makhijani

Nuclear test site selection and nuclear test explosions

France conducted four atmospheric nuclear weapon tests in Algeria at Hammoudia, about 70 km to the southwest of Reggane, an oasis. Three tower and one surface burst explosions were done between 13 February 1960 and 25 April 1961, while the war for independence was still raging. In arriving at the accord for Algeria's independence in 1962, France negotiated retaining control for five years of the sites In Ekker (also spelled Eker) and the Colomb-Becchar-Hammaguir region where it carried out 13 underground tests in the period 7 November 1961 to 16 February 1966; France also retaining control of the Reggane site in this period.[1]

The Commissariat à l'Énergie Atomique examined a number of sites in France itself. Six were found unsuitable; one, in Corsica was found politically risky. One of the eight sites was considered suitable, but it was thought that the time for characterization would be too long. France wanted to announce its intention to test before the testing moratorium that the United States, Soviet Union, and Britain were negotiating in 1958.[2] Evidently, France did not take very long to characterize the Hammoudia site near Reggane.

The Hammoudia (also spelled Hamoudia) test site is roughly 700 km south of the city of Béchar. The four tests carried out there were named after a desert-residing rodent called "gerboise" – each test labelled with a colour: bleue, blanche, rouge, and verte, the first three being the colours of the French flag. Thirty-five sub-critical plutonium tests, with 20 g of plutonium each, were also carried out at the Gerboise verte location between 1961 and 1963. Finally, five plutonium dispersal tests, containing between 20 g and 200 g of plutonium each were carried out between May 1964 and March 1966 at the Tan Afella underground testing location.[3]

The first atmospheric test, Gerboise bleue, had an explosive power of 70 kt. The other three were less than 5 kt each[4]; the total explosive power of the French atmospheric tests in Algeria is estimated at 73 kt.[5]

Health impacts

French tests in Algeria were carried out with great secrecy; for decades the French government denied that any significant impacts had occurred. A compensation law was passed in 2010 under which both military and civilian personnel could seek compensation. The law covered testing in Algeria as well as

1 Bruno Barrillot, "French Nuclear Tests in the Sahara: Open the Files", Science for Democratic Action, Vol. 15, No. 3, April 2008, at http://ieer.org/wp/wp-content/uploads/2012/02/15-3.pdf

2 Barrillot 2008

3 IAEA 2005, p. 16 – International Atomic Energy Agency. Radiological Conditions at the Former Nuclear Testing Sites in Algeria. Vienna, Austria: International Atomic Energy Agency, 2005 at http://www-pub.iaea.org/MTCD/Publications/PDF/Pub1215_web_new.pdf ; Véterans des essais nucléaires, "Quelques vérités sur les essais nucléaires français au Sahara: Communiqué de presse", Observatoire des armements / CDRPC, Lyon, France, 15 March 2007, p.1.

4 Délégation à l'Information et à la Communication de la Défense. Dossier de presentation des essais nucléaires et leur suivi au Sahara. Paris, France: Ministère de la Défense, 2007 at https://bibliotheques-numeriques.defense.gouv.fr/document/df501911-01a3-43b3-89c7-0ed8e8bf61b6 may be difficult to download.

5 SCOPE 1999, Chapter 3, Table 3.4 pdf p. 15 – Frederick Warner, Rene JC Kirchmann (eds), Scientific Committee on Problems of the Environment, International Council of Science (SCOPE 59). Nuclear test explosions: Environmental and human impacts. Chichester, UK: John Wiley & Sons, 2000. Can be downloaded chapter by chapter at https://scope.dge.carnegiescience.edu/SCOPE_59/SCOPE_59.html

TUAREG IN TAMANRASSET. THE ALGERIAN GOVERNMENT FINALLY ERECTED A 40 KM LONG FENCE AROUND THE RADIOACTIVE MOUNTAIN IN 1999. MANY NOMADS ENTERED THE CONTAMINATED REGION WITH THEIR HERDS WITHOUT ANY IDEA OF THE DANGERS.

Polynesia. In total 150,000 military and civilian personnel are estimated to have participated in the tests from 1960 to 1996, when the last test was carried out in Polynesia. In nearly a decade from the law's passage to March 2019, only 1,476 people from all three places (France, Algeria, and French Polynesia) had applied for compensation, amounting to just one percent of the people who participated in the testing. Only 49 of them were from Algeria.[6] There is clear technical evidence and personal testimony of high fallout and contamination from the participants in the testing.

Contamination and exposure also occurred from the underground tests. Four tests were "not fully contained" according to

Two personal accounts were summarized in Barrillot 2008 (p. 10):

1. Roland W., a radiologist, recounts that he was sent to ground zero after the February 13, 1960 test (Gerboise bleue) without adequate protection. Two film badges (one in February, the other in April 1960) revealed high exposure. In between, in March 1960, he had a surgical intervention in his groin due to an inflamed lymph node. Subsequently, in 1968, he had another surgical intervention for osteomyelitis in his thigh bone and, in 1987, his thyroid was removed.

2. Lucien P. worked as a miner and mason to prepare the galleries for the underground tests. (See the following sections). He recounts that on the day of the May 1st, 1962 test he was 800 meters from the explosion and claims that he was irradiated by the radioactive cloud that escaped from the mountain. On May 14th, he resumed his work in a new gallery of the same mountain. One year later small areas of skin cancer appeared on his face and then a cancer in his jaw. Sometime later he suffered from polycythemia and then pulmonary sarcoidosis.

6 Collin and Bouveret 2020, p. 12 – Jean-Marie Collin and Patrice Bouveret. The Waste From French Nuclear Tests in Algeria Radioactivity Under the Sand: Analysis with regard to the Treaty on the Prohibition of Nuclear Weapons. Heinrich Böll-Stiftüng, 2020, at https://eu.boell.org/sites/default/files/importedFiles/2020/07/13/Collin-Bouveret-2020-Radioactivity-Under-The-Sand.pdf

a French Senate report on the country's testing program.[7] The worst exposures during the tests in Algeria are estimated to have occurred due the venting of the "Beryl" test on 1 May 1962 at Taourirt Tan Afella (sometimes abbreviated as Tan Afella). While the explosive power was apparently estimated at between 10 and 30 kt, it may have been much higher. There was a substantial vent from this tunnel test, which was observed by about 2,000 spectators, including two French ministers. There was panic as the people fled, when "black smoke, resembling the smoke from a train engine" rose from the site "to take the shape of a real cloud"[8], and evident in photographs of the time[9].

The official French Senate report on the impact of testing has estimated the following distributions of external exposures from the Beryl tests[10]:

- 1,662 people received between 0 and 5 mSv;
- 224 people received between 5 and 50 mSv (the latter being the then official limit per year);
- 87 people received between 50 and 200 mSv;
- 12 people received between 200 and 600 mSv, which was estimated to be the highest dose.

It bears stressing that these are only external radiation exposures. Radiation doses due to inhalation of radionuclides or ingestion or incorporation through cuts and wounds are not included; they would add to these totals.

Each of the four atmospheric tests also produced external exposures at or above the 50 mSv limit. The maximum exposure at Gerboise bleue and Gerboise rouge was 100 mSv, Gerboise blanche about 60 mSv, and Gerboise verte about 50 mSv.[11]

An official summary of total external doses from French testing in Algeria is as follows[12]:

- 17,750 people had no exposure;
- 6,466 people had exposures between 0 and 5 mSv;
- 213 had exposures between 5 and 10 mSv;
- 164 had exposures between 10 and 20 mSv;
- 102 people had exposures between 20 and 50 mSv;
- 53 had exposures between 50 and 100 mSv;
- 37 had exposures between 100 and 200 mSv;
- 12 had exposures between 200 and 600 mSv.

Essentially all external exposures above 100 mSv were from the Beryl test; the vast majority of exposures between 20 and 100 mSv were also due to that test.

Two things are important to put these dose estimates in context. First, these are only external exposure estimates; the people listed as unexposed may well have received internal doses. Second, official dose estimates have not been independently confirmed. An independent assessment of radiation doses from French tests in Polynesia estimated doses that were generally higher than official estimates and in some cases many times higher. The differences were generally in internal dose estimates.[13] Official U.S. dose estimates for Marshall Islands exposures are also much lower than independent ones.[14]

Environmental contamination

Fallout from the atmospheric testing and the Beryl test venting spread over large distances. Air concentrations of radioactivity between 370 and 3,700 Bq/m^3 were measured four days after the test hundreds of kilometres away in Amguid. Lower concentrations were measured roughly 2,000 km away in Fort Lamy[15], which is in Chad, separated from Algeria by Niger, which itself is a vast country and must be presumed to have received some of the fallout. The map at the end of this article, declassified by the French Defence Ministry in 2013, shows the immense scale

7 Bataille and Revol 2002 – Christian Bataille and Henri Revol, Les incidences environnementales et sanitaires des essais nucléaires effectués par la France entre 1960 et 1996 et éléments de comparaison avec les essais des autres puissances, AN n° 3571, Senat n°207, 5 February 2002 at https://www.senat.fr/rap/r01-207/r01-2073.html

8 letter of a participant, Michel R., quoted in Barrillot 2008, p. 11.

9 see, for example, Jill Jarvis, "Terra Incognita: Mapping the Afterlives of French Nuclear Imperialism in the Sahara", Maghrib in Past and Present: Podcasts, Episode 112, Slide 18, 2021, at https://www.themaghribpodcast.com/2021/03/terra-incognita-mapping-afterlives-of.html

10 Bataille and Revol 2002

11 read from a bar chart in Bataille and Revol 2002

12 Bataille and Revol 2002

13 Sébastien Philippe, Sonya Schoenberger, Nabil Ahmed. Radiation Exposures and Compensation of Victims of French Atmospheric Nuclear Tests in Polynesia. https://arxiv.org/pdf/2103.06128.pdf

14 Bernd Franke, Review of Radiation Exposures of Utrik Atoll Residents. Heidelberg, Germany: ifeu-Institut für Energie- und Umweltforschung, GmbH, prepared for Sanford Cohen & Associates, 2002, p. 39

15 Bataille and Revol 2002

of the fallout from just the first test, the 70-kiloton Gerboise bleue, covering much of the Sahara desert and Sahel region, and extending farther south to equatorial West Africa. Indeed, fallout from this test was measured as far north as Sweden at the end of February 1960 and in early March 1960, two-and-half to three weeks after the test, by that country's Research Institute of National Defence. It was possible to attribute the elevated radioactivity in the air and rain to the French test because the other nuclear weapon states at the time – the United States, Soviet Union, and Britain – had been observing a test moratorium since 1958.[16]

There has even been, what ACRO, an independent French scientific organization that investigates radioactive pollution, has called a "boomerang effect". Fine particles carried over Europe by a massive Saharan sandstorm had so much dust that the air in the Jura region had an "orange" tinge on 6 February 2021, almost exactly 61 years after the Gerboise bleue test. It contained small amounts of cesium-137 – a radionuclide that could only be present in Saharan dust due to French nuclear weapon testing in Algeria The dust storm is estimated to have deposited 80,000 Bq/km^2 of Cs-137 in the region.[17]

ACRO also detected the same phenomenon in 2022, stressing that the concentrations were too small to pose a significant health risk, though, as ACRO noted, it added to the fallout in France from the 1986 Chernobyl accident. It is worth noting that, at 22 Bq/kg, the radioactivity in the sand that blew over France, as measured by ACRO[18], was the same order of magnitude as the highest levels of residual radioactivity measured in the vicinity of the Semipalatinsk test site a few years before in Kazakhstan at Sarzhal (35 Bq/kg; ~100 km from the test site) and Kainar (23 Bq/kg; ~200 km from the test site).[19]

ACRO also drew the following inference from its measurements:

> *"This radioactive pollution – still observable 60 years after the nuclear explosions – is a reminder of the persistent radioactivity in the Sahara for which France is responsible and suggests that the fallout during the 1960s [when the nuclear tests were done] must have been particularly high."*[20]

A large amount of plutonium and fission product contamination from the sub-critical and atmospheric tests was left behind in the desert sand, some of which had been vitrified by the heat of the atomic explosions. The 1999 IAEA investigation of French testing in Algeria (the report was published years later, in 2005) found that all four of the Hammoudia atmospheric test locations, near Reggane, were contaminated; two of them – the Gerboise blanche site and the Gerboise bleue sites were found to be "locally highly contaminated, with most of the contamination residing in the black, vitreous and porous material" – that is, sand that melted "at the time of the explosion and then solidified". The IAEA's measurements showed very high levels of plutonium – more than a million becquerels per kilogram of vitrified material; strontium-90 and cesium-137 contamination levels were also high, though considerably lower than plutonium. The non-vitrified sand – which is most of the material – was also contaminated, but 100 to 1,000 times less than the vitrified material.[21] These levels of contamination were found even though much of the fission product contamination had decayed and "the finest contaminated particles" had been dispersed by desert winds in the intervening decades.[22] The finest radioactive particles are the most dangerous to health because they can be inhaled deep into the lung. Plutonium particles from nuclear testing or fires tend to be highly insoluble and can stay in the lung for decades.[23]

The dose to the lung, and hence cancer risk, per unit of plutonium inhaled is thereby significantly increased, while that to other organs, like the liver, is decreased.

16 Gunnar Lindblom, "Advection over Sweden of Radioactive Dust from the First French nuclear Test Explosion", Tellus, Vol. XIII, 1961, at https://www.tandfonline.com/doi/pdf/10.3402/tellusa.v13i1.9429?needAccess=true

17 ARCO 2021 – Association pour le Contrôle de la Radioactivité dans L'Ouest. Nuage de sable du Sahara : une pollution radioactive qui revient comme un boomerang. Hérouville St Clair, France, 24 February 2021, at https://www.acro.eu.org/wp-content/uploads/2021/02/CP-ACRO-vent-du-Sahara-v2.pdf

18 ACRO 2022 – Association pour le Contrôle de la Radioactivité dans L'Ouest. Nuage de sable du Sahara : nouvelle mesure de la radioactivité. Hérouville St Clair, France, 22 March 2022, at https://www.acro.eu.org/nuage-de-sable-du-sahara-nouvelle-mesure-de-la-radioactivite/

19 distances estimated from Figure 1 in Sergazy Duyssembaev, Ainur Serikova, Eleonora Okuskhanova, Nadir Ibragimov, Nailya Bekturova, Nurgul Ikimbayeva, Yaroslav Rebezov, Olga Gorelik, and Malika Baybalinova, "Determination of Cs-137 Concentration in Some Environmental Samples around the Semipalatinsk Nuclear Test Site in the Republic of Kazakhstan", Annual Research & Review in Biology, January 2017, at https://www.researchgate.net/publication/319062715

20 ACRO 2022, translated from the French by the author.

21 IAEA 2005, pp. 26-27.

22 IAEA 2005, p. 7.

23 calculated by the author from clearance coefficients in Maia Avtandilashvili, Richard Brey, Anthony C. James, Alan Birchall, Inhalation of Highly Insoluble Plutonium: Case Studies from the Rocky Flats Plutonium Fire. Pocatello, Idaho: Idaho State University, 2016, at https://s3.wp.wsu.edu/uploads/sites/1058/2016/05/USTUR-0264-09A.pdf

The IAEA also found significant residual plutonium, strontium-90, and cesium-137 in the lava expelled when underground tests at Taourirt Tan Afella vented. Even dry stream beds were found to be contaminated.[24]

Based on available data, this author estimates that about 10 kg of plutonium have been dispersed in the Algerian environment due to the atmospheric and subcritical tests in the Reggane area, with roughly 90 % of that being from the four atmospheric tests. About 60 MBq of strontium-90 and 100 MBq of cesium-137 remain (decay corrected to 2020). About 30 kg of plutonium has been left due to the 13 underground tests, both underground and on the surface due to the lava that was expelled during the venting events associated with four of those tests. As the 2021 and 2022 ACRO measurements in France show, these radioactive materials are also available for wide dispersal well beyond Algeria.

French testing in Algeria also created large amounts of radioactive and hazardous waste (as is typical of such situations). This is likely to have resulted in exposures of the Algerian population in the vicinity:

> *"Vehicles, planes, and other military materials were exposed during the test, enormous quantities of water and liquids were employed for the decontamination of the materials and the personnel. This waste was buried under a couple inches of sand. Algerian witnesses affirm that most of these materials were taken by the local population, unaware of the potential health risks."*[25]

The "Pollen" tests, done about 30 km from Taourirt Tan Afella, presented their own risks, because they were meant to study plutonium dispersal:

> *"The Pollen experiments were designed to simulate an accident involving plutonium and to measure its consequences, including the degree of contamination that might arise in the vicinity .... Five experiments involving 20 to 200 g of plutonium were carried out between May 1964 and March 1966, using the same firing area. The experiments were performed when winds were blowing across the sector planned for collection of the fallout. ...After each experiment, the most contaminated area was covered with asphalt to limit resuspension. On the basis of the experiments performed at this site, low residual activity might still be detected near the ground zero point."*[26]

In sum, nuclear testing in Algeria has left behind a legacy of the serious contamination and hazards from the atmospheric tests, the ventings of tunnel tests, and the sub-critical plutonium tests. For instance, the IAEA explicitly recognized the risks presented by "hot particles":

> *"The Pollen experiments would have been expected to disperse some active particles ('hot particles') in the area, with the larger and heavier ones settling closest to the site of dispersion in the area of the bitumen overlay. Small particles in the respirable range have probably been widely dispersed in the intervening years by the wind."*[27]

The overall situation is roughly comparable to the British tests done in a desert environment in Australia. Despite expensive clean-up operations, the situation there remains unsatisfactory in many respects, including significant areas that are too contaminated for human habitation. Fencing or boundary markers are, of course, no match for plutonium-239, with its half-life of more than 24,000 years.[28]

Clean-up, site markings, fencing, and other measures to protect the local population, such as covering contaminated areas to prevent the dispersal of radioactivity remain a need in Algeria.[29]

24 IAEA 2005, p. 27

25 the quote is from Barrillot 2008, p. 12; see also Collin and Bouveret 2020.

26 IAEA 2005, p. 16.

27 IAEA 2005, p.27.

28 Alan Parkinson. Maralinga: The Clean-Up of a Nuclear Test Site. Medicine & Global Survival, Vol. 7, No. 2, 2002, pp. 77-81 and Alan Parkinson. The Maralinga Rehabilitation Project: Final Report. Medicine, Conflict and Survival, Vol. 20, No. 1, 2004; pp. 70-80.

29 Collin and Bouveret 2020, p. 51.

Conclusions

Algeria, like other non-nuclear weapon countries subjected to nuclear testing, is left asking for openness, scientific studies, and reparations, as is evident from the following text prepared at a 2007 official Algerian conference in Algiers. The recommendations are quoted in full below[30]:

We recommend:

1. To carry on with organising this type of specialist gathering, and to collect eyewitness testimony and documents relevant to this issue.

2. The lifting of the "national security" seal from all archives relating to the French nuclear tests and experiments in the Algerian Sahara, so that they can serve as reference documents for researchers and experts.

3. The undertaking of detailed scientific studies by specialist organisations

» on the effects of radiation on human beings, flora and fauna,

» on the geology of the test sites,

» as well as undertaking a radiological analysis of the zones surrounding Reggane and In Eker.

4. Develop co-operation between the different sectors and national institutions affected by this issue, to allow the effective management of all aspects related to the French nuclear tests and experiments in the Algerian Sahara.

5. Intensify the efforts of experts, historians and jurists to establish the truth of the allegation that civilian and military personnel were used as guinea pigs, and to add an additional protocol to the Comprehensive Test Ban Treaty (CTBT), guaranteeing the rights of victims.

6. Encourage and strengthen co-operation between non-government organisations of nuclear testing victims, and extend this network to all affected countries.

7. Call on France for reparations for all the consequences of the nuclear tests in the Algerian Sahara, including:

» The identification and restriction of all sites for nuclear testing and experiments.

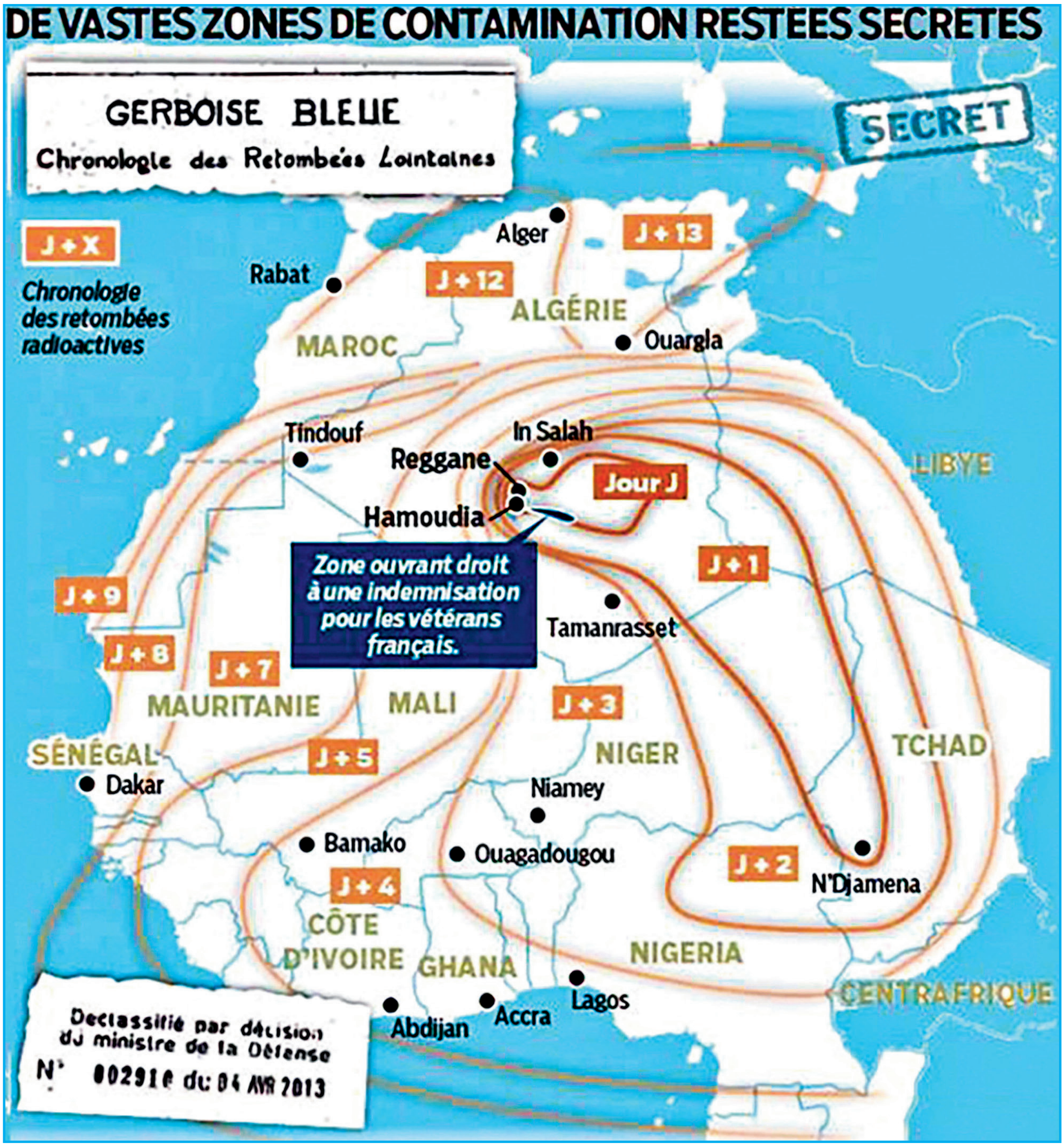
» The identification of the exact locations where radioactive wastes have been disposed.

» A contribution to the establishment of a monitoring system for the Algerian sites, modelled on that which has been set up in French Polynesia and other regions of the world.

» Compensation for all victims of nuclear testing.

» Contribution to the training of Algerian personnel in radiation decontamination.

30 Ministry of Moudjahidine, International conference on The consequences of nuclear testing around the world: the case of the Algerian Sahara, Algiers: République Algérienne Démocratique et Populaire, 13-14 February 2007, bold in the original; the entire text below up to the end of this article is a quote from the conference communiqué.



Source: Ministry of Defence, Government of France, declassified on 4 April 2013, as published in Jarvis 2021, slide 12. The fallout extent is shown by day, with the number after "J +" indicating the number of days after the test ("jour" = day). "Jour J" represents the day of the test, 13 February 1960. Additional maps can be found in: Délégation à l'Information et à la Communication de la Défense. Dossier de presentation des essais nucléaires et leur suivi au Sahara. Paris, France: Ministère de la Défense, 2007. Maps of contamination in Northern Europe from the 13 February 1960 Gerboise bleue test can be found in Lindblom 1961.

Despite international criticism, the French government conducted an estimated 193 to 198 nuclear tests on the French Polynesian atolls of Moruroa and Fangataufa between 1966 and 1996

Photo Credit: Moruroa Atoll, 1970, Französisches Militär

French nuclear weapons tests in Polynesia

Tilman Ruff

The nuclear test explosions

After four atmospheric tests at Reggane, Algeria, in 1960–61, France continued its nuclear testing programme there even after independence in 1962, with 13 underground tests at In Ekker between 1961 and 1966 while its Pacific Testing Centre was being built. France then undertook 46 atmospheric nuclear tests in Polynesia from 2 July 1966 on. France refused US urging to sign the Partial Test Ban Treaty of 1963, which banned nuclear test explosions anywhere but underground. It continued atmospheric tests until 24 August 1974 (only China conducted atmospheric tests later, until 1980). Five of the atmospheric tests were safety tests of fission weapons; two of these produced small nuclear explosive yield (0.001 kt).[1] The explosive yield of the 41 at or above ground nuclear explosions was 10.13 Mt [2], with 6.5 Mt of this estimated to be from fission[3].

After a moratorium on nuclear tests from 1992–95, France conducted a final six underground nuclear tests – making a total of 147 – in 1995–96 in order to be able to continue developing new nuclear weapons without explosive testing, prior to signing the CTBT when it opened for signature on 24 September 1996.[4]

France's nuclear test programme was associated with an extreme level of secrecy about all its aspects and initially categorical denial of any health or environmental impacts. Intelligence agencies undertook sabotage of protest boats and infiltrated organizations opposed to nuclear tests. The French State went to the violent lengths of destroying the Greenpeace flagship Rainbow Warrior with two mines, on 7 July 1985, while it was moored in Auckland Harbour en route to Moruroa. The operation, which killed photographer Fernando Pereira, was reportedly sanctioned by President Mitterrand.[5] Two captured perpetrators returned to France after cursory detention, received military promotions, and one a military medal.[6] Despite greater transparency since the end of the testing, piecemeal release of information, such as radioactive fallout measurements, has been drawn-out over decades.

1 SCOPE 1999, Chapter 8, p. 241-2 – Frederick Warner, Rene JC Kirchmann (eds), Scientific Committee on Problems of the Environment, International Council of Science (SCOPE 59). Nuclear test explosions: Environmental and human impacts. Chichester, UK: John Wiley & Sons, 2000. Can be downloaded chapter by chapter at https://scope.dge.carnegiescience.edu/SCOPE_59/SCOPE_59.html

2 SCOPE 1999, Chapter 3, p. 27.

3 SCOPE 1999, Chapter 4, p. 60.

4 Nic Maclellan et al. 1998, p. 102 – Nic Maclellan, Jean Chesneaux. After Moruroa: France in the South Pacific. Melbourne: Ocean Press, 1998.

5 Marlise Simons. Report Says Mitterand Approved Sinking of Greenpeace Ship. International New York Times, 10 July 2005. www.nytimes.com/2005/07/10/world/europe/report-says-mitterrand-approved-sinking-of-greenpeace-ship.html

6 Nic Maclellan et al. 1998, p. 215.

Physical damage, leakage and tsunami risk

Tests were conducted at Moruroa (42 atmospheric and 137 underground) and Fangataufa (4 atmospheric and 10 underground)[7], two coral atolls atop extinct underwater volcanos in the Tuamotu Archipelago. Fangataufa was a closed atoll, so a 400 m wide channel was made through the atoll. Most of the early atmospheric tests were performed on the surface or on barges in the lagoon, resulting in high levels of radioactive fallout (e.g., up to 1 Gy/hr up to 70 km from the 125 kt Rigel explosion on 24 September 19668). So, most later tests involved warheads hanging under balloons several hundred meters in the air. The first two-stage fission-fusion explosion on 24 August 1968 at Fangataufa, was the largest explosion at 2.6 Mt.[9]

Extensive physical damage to the testing atolls occurred, with subsidence and ongoing risks of collapse and leakage. The underground tests were detonated down 500–1200 m shafts drilled into the basalt underlying the coral and limestone of the atolls. Early tests were conducted under the atoll rim, until extensive fracturing and fissures in the coral and underlying basalt, subsidence and subterranean landslides necessitated use of the central lagoon. In the Tydee test, a 150 kt explosion beneath the reef at Moruroa was detonated on 25 July 1979, despite the device becoming stuck 800 metres down a 1,000-metre shaft. This caused a submarine landslide dislocating an estimated 110 million m^3 of coral and rock, resulting in a 3-metre wave which swept over the southern part of Moruroa and through the Tuamotu Archipelago.[10] In 1981 larger tests were moved to under the lagoon, and all tests were performed there from 1986.[11]

Reports from 2011 and 2013 by the French Delegate for Nuclear Safety and Radiation Protection for Defense Activities (Délégué à la Sûreté Nucléaire et à la Radioprotection pour les Activités Intéressant la Défense)[12] and France's Atomic Energy Commission (Commissariat à l'Énergie Atomique et aux Énergies Alternatives)[13] respectively acknowledge previous collapses of the outer wall of the atoll – carbonates, mostly limestone and dolomite, atop a basalt base. The reports note that even though the tests have ended, this type of event could happen again, particularly in three areas on the northeast flank of Moruroa, where six of 28 underground tests released radioactivity into the ocean through fissures in the basalt. The CEA envisaged a possible scenario of a landslide of some 670 million m^3 of rock, creating a 15-to-20 meter tsunami wave, swamping the east of the atoll and threatening neighbouring inhabited islands, estimates which continue to be stated in reports of ongoing monitoring of the physical integrity of Moruroa and Fangataufa.[14]

Extensive abandoned equipment and materiel, radioactive, chemical and other waste on land, in lagoons and in the ocean remains both at the former testing sites and at a network of facilities and infrastructure supporting the massive nuclear weapons enterprise. This includes the military harbours in Papeete and Mangareva, and the huge staging base for the nuclear test programme at Hao Atoll, which became the largest military base in the South Pacific. This legacy was examined comprehensively for the first time under local control by a commission established by the Assembly of French Polynesia in 2005-6.[15]

In 2006, the DSND revealed that between 1967 and 1982 large amounts of radioactive material were dumped in the ocean –

7 Tilman A Ruff. The humanitarian impact and implications of nuclear test explosions in the Pacific region. International Review of the Red Cross 2016, 97(899):775-813. https://international-review.icrc.org/articles/humanitarian-impact-and-implications-nuclear-test-explosions-pacific-region

8 SCOPE 1999, Chapter 4, p. 60-1.

9 IPPNW and IEER 1991, p. 135 – International Physicians for the Prevention of Nuclear War and Institute for Energy and Environmental Research. Radioactive Heaven and Earth: The Health and Environmental Effects of Nuclear Weapons Testing In, On, and Above the Earth. New York: Apex Press 1991, at http://ieer.org/wp/wp-content/uploads/1991/06/RadioactiveHeavenEarth1991.pdf

10 IPPNW and IEER 1991, p.145.

11 IPPNW and IEER 1999, p.135-7.

12 Délégué à la Sûreté Nucléaire et à la Radioprotection pour les Activités Intéressant la Défense. Surveillance geomecanique de Mururoa. 25 January 2011, pp. 1–6.

13 CEA 2013, p. 13 – Departement de Suivi des Centres D'Experimentations Nucleaires, Ministere de la Defense et des Anciens Combattants. Surveillance des atolls de Mururoa et de Fangataufa, Vol. 2: Bilan de l'evolution geomecanique des atolls de Mururoa et Rangiroa. DO 312 CEA/DIF/DASE/LDG, 13 September 2013, pp. 5–53.

14 CEA 2021, p. 10 – Departement de Suivi des Centres D'Experimentations Nucleaires. Surveillance des atolls de Mururoa et de Fangataufa. Tome II: Bilan geomecanique, Annee 2020. N°182 DGA/DO/UM NBC/SCEN du 06 septembre 2021 CEA/DIF/DASE/LDG/62/2021/DO du 08 juin 2021 https://www.defense.gouv.fr/sites/default/files/ministere-armees/2020%20-%20tome%202%20-%20bilan%20géomécanique%20- %20surveillance%20des%20Atolls.pdf

15 CESCEN 2006 – Commission d'Enquete sur les Consequences de Essais Nucleaire (CESCEN). Les polynesiens et les essais nucleaires. Deliberation No. 2005-072, Assemblee de la Polynesie Francaise, 2006. https://www.service-public.pf/wp-content/uploads/2017/09/CESCEN-2006.pdf

2,656 tons in two sites at Moruroa, and 532 tons at Hao.[16] The stated amounts, which are extremely difficult to verify, were $7x10^9$ Bq of beta and gamma emitters and $6.7x10^{10}$ Bq of alpha emitters (predominantly plutonium) in Moruroa and $1.5x10^{10}$ Bq of beta and gamma emitters and $3x10^7$ Bq of alpha emitters in Hao. Over time, all the waste on atolls and in lagoons becomes more difficult to monitor, recover or otherwise remediate, and will increasingly be released into the marine environment as a result of accelerating sea-level rise related to global heating and extensive test-related subsidence of Moruroa; whilst declining physical integrity, and storms and hurricanes of increasing intensity, accelerate its disruption and dispersal.

Despite extremely limited access and sampling opportunities, previous independent investigations have documented the presence of short-lived isotopes including iodine-131, tritium and caesium-134 in coral interstices and in lagoon sediment and plankton, indicating rapid leakage of fission products over a timeframe as short as days, not centuries or millennia as previously claimed by French authorities. In addition, more than 20 kg of plutonium is estimated to be scattered across the Moruroa and Fangataufa lagoons.[17]

The efforts of governments to establish and license disposal sites for radioactive waste from other sources have been difficult and protracted, and worldwide no high-level radioactive waste repository is yet operational. In stark contrast, underground nuclear explosion sites effectively become unregulated high level radioactive waste repositories, in which the explosion which creates and injects radioactive materials also compromises the ability of the fractured and fissured underground environment to contain the materials.[18] Nowhere is this more apparent than in coral atolls in a marine environment. Indefinite monitoring of such sites is required.

Fallout

Although tests were generally conducted when fallout would mostly be carried eastwards towards South America, Africa and Australia before reaching the western parts of the South Pacific, circling the earth in lower and middle latitudes, sometimes varying winds and high-pressure systems carried fallout westwards and northwards towards populated areas, neighbouring Pacific-island countries, New Zealand and Australia.

Fallout in French Polynesia/Maohi Nui

For example, following a test on 19 July 1974, the fallout from which travelled straight towards Tahiti, average total beta activity in air increased from less than 0.3 to 1,460 mBq per m^3 in the capital, Papeete.[19] Because of the presence, insistence and impatience of President de Gaulle, despite unfavourable winds to the west, an explosion on 11 September 1966 carried fallout directly towards populated areas.[20] In Apia, Samoa, 3,700 km downwind, as a result of rainout, total beta radioactivity increased from the usual level of around 200 MBq/km^2 to 370,000 MBq/km^2 after this test.[21]

Fallout repeatedly contaminated the closest inhabited neighbouring islands of Tureia and Mangareva, where the population totalling 1,100 were repeatedly evacuated to shelters.

After years of intense secrecy and denial of adverse environmental and health impacts of the tests, information about fallout measurements has emerged incrementally. In 2006, the French military published estimates of radiation exposures for six locations for the six tests that it stated led to the highest fallout.[22] The highest estimated effective doses after a single test were up to 10 mSv for infants in the Gambier Islands, and an average of 5.2 mSv for infants in Tahiti, 1,250 km away. External doses as low as 4.5 mGy (= 4.5 mSv in the case of external radiation) have been found to increase cancer risk in children.[23] Thyroid doses for infants of up to 80 mSv in the Gambiers and up to 49 mSv in Tahiti were estimated, again following single tests. Primary data and details of computational methods were not provided.

By way of perspective, these doses are within the range of anticipated thyroid radiation exposure for children under 18 years, along with pregnant and lactating women, warranting administration of stable iodine to protect against uptake of radioactive

16 DSND 2006, pp. 20-1 – Jurien de la Gravière Marcel. Les essais nucléaires français dans le Pacifique : Mission du délégué à la sûreté nucléaire et à la radioprotection pour les activités et installations intéressant la défense (DSND), Mai 2006. Paris, France: Ministère de la défense, May 2006.

17 IPPNW and IEER 1991, p. 143-9.

18 IPPNW and IEER 1991, p. 165.

19 IPPNW and IEER 1991, p.143.

20 Bengt Danielsson. Poisoned Pacific: The Legacy of French Nuclear Testing. Bulletin of the Atomic Scientists, 1990 Vol. 46 (2): 22-31, at https://www.tandfonline.com/doi/abs/10.1080/00963402.1990.11459794 . More detailed background can be found in: Bengt Danielsson, Marie-Therese Danielsson. Poisoned reign: French nuclear colonialism in the Pacific. 2nd revised ed. Ringwood: Penguin Books, 1986.

21 IPPNW and IEER 1991, p. 143.

22 DSND 2006, p. 9-12.

23 John D. Mathews, Anna V Forsythe, Zoe Brady, Martin W Butler, Stacy K Goergen, Graham B Byrnes, Graham G Giles, Anthony B Wallace, Philip R Anderson, Tenniel A Guiver, Paul McGale, Timothy M Cain, James G Dowty, Adrian C Bickerstaffe, and Sarrah C Darby. Cancer risk in 680 000 people exposed to computed tomography scans in childhood or adolescence: data linkage study of 11 million Australians. British Medical Journal May 21, 2013 Vol. 346: f2360, at https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3660619/

iodine (the threshold recommended by WHO[24] and by the US FDA[25] for those groups is 50 mGy. Independent researchers concluded that the limited data available likely miss areas of high exposure and probably underestimate the doses received.[26]

French data on fallout provided to the UN Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) was summarised and incomplete.[27] An IAEA evaluation of French retrospective radiation dose estimates in French Polynesia made clear it was unable to assess the validity of the data or calculated estimates provided.[28]

In 2013, 233 documents, over 2,000 pages, on fallout from the tests were declassified by the French Ministry of Defence after a long legal battle between the French government and French and Polynesian test survivors' organisations.[29] To date, these have been utilised by researchers on cancer, especially thyroid cancer, in French Polynesia, and by the collaborative Moruroa Files project[30].

A thorough independent re-evaluation of three of the tests has recently been undertaken.[31] They utilised data underpinning the 2006 official estimates in addition to data released in 2013. Five tests had previously officially been identified as most consequential for inhabited locations – the Aldebaran (2 July 1966) and Phoebe (8 August 1971) tests for the Gambier Islands; the Acturus (2 July 1967) and Encelade (12 June 1971) tests on Tureia atoll; and the Centaure (17 July 1974) test on Tahiti.[32] Re-evaluations were undertaken for these and one additional test – Rigel on 24 September 1966.

The researchers used official data to reconstruct fallout clouds and their movement using the US National Ocean and Atmospheric Administration's HYSPLIT model, calculated doses for one year rather than six months, and re-evaluated data on water contamination and consumption. For Aldebaran fallout on the Gambiers, they estimate that radiation exposure from water contamination in the 2006 CEA estimates could have been underestimated by a factor of 20, and maximum effective whole body and thyroid doses for children and adults could have been underestimated by a factor of 2.5. For Rigel fallout, the factor was between 10 and 20. The Centaure test is particularly significant because although the plutonium bomb was only 4 kt in explosive yield, its fallout travelled directly towards Tahiti and neighbouring islands where 90 % of the Polynesian population lives, resulting in revised effective doses, depending on age, between 10 % and 120 % higher than official estimates. About 90 % of the Polynesian population may thus have received a dose greater than 1 mSv in the first year after this single test.

For the other three tests for which official fallout estimates have been produced, the researchers found that maximum effective whole body and thyroid doses could have been underestimated by factors of 1.5 – 4 and 1.5 – 2.5 respectively.[33]

These findings have important implications, since in nuclear test-related compensation claims in France, the adjudication process currently applies an effective radiation dose threshold of 1 mSv/yr. The findings described could enlarge the number of eligible applicants in Polynesia from 11,000 to more than 110,000.[34]

These findings highlight that fallout consequences of nuclear tests are not simply proportional to their explosive yield. Three tests contributed about 94 % of the total radioactive fallout deposited in Tahiti from all 41 test explosions.[35] These findings

24 World Health Organization. Iodine thyroid blocking. Guidelines for use in planning for and responding to radiological and nuclear emergencies. Geneva: WHO, 2017, p. 10. At: https://www.who.int/publications/i/item/9789241550185

25 Food and Drug Administration. Guidance. Potassium iodide as a thyroid blocking agent in radiation emergencies. Rockville MD: US Department of Health and Human Services, Dec 2001, p. 6. At: https://www.fda.gov/media/72510/download

26 de Vathaire 2010 – Florent de Vathaire, Vladimir Drozdovitch, Pauline Brindel, Frederique Rachedi, Jean-Louis Boissin, et al. Thyroid cancer following nuclear tests in French Polynesia. Br J Cancer 2010, 103: 1115-21. At: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2965871/pdf/6605862a.pdf

27 Drozdovitch 2021b – Vladimir Drozdovitch, Florent de Vathaire, André Bouville. Radiological Impact of Atmospheric Nuclear Weapons Tests at Mururoa [sic] and Fangataufa Atolls to Populations in Oceania, South America and Africa: Comparison with French Polynesia. Asian Pac J Cancer Prev 2021, 22 (3): 801-809. At: http://journal.waocp.org/article_89518.html

28 Philippe 2021, p. 4 – Sébastien Philippe, Sonya Schoenberger, Nabil Ahmed. Radiation Exposures and Compensation of Victims of French Atmospheric Nuclear Tests in Polynesia. At: https://arxiv.org/pdf/2103.06128.pdf

29 available at: https://moruroa-files.org/en/declassified-documents

30 Disclose, Princeton University's Program on Science and Global Security, Interprt. Moruroa files. https://moruroa-files.org/en/

31 Philippe 2021, and discussed at https://moruroa-files.org/en/

32 No detailed official dose estimates have been presented for the other 35 atmospheric test explosions.

33 Philippe 2021

34 Philippe 2021

35 Drozdovitch 2020 – Vladimir Drozdovitch, Florent de Vathaire, Andr e Bouville. Ground deposition of radionuclides in French Polynesia resulting from atmospheric nuclear weapons tests at Mururoa and Fangataufa atolls. Journal of Environmental Radioactivity 2020, 214-215: 106176. At: https://www.sciencedirect.com/science/article/abs/pii/S0265931X-19306526?via%3Dihub

Photo credit: Raivavae-Atoll, 1966, Alain Treboz

About 5,000 people lived in the region around the test sites during the three decade long era of testing. Moruroa and Fangataufa were severely affected by radioactive fallout, surrounding islands were also contaminated. Many Polynesian people working on Moruroa und Fangataufa became ill after they had returned to their home islands; oftentimes, their offspring have also been affected.

also highlight the importance of independent evaluation in the face of what the researchers described as: "dose reconstruction studies that are at best incomplete and uncertain, and at worst systematically under-representative of levels of external and internal radiation exposures"[36].

The same fallout reports, belatedly released in 2013, have also been utilised by health researchers examining thyroid cancer in Polynesia, contributing to an updated ground radionuclide deposition assessment, which produced deposition estimates due to beta activity in air and iodine-131 that are respectively 60 % and 20 % higher than those derived from official data provided to UNSCEAR.[37] The resulting revised thyroid dose estimates are significantly higher than the researchers' 2008 estimates by a factor of 3 for median and almost 2 for mean doses.[38] People resident in the Gambier Islands during 1966–74 had mean estimated thyroid doses of 17 mGy, with a maximum of 36 mGy. They note that a child born in 1966 living in Tureia through to 1974 could have received a thyroid dose of up to 500 mGy.

Fallout in other regions

Fallout patterns are complex and variable, and hotspots can occur at considerable distances, particularly when rain or snow increase fallout intensity. Researchers have used the reports declassified in 2013 and other published reports to evaluate the fallout exposures from atmospheric French Pacific tests in

36 Philippe 2021, p. 20.

37 Drozdovitch 2020

38 Drozdovitch 2021a – Vladimir Drozdovitch, André Bouville, Marc Taquet, Jacques Gardon, Tetuaura Tetuanui, Constance Xhaard, Yan Ren, Françoise Doyon, Florent de Vathaire. Thyroid doses to French Polynesians resulting from atmospheric nuclear weapons tests: estimates based on radiation measurements and population lifestyle data. Health Physics 2021, 120(1): 34–55. At: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7710602/

other countries.[39] They found that iodine-131 in cow's milk produced in Australia (Malanda), Peru (Lima, Tacna and Arequipa), Chile (Santiago), Bolivia (La Paz) and Madagascar (Antsiranana) in three years during 1966–1972 was even higher than in milk produced in Tahiti; and that in 1968 thyroid radiation exposure was higher for one-year old infants in Peru (0.35 mGy) and Madagascar (0.30 mGy) than in Tahiti (0.25 mGy). In Oceania, the highest estimated thyroid doses were in Tahiti, followed by Samoa. Total beta concentration in air was almost twice as high in 1970 in Lima, Peru and in 1972 in Santiago, Chile than in Tahiti.[40]

Health effects

In 2020 the French National Institute for Health and Medical Research (Inserm), issued a report: "Nuclear tests and health – consequences in French Polynesia", commissioned by the Ministry of Defense.[41] The report concluded that the links between the fallout from atmospheric tests and the occurrence of radiation-induced pathologies cannot be established. However, the authors also stated that their "results do not make it possible to exclude the existence of health consequences" and recommend "to refine the estimates of doses received" by the local population.

Cancer

During the decades of the testing programme, protection, health monitoring and care of those at greatest risk were grossly neglected. Health data were inadequate – a cancer registry was only established in 1988. No medical follow-up was undertaken of the up to 13,000 Polynesians who worked in the test programme.[42] Over the period 1986–2001, the incidence of acute myeloid leukaemia in French Polynesia was the highest in the world.[43] International Agency for Research on Cancer global cancer data showed that for the period 1998–2002, French Polynesian women had the highest rates of thyroid cancer and myeloid leukaemia in the world[44]; both these cancers are among those most strongly associated with radiation exposure, and tend to peak earlier than most solid tumours.

A clear gradient of thyroid cancer incidence associated with the level of radiation to the thyroid from the atmospheric nuclear tests has been demonstrated. Thyroid dose estimates have been improved, including with the additional official fallout data released in 2013.[45]

The earlier case-control study of thyroid cancer in French Polynesia covering the period 1981–2003[46] has been extended to include cases occurring up to 2016, using updated dose estimates based on official records declassified in 2013, which as noted above indicate mean lifetime thyroid doses approximately double previous estimates. This study uses lifetime risk modelling from the 2006 BEIR VII report to estimate that 2.3 % of differentiated thyroid cancer, or 29 cancers over the life of the French Polynesian population exposed to fallout from the French atmospheric nuclear tests there, can be attributed to test fallout.[47] Case ascertainment was constrained by lack of effective functioning of the Cancer Registry of French Polynesia, which has yielded no peer-reviewed publications in its 40 year history and has not provided data to the International Agency for Research on Cancer since at least 2007, a significant deficiency in public health surveillance.

Ciguatera fish poisoning

An important environmental and health impact of the nuclear test programme in French Polynesia is outbreaks of ciguatera fish poisoning. Ciguatera is the most common type of toxin poisoning by marine foods worldwide, and is found across many tropical regions. It is a disease of the food chain, with microscopic dinoflagellate plankton producing toxins which concentrate up the food chain, producing sometimes severe and protracted illness.

39 Drozdovitch 2021b

40 Drozdovitch 2021b

41 Inserm. Essais nucléaires et santé. Conséquences en Polynésie française. Collection Expertise collective. Montrouge: EDP Sciences, 2020. At: https://presse.inserm.fr/essais-nucleaires-et-sante-consequences-en-polynesie-francaise-une-expertise-collective-de-linserm/42219/

42 CESCEN 2006, p. 135.

43 Bernard Rio, Laurence Heuberger, Gilles Soubiran, Robert Zittoun, Jean-Pierre Marie. Incidence rates of leukemia in French Polynesia. International Journal of Cancer 2012, Vol. 131 (6): 1486-7. At: https://onlinelibrary.wiley.com/doi/epdf/10.1002/ijc.27364

44 Christine Bouchardy, Simone Benhamou, Florent de Vathaire, Robin Schaffar, Elisabetta Rapiti. Incidence Rates of Thyroid Cancer and Myeloid Leukaemia in French Polynesia. International Journal of Cancer, 2011, Vol. 128: 2241-3. At: https://onlinelibrary.wiley.com/doi/epdf/10.1002/ijc.25545

45 Drozdovitch 2021a

46 Xhaard 2014

47 Florent de Vathaire, Monia Zidane, Constance Xhaard, Vincent Souchard, Sylvie Chevillard, et. al. Assessment of differentiated thyroid carcinomas in French Polynesia after atmospheric nuclear tests performed by France. JAMA Network Open. 2023;6(5):e2311908. doi:10.1001/jamanetworkopen.2023.11908. At: https://jamanetwork.com/journals/jamanetworkopen/fullarticle/2804558

Fish most likely to be toxic are larger carnivorous inshore reef fish accessible to local people and prized for eating. The toxins cannot be identified by any simple means and survive cooking.

Ciguatera plankton preferentially proliferate on dead or damaged coral surfaces. Outbreaks of ciguatera have been associated with many types of damage to coral reefs, including blasting, waste dumping, construction activities and nuclear test explosions in French Polynesia, as well in the Marshall Islands and Kiribati. There is clear evidence of a dramatic rise to high levels of ciguatera cases in French Polynesia coincident with the testing programme, extremely high levels of toxicity at Moruroa and in the military harbour at Mangareva, and extensive outbreaks associated with coral reef damage from construction, shipping and waste dumping associated with the nuclear test programme. For example, during construction of the nuclear test staging base at Hao Atoll, a large outbreak affected almost half the population in 1968.[48] Ciguatera has important nutritional, social and economic implications, interfering with local inshore, largely subsistence, traditional fishing and increasing dependence on imported foods, with their exacerbation of risk factors for chronic disease.[49]

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48 Tilman Ruff. Ciguatera in the Pacific: A Link with Military Activities. Lancet 1989; 1: 201-5 https://www.ncf-net.org/pdf/RuffCiguateraALinkWithMilitaryActivities.pdf ; summarised in: Tilman Ruff. Bomb Tests Attack the Food Chain. Bulletin of the Atomic Scientists, 1990, Vol. 46 (2): 32-4.

49 Tilman Ruff. Bomb Tests Attack the Food Chain. Bulletin of the Atomic Scientists, 1990, Vol. 46 (2): 32-4.

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View of Christmas Island from a freight and transporter airplane. Several British hydrogen bombs were tested on the atoll from 1957 to 1962 when the USA "borrowed" the islands from the UK to conduct a series of 24 above-ground nuclear tests. During this time, the island was inhabited by both thousands of military personnel and the indigenous population. No one was evacuated.

Photo credit: Dennis Hobbs/ public domain

British nuclear weapons tests in the Central Pacific

Tilman Ruff

The nuclear test explosions

With mounting public concern over radioactive fallout from British nuclear tests conducted in Australia, the Australian government in 1956 rejected proposed hydrogen bomb test explosions for "safety reasons". As a consequence, Britain had to take its hydrogen bomb "Grapple" development to its then-colonized area of the Gilbert and Ellice Islands Colony in the central Pacific. Undertaken in considerable haste because of an impending agreement to suspend all forms of nuclear testing which the UK, USA and USSR signed and lasted between 1958 and 1961, the UK detonated its first three hydrogen bombs at Malden Island in 1957. Despite being airbursts, these massive explosions contaminated Malden, and subsequent tests were moved to Christmas Island (known locally as Kiritimati Island, now part of the Republic of Kiribati), the largest coral island in the world, comprising almost half the total land area of Kiribati. In both places, British soldiers and sailors, 551 crew on two New Zealand frigates, and nearly 300 Fijian soldiers and sailors worked in close proximity, as well as local Gilbertese plantation workers and their families. The latter were evacuated to Fanning Island or kept on ships during the initial but not the later 1958 tests.[1] Nearly 14,000 British military and scientific staff travelled to the then colony as part of Britain's H-bomb program.[2]

The total explosive yield of the 12 British nuclear test explosions in Australia was 0.180 Mt; that of the 9 explosions at Malden and Kiritimati was 7.87 Mt.[3] All were air bursts except for tests on 22 May and 23 September 1958 which were suspended by balloon at 450 m height. The Kiritimati tests were conducted over and just off the southeast tip of the island. It is noted for completeness that, in 1962, the United States conducted 24 nuclear test explosions in the Christmas Island area totaling 23.25 Mt; all were airdrops.[4]

British military documents reveal that one of the purposes of the tests was to study the effects of nuclear explosions on people – for example: "The Navy requires information on the effects of various types of atomic explosions on ships and their contents and equipment ... The Army must discover the detailed effects of various types of explosion on equipment, stores and men, with and without various types of protection" and "the RAF will gain invaluable experience in handling the weapons and demonstrating at first hand the effects of nuclear explosions on personnel and equipment".[5]

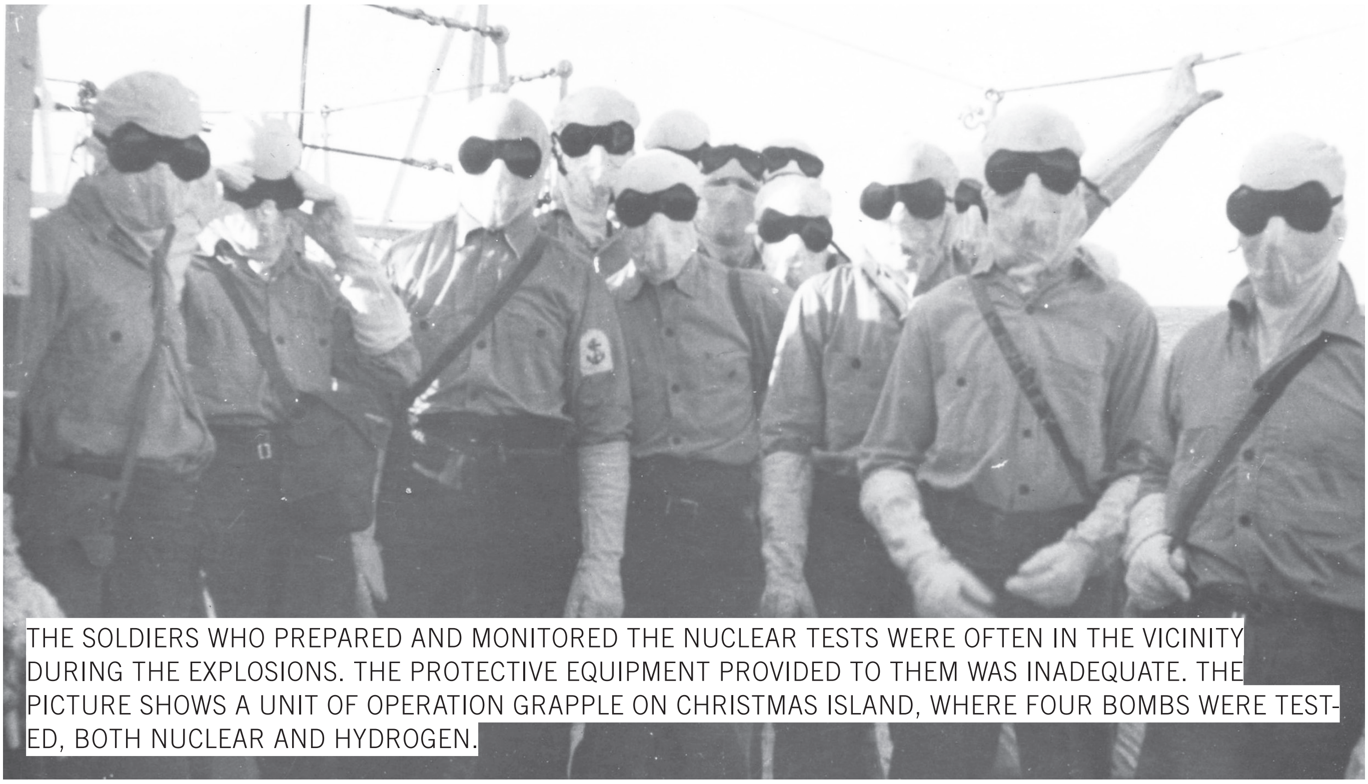
1 Losena Tubanavua-Salabula, Josua M Namoce, Nic Maclellan (eds). Kirisimasi: Fijian Troops at Britain's Christmas Island Nuclear Tests. Suva: Pacific Concerns Resource Centre, 1999, p. 15.

2 Nic Maclellan. Grappling with the bomb. Britain's Pacific H-bomb tests. Acton ACT: ANU Press, 2017, at https://press.anu.edu.au/publications?search=Grappling+with+the+bomb&sort=

3 SCOPE 1999, Chapter 3, p. 26 – Frederick Warner, Rene JC Kirchmann (eds), Scientific Committee on Problems of the Environment, International Council of Science (SCOPE 59). Nuclear test explosions: Environmental and human impacts. Chichester, UK: John Wiley & Sons, 2000. Can be downloaded chapter by chapter at https://scope.dge.carnegiescience.edu/SCOPE_59/SCOPE_59.html

4 SCOPE 1999, Chapter 3, Table 3.1, pp. 19-22 and SCOPE 1999, Appendix, Table A4, pp. 240-257

5 Maclellan 2017, p. 109



THE SOLDIERS WHO PREPARED AND MONITORED THE NUCLEAR TESTS WERE OFTEN IN THE VICINITY DURING THE EXPLOSIONS. THE PROTECTIVE EQUIPMENT PROVIDED TO THEM WAS INADEQUATE. THE PICTURE SHOWS A UNIT OF OPERATION GRAPPLE ON CHRISTMAS ISLAND, WHERE FOUR BOMBS WERE TESTED, BOTH NUCLEAR AND HYDROGEN.

Health aspects

As in Australia, radiation exposures for service personnel in the Christmas and Malden Island tests were not systematically monitored, and personal protection was minimal. Personnel were assembled in the open at varying distances with "backs to the blast" on land or on the decks of ships during each nuclear explosion.[6] Test participants wore standard shorts, shirts and boots, lived in tents, and drank surface fresh water.[7]

Protection standards were applied according to race. The Grapple Task Force Commander Air Vice Marshall Wilfred Oulton circulated to senior Task Force members a top-secret document explaining this:

> *"For civilised populations, assumed to wear boots and clothing and to wash, the amount of activity necessary to produce this dosage is more than is necessary to give an equivalent dosage to primitive peoples who are assumed not to possess these habits. For such peoples the corresponding level of activity is called level B'. It is assumed that in the possible regions of fall-out at Grapple there may be scantily clad people in boats to whom the criteria of primitive peoples should apply. ... It is desirable that the Declared Danger Area should at least enclose the whole region in which there is a possibility that level B' may be produced. The dosage at this level is about 15 times higher (for primitive peoples) than that which would be permitted by the International Commission on Radiological Protection."*[8]

6 IPPNW and IEER 1991, p.126-8 – International Physicians for the Prevention of Nuclear War and Institute for Energy and Environmental Research. Radioactive Heaven and Earth: The Health and Environmental Effects of Testing Nuclear Weapons In, On, and Above the Earth. New York: Apex Press 1991, at http://ieer.org/wp/wp-content/uploads/1991/06/RadioactiveHeavenEarth1991.pdf

7 Tubanavua-Salabula et al. 1999 – Losena Tubanavua-Salabula, Josua M Namoce, Nic Maclellan (eds). Kirisimasi: Fijian Troops at Britain's Christmas Island Nuclear Tests. Suva: Pacific Concerns Resource Centre, 1999.

8 Maclellan 2017, pp. 113-4

"Clean-up" operations included disposing of thousands of seabirds maimed, blinded or killed by the nuclear explosions, as well as dumping drums of nuclear waste into the ocean. The massive 3 Mt Grapple Y explosion, on 28 April 1958, detonated lower than anticipated and sucked up large quantities of water and debris, accentuating the radioactive fallout, which was also exacerbated by a wind change that blew the main fallout cloud over Christmas Island. Personnel report being soaked by radioactive rainout after various blasts, with reports of hair loss and skin burns soon afterwards suggestive of acute radiation effects (and therefore high doses).[9] "Sniffer" aircraft that flew through mushroom clouds minutes after the explosions to collect samples were associated with high exposures to the crews, with a mean of over 50 mSv per person per test.[10]

Well-conducted later studies among the New Zealand test veterans (who on average participated in 3 times as many nuclear tests as their British counterparts) demonstrated an excess of haematological (blood) cancers, including leukaemia.[11]

Sophisticated genetic studies in a group of veterans, compared with ex-servicemen controls extremely well matched except for their absence of nuclear test service, showed highly statistically significant (three-fold) higher rates of chromosomal abnormalities, such as translocations, dicentric chromosomes and complex chromosomal rearrangements, among the test veterans.[12] It is significant that such evidence of long-term genetic damage was evident fifty years after the veterans' exposure to nuclear tests. The New Zealand government in 1998 provided full war pensions for disabilities relating to their service for Christmas Island nuclear test veterans.

Successive British governments have systematically resisted long-standing legal claims for compensation from veterans of their nuclear tests in Australia and Kiribati, despite the fact that some British veterans who also worked on the 1962 US tests in Christmas Island received compensation from the US government for illnesses that would not be compensated by the UK.[13]

9 Tubanavua-Salabula et al. 1999, p17-18, 60-1; Maclellan 2017, p. 254.

10 IPPNW and IEER 1991, p. 128.

11 Neil Pearce, Ian Prior, David Methven, Christine Culling, Stephen Marshall, Jackie Auld, Gail de Boer, Peter Bethwaite. Follow-Up of New Zealand Participants in British Atmospheric Nuclear Weapons Tests in the Pacific. British Medical Journal, May 1990, Vol. 300 (6733): 1161-6. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1662929/pdf/bmj00177-0017.pdf

12 May Abdel Wahab, Elizabeth M Nickless, Radhia Najar-M'Kacher, Claude Parmentier, John V. Podd, R E Rowland. "Elevated Chromosome Translocation Frequencies in New Zealand Nuclear Test Veterans", Cytogenetic and Genome Research, June 2008, Vol. 121:79-87.

13 Maclellan 2017, p. 277

Fiji response

Fiji's Prime Minister Bainimarama (whose father who led the first Fijian naval contingent sent to Christmas Island) announced on 30 January 2015 that the Fiji government would grant compensation to the surviving Fijian military personnel who witnessed the UK Grapple nuclear tests in 1957–58:

"To this day, Britain has refused to pay compensation to anyone despite successive surveys that have shown veterans suffering from a range of terrible ailments – leukemia, other blood disorders, skin complaints and other conditions. And worse, these effects appear to have passed to some of their children, who were born with congenital deformities and a range of diseases. …

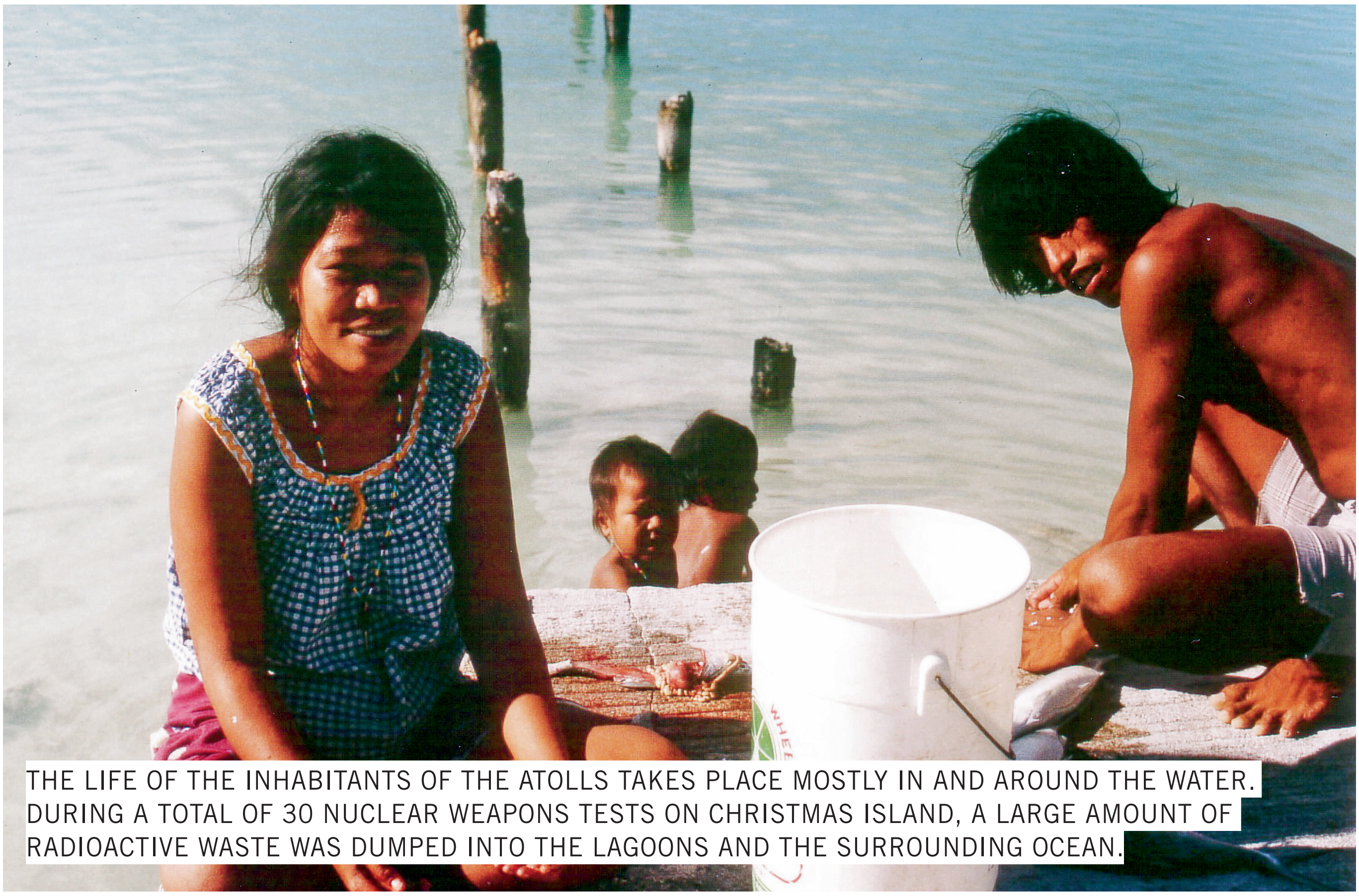
You may ask: why is Fiji taking responsibility for something that is the fault of Britain? My answer is this: Too much time has passed. The ranks of these survivors are rapidly thinning. Too many men – our fellow Fijians – have gone to their graves without justice. Those who remain deserve justice and Fiji as a nation is determined for them to finally get it. … There is a saying that justice delayed is justice denied. …

You are living testament to our determination to never again allow our pristine Pacific environment to be violated by outside powers in such a destructive and terrible manner.

… [N]ot only the British but other colonial powers such as the United States and France, used the Pacific to test weapons of mass destruction that some of them would never have tested in their own backyards. … As one, the Pacific nations stand and say: Never again. …

It is a form of madness that we in the Pacific – the ocean that takes its name from the word "peace" – find incomprehensible. … [W]e will always be on the side of those nations pressing for the dismantling of the world's nuclear arsenals. And to finally draw a line under the era that these men here today witnessed for themselves."[14]

14 Voreqe Bainimarama. Hon PM Bainimarama Speech at the First Pay-out to Veterans of Operation Grapple, Christmas Island. Fijian Government, 30 January 2015, at www.fiji.gov.fj/Media-Center/Speeches/HON-PM-BAINIMARAMA-SPEECH-AT-THE-FIRST-PAY-OUT-TO-.aspx



THE LIFE OF THE INHABITANTS OF THE ATOLLS TAKES PLACE MOSTLY IN AND AROUND THE WATER. DURING A TOTAL OF 30 NUCLEAR WEAPONS TESTS ON CHRISTMAS ISLAND, A LARGE AMOUNT OF RADIOACTIVE WASTE WAS DUMPED INTO THE LAGOONS AND THE SURROUNDING OCEAN.

Photo credit: Ingrid Schilsky

Clean-up

British forces left Kiritimati in 1963 after the Partial Test Ban Treaty became effective (which banned nuclear test explosions in every location except underground). Further material was dumped in the ocean; rusting trucks and vehicles and other equipment, batteries, drums of asphalt and oil, asbestos, and other materiel and debris were abandoned. Dispersal into the atoll environment and contact with people is inevitable over subsequent decades. Some equipment such as drums and corrugated iron sheeting were re-purposed by local people for housing and pig pens. In 2005, the UK Ministry of Defence provided 9.1 million pounds for a private contractor to remove and transport back to the UK 23,000 m^3 of material remaining from the tests carried out decades earlier.[15]

The island was subject to repeated local fallout, particularly from the largest Grapple Y test of 3 Mt on 28 April 1958. Two of the test weapons were suspended from balloons at 450m altitude over the southeast part of the island, producing low-altitude airbursts.

15 Maclellan 2017, p. 276-7

After Kiribati became independent from the UK in 1978, the Kiribati government sought confirmation of environmental radiation levels. The UK government requested and funded the New Zealand National Radiation Laboratory (NRL) to undertake a survey of residual radiation at Kiritimati. This was undertaken in March 1981. The survey report notes that "A British report on the final radiological survey and decontamination operations at Christmas Island prior to the closing down of the base in 1964 was made available to NRL".[16] The NRL concluded that radioactivity concentrations in soil were "found to be consistent with global fallout levels for a low rainfall equatorial area" and that "committed dose equivalents from drinking-water and locally produced foodstuffs for a postulated Gilbertese diet were estimated to be of the order of 0.01 mSv per year", and no restrictions on land use were recommended.[17] While this report is reassuring, questions remain around the monitoring and sam-

16 McEwan et al 1981, p.1 – AC McEwan, KM Matthews, LP Gregory. An Environmental Radiation Survey of Christmas Island, Kiribati. Report No. 1981/9 Christchurch: National Radiation Laboratory, 1981. https://cpb-us-w2.wpmucdn.com/blogs.pace.edu/dist/0/195/files/2018/08/newzealandsurveychristmasisland-002-1d16zt7.pdf

17 MacEwan et al 1981, Summary, p. 10-11.

pling procedures. According to the report, gamma measurements and soil samples were taken only from areas of undisturbed soil, and no purposive sampling in relation to test sites or sites of supportive infrastructure and material or waste on land or sea appears to have been undertaken. Sampling of foodstuffs and fresh water appears to have been very limited, for example testing water only on the western side of the island, and testing only two landcrabs, and one fish from unspecified locations of each of several species. Until the 1981 NRL report was put on the Pace University website in 2021 by independent researcher Matthew Bolton, none of the official radiological survey reports were available publicly.[18]

In 1992, the South Pacific Regional Environment Program called for radiological evaluation of the island:

> *"It is thus seen as critical to have Kiritimati Island reassessed for radioactive contamination in light of the increasing evidence based on the cancer levels in the Marshall Islands."*[19]

18 Becky Alexis-Martin, Matthew Breay Bolton, Dimity Hawkins, Sydney Tisch, Talei Luscia Mangioni. Addressing the humanitarian and environmental consequences of atmospheric nuclear weapons tests: a case study of UK and US test programs at Kiritimati (Christmas) and Malden Islands, Republic of Kiribati. Global Policy 2021 doi: 10.1111/1758-5899.12913.

19 Maclellan 2017, p. 276.

Signs in Maralinga are supposed to warn people about the radioactive environment. However, the indigenous people living in the area often could not read the signs. Since the warnings were not communicated in any other way, most of the inhabitants remained uninformed about the consequences of the test explosions.

Photo credit: Wayne England, https://creativecommons.org/licenses/by-nc-nd/2.0/

British nuclear weapons tests in Australia

Tilman Ruff

The nuclear test explosions

Between 1952 and 1957, the United Kingdom undertook 12 nuclear test explosions in Australia – three at the Monte Bello Islands in Western Australia, two at Emu Field, and seven at Maralinga, South Australia. These were a mixture of ground and airbursts, up to 98 kt in size, and supported the development of both fission weapons and thermonuclear (hydrogen) bombs.[1]

The major tests produced varying complex fallout patterns which contaminated the whole Australian continent, including cities, with the exception of the very southwest corner of Western Australia in the vicinity of Perth (see Maps). A 1985 Royal Commission found that the Australian Weapons Test Safety Committee failed in many of its tasks, and "at times it was deceitful and allowed unsafe firing to occur".[2].

Official fallout measurements were incomplete and were concealed from the public and in many cases the government.[3]

"Minor" trials

In addition, about 600 "minor trials" were conducted at Emu and Maralinga, between 1955 and 1963. No Australians were present at any of the minor trials, and their nature and the extent of contamination they caused were barely known until a Royal Commission examined the nuclear tests in 1985. The minor trials involved neutron initiator development trials using polonium-210 and beryllium (code-named Kittens); fissile material compression tests involving uranium, plutonium, beryllium and intense gamma sources (Tims and Rats); burning trials on rods of plutonium, uranium and beryllium, involving combustion and dispersion, and explosive dispersion of plutonium (Vixen A); and safety and development trials including detonations and subjecting nuclear weapons components and subassemblies to impacts, fire and other accidents (Vixen B).[4] The Vixen trials pose the greatest long-term contamination hazard because they involved high explosive detonations scattering of 22 kg of plutonium over distances of hundreds of kilometres.

1 Royal Commission 1985, Vol. 1 – Royal Commission into British Nuclear Tests in Australia. The Report of the Royal Commission into British Nuclear Tests in Australia. Canberra: Australian Government Publishing Service, 1985. Vol 1: https://parlinfo.aph.gov.au/parlInfo/search/display/display.w3p;query=Id:%22publications/tabledpapers/HP-P032016010928%22;src1=sm1

2 Royal Commission 1985, Vol. 3, Conclusion 47 – Royal Commission into British Nuclear Tests in Australia. The Report of the Royal Commission into British Nuclear Tests in Australia. Canberra: Australian Government Publishing Service, 1985. Vol 3: Conclusions and Recommendations: https://parlinfo.aph.gov.au/parlInfo/search/display/display.w3p;page=0;query=British%20nuclear%20tests%20in%20Australia%20volume%203;rec=2;resCount=Default

3 Royal Commission 1985, Vol. 3, Conclusions 2, 6, 9, 27–32, 47, 48 and others.

4 MARTAC 2003, p.10-13 – Maralinga Rehabilitation Technical Advisory Committee. Rehabilitation of former nuclear test sites at Emu and Maralinga (Australia) 2003. Canberra: Department of Education, Science and Training. https://www.industry.gov.au/data-and-publications/rehabilitation-of-former-nuclear-test-sites-at-emu-and-maralinga-australia-2013

It was not until the 1985 Royal Commission that much of the truth about the nuclear tests emerged, particularly the "minor trials", which were not minor in their consequences and indeed were responsible for the bulk of persistent contamination. The Royal Commission described "persistent deception and paranoid secrecy", with "British authorities embarked on a course of determined concealment of information from the Australian Government"[5].

The minor trials are assessed to have used the following radioactive and toxic materials[6]:

- 24.2 kg of plutonium (Pu)
- 15,900 kg of natural uranium/U-238
- 24 kg of enriched uranium
- 144 kg of beryllium
- 225 TBq of polonium-210
- 78.7 TBq of scandium-46
- 4.4 TBq of lead-212
- 5 MBq of actinium-227

Inadequate measurements led to the levels of plutonium reported by the UK in 1968 being about an order of magnitude (tenfold) lower that field results measured by the Australian Radiation Laboratory in 1985.[7]

High energy and temperature dispersal of plutonium and uranium in the Vixen B trials created myriad tiny heterogeneous micron-sized radioactive 'hot' particles. Oxidation and mobility of uranium is widespread in the environment. Most hot particles contain low valence plutonium-uranium-carbon compounds which are chemically reactive, but initially protected by their inclusion in metallic alloys. Chemical and physical weathering likely result in long-term, slow release of plutonium into dust or groundwater, now mobile and bio-available to be taken up by wildlife. Plutonium particles released by weathering are not only mobile, but smaller, increasing their surface area and the radiological risk associated with plutonium's alpha emission. Nano-particle-facilitated transport of plutonium in groundwater has been identified at the Nevada Test Site, Rocky Flats and Hanford in the US, at Mayak in Russia, and at Chernobyl (Ukraine), Sellafield (UK) and Marcoule (France).[8]

Aboriginal people

Those at highest radiation exposure risk were local Aboriginal people and pastoralists, who were not systematically evacuated or even informed; and over 16,000 workers directly exposed to the tests.[9] Warning signs in English were usually incomprehensible to the Aborigines. Some were enveloped and irradiated by local fallout (the "Black Mist" phenomenon after the Totem 1 test on 15 October 1953) sufficient for a high proportion of inhabitants of the communities of Wallatina and Mintabie and neighbouring homesteads in northern South Australia to develop typical symptoms of acute radiation sickness, signifying a high level of acute radiation exposure, after the first test at Emu Field (Totem 1).[10] The Royal Commission concluded that the phenomenon had been real, despite earlier denials by various British and Australian officials.

The Royal Commission report was scathing about the appalling treatment of indigenous Australians during the tests. Aboriginal people were within prohibited zones and lived in them during and for up to six years after tests. Officials responsible for their safety demonstrated "ignorance, incompetence and cynicism" and failed to consider "their special vulnerability to radioactive fallout". The Royal Commission assessed that decades of denial of access to their traditional lands by Aboriginal people "contributed to their emotional, social and material distress and deprivation"[11].

Aboriginal people were put in double jeopardy by being disproportionately exposed to test radiation, and through greater radiation exposure that is associated with traditional and cultural practices – often involving dusty play environments for children, walking barefoot, light clothing, sitting and sleeping on the ground, hunting, gathering and eating local foods, cooking on open fires, being on and taking care of country and ceremonies.

5 Royal Commission 1985, Vol. 2, p.414 – Royal Commission into British Nuclear Tests in Australia. The Report of the Royal Commission into British Nuclear Tests in Australia. Canberra: Australian Government Publishing Service, 1985. Vol 2: https://parlinfo.aph.gov.au/parlInfo/search/display/display.w3p;query=Id%3A%22publications%2Ftabledpapers%2FHPP032016010929%22;src1=sm1

6 MARTAC 2003, p.13.

7 MARTAC 2003, p.27.

8 Megan Cook, Barbara Etschmann, Rahul Ram, Konstantin Ignatyev, Gediminas Gervinskas, Steven D. Conradson, Susan Cumberland, Vanessa N. L. Wong and Joël Brugger. The nature of Pu-bearing particles from the Maralinga nuclear testing site, Australia. Scientific Reports 2021, Vol. 11:10698. At: https://www.nature.com/articles/s41598-021-89757-5

9 Gun et al 2006, p.xvii – Richard Gun, Jacqueline Parsons, Philip Ryan, Philip Crouch and Janet Hiller. Australian Participants in British Nuclear Tests in Australia, Vol. 2: Mortality and Cancer Incidence, Department of Veterans Affairs, Canberra, 2006. At: https://www.dva.gov.au/documents-and-publications/british-nuclear-testing-australia-studies

10 Royal Commission Report 1985, Vol. 3, Conclusion 97, and Vol. 1, para. 6.4.92, p. 194 and accompanying account pp. 174–194.

11 Royal Commission 1985 Vol. 1, p. 319, 323, and Royal Commission, Vol. 3, Conclusions 90, 91, 117, 124–125, 140, 186.

These are associated with increased soil and dust ingestion and inhalation.[12]

Important documentation of the experience of the inhumane impacts of the British nuclear tests on Aboriginal people includes Yalata 2009[13] and Lester 1993[14].

Test site workers

Permissible radiation dose limits for whole-body penetrating radiation for workers from 1950 were 5 millisieverts (mSv) per week[15], compared with current occupational limits averaging 20 Sv per year and 1 mSv per year for the public. Yet measures to comply with even the low standards of the time were frequently deficient. Veterans describe lack of protective clothing and equipment, soldiers sent into ground zero the same day after an explosion, and unpressurized aircraft flying through fallout clouds.[16] The Royal Commission described "departures, some serious and some minor, from compliance with the prescribed radiation protection policy and standards"[17]. Despite no more than 4 % of veterans having radiation film-badge data available, external exposures of more than 400 mSv (following the first Monte Bello test) were documented.[18]

Accounts from test participants provide illuminating evidence about the conduct, monitoring, working conditions and health and safety management. Some of the most informative accounts are those by Tynan 2016[19], Walker 2014[20] and Cross and Hudson 2005[21].

12 SM Haywood and J Smith. Assessment of the potential radiological impact of residual contamination in the Maralinga and Emu areas. NRPB-R237, National Radiation Protection Board (NRPB).

13 Yalata and Oak Valley communities, with Christobel Mattingley. Maralinga. The Anangu story. Crows Nest: Allen & Unwin, 2009.

14 Yami Lester. Yami. 2nd ed. Alice Springs: Jukurrpa Books, 2000.

15 Royal Commission 1985, Vol. 1, p. 39–85, especially Table 4.5.1, p. 78.

16 Royal Commission 1985, Vol. 1.

17 Royal Commission 1985, Vol.3, Conclusion 52, p. 12.

18 Royal Commission 1985, Vol. 3, Recommendation 52 and Royal Commission, Vol. 1 p.125-6.

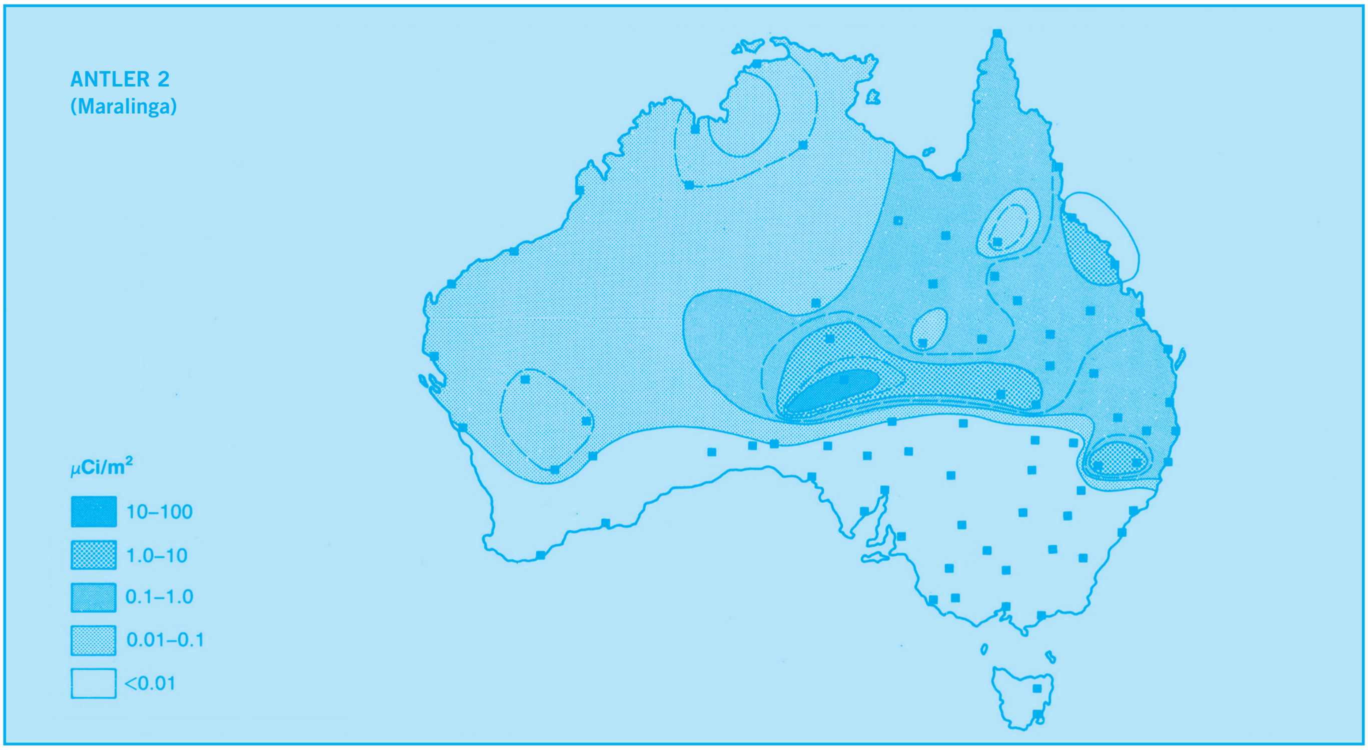
19 Elizabeth Tynan. Atomic thunder. Sydney: NewSouth Publishing, 2016.

20 Walker 2014 – Frank Walker. Maralinga. Sydney: Hachette Australia, 2014.

21 Roger Cross, Avon Hudson. Beyond belief. Kent Town: Wakefield Press, 2005.

NOT ALL PARTICIPANTS IN THE NUCLEAR TESTS IN AUSTRALIA (SEEN HERE: MARALINGA) WERE PROVIDED WITH SUCH PROTECTIVE EQUIPMENT. MANY SOLDIERS HAD TO FIGHT FOR A LONG TIME TO HAVE HEALTH PROBLEMS RECOGNIZED AS CONSEQUENCES OF THE NUCLEAR EXPLOSIONS. THE ABORIGINES LIVING IN THE SURROUNDING AREA WERE ALSO NOT PROTECTED OR EVEN INFORMED.

Photo credit: Australian Government, public domain



Measured radioactive fallout after the tests. 1 microcurie (μCi) = 37,000 Bq = 37 kBq. Square = test station

A belated government-funded mortality and cancer study of test veterans was concluded in 2006. Despite a "healthy worker effect" (evident in reduced non-cancer mortality rates) and major methodological limitations of a retrospective study with incomplete data fifty years after the nuclear tests began, it found statistically significant 23 % higher rates of cancer and 18 % higher cancer mortality between 1982 (29 years after the first test) and 2001 in veterans exposed to nuclear tests compared with the general population.[22]

Clean-ups

A hasty British clean-up in 1967 involving ploughing and disc-harrowing of plutonium-contaminated areas, and shallow burial of material from 180 hectares of heavily contaminated land (which was then declared "radiologically safe"), led to a 1968 agreement between the British and Australian governments releasing Britain from liability for any future claims related to its nuclear tests.[23] However, a 1984 study by the Australian Radiation Laboratory demonstrated far more extensive and severe contamination than had previously been revealed, proving invalid the information and hazard assessment on which the 1968 agreement had been based.[24] The Commission recommended that "action should be commenced immediately to effect the clean-up of Maralinga and Emu … so that they are fit for unrestricted habitation by the traditional Aboriginal owners as soon as practicable", and that "[a]ll costs of any future clean-ups at Maralinga, Emu and Monte Bello Islands should be borne by the United Kingdom Government"[25].

Maralinga was declared 'safe' in 2000 after a second limited A$108 (US$76) million clean-up funded by both governments, despite expert concerns and failure to implement the planned process of immobilizing plutonium fragments through in situ vitrification after an explosion occurred in a pit.[26] During the clean-up 1994–9, 40 ground zero sites were found rather than the 26 documented by the UK, additional waste pits were found, thousands of tonnes of contaminated debris were iden-

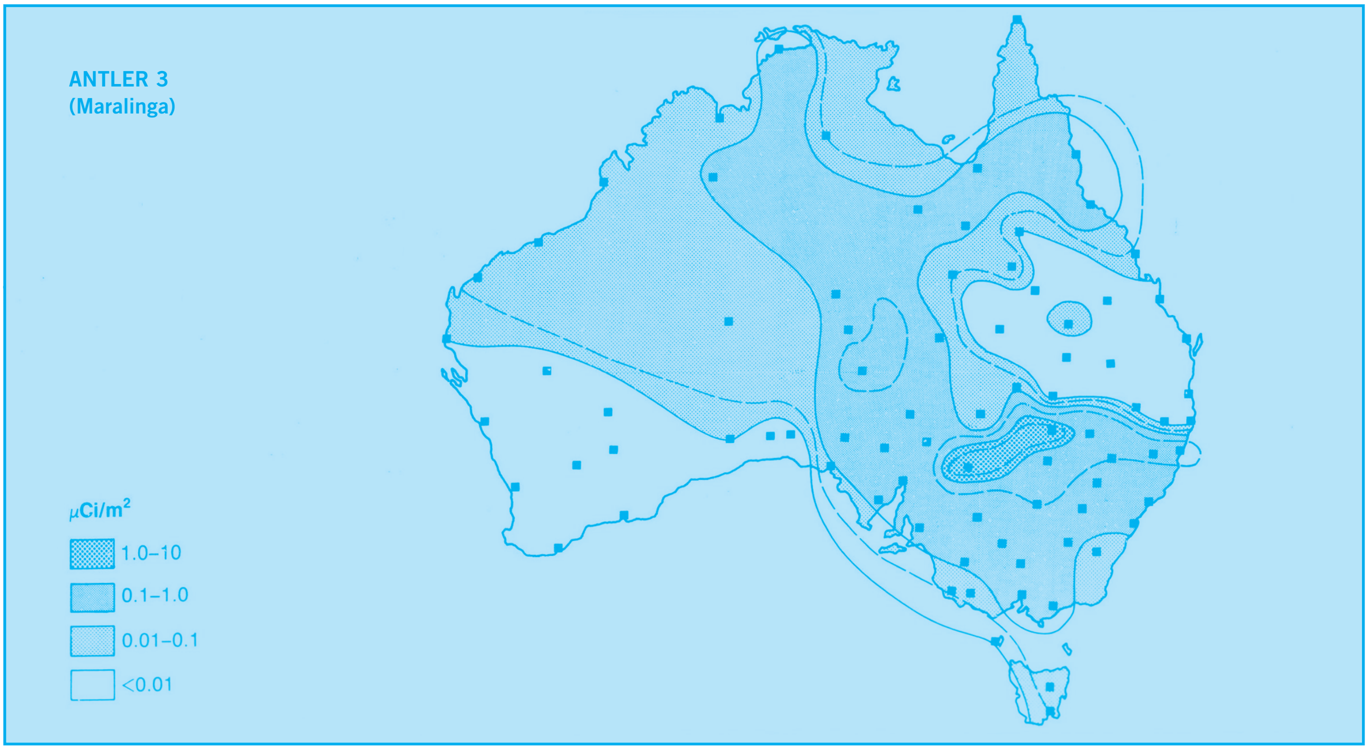
22 Gun et al 2006.

23 Royal Commission 1985, Vol. 2, pp.539-40.

24 Royal Commission 1985, Vol. 2, pp. 539–540, 549–552.

25 Royal Commission 1985, Vol. 3, recommendations 3 and 6.

26 Parkinson 2002, pp.77-81 – Alan Parkinson. Maralinga: The Clean-Up of a Nuclear Test Site. Medicine & Global Survival, Vol. 7, No. 2, 2002; Alan Parkinson. The Maralinga Rehabilitation Project: Final Report. Medicine, Conflict and Survival, Vol. 20, No. 1, 2004, pp.70-80.



Measured radioactive fallout after the tests. 1 microcurie (μCi) = 37,000 Bq = 37 kBq. Square = test station

tified beyond pit boundaries, and at least 3 contaminated sites were found by accident.[27]

A region of 412 km² marked with boundary markers remains unsuitable for permanent occupation with boundary markers that will last fifty years, while half the plutonium-239 will still be there in 24,400 years.[28] This area enclosing most of the Vixen B plumes from Taranaki is notionally restricted to traditional hunting and transit on the basis that radiation exposure with unrestricted use could be expected to be over 5 mSv/y, and up to 13 times greater within that area.[29] However official estimates by the end of the clean-up suggested radiation doses at the boundary were unlikely to reach greater than 1 mSv/y.[30] Less than 2 % of contaminated areas clean-up at the Taranaki "minor trials" site meet the clean-up clearance criteria of less than 3 kBq americium-241/m² (based on the 1998 plutonium:americium ratio), and 84 % of the plutonium contamination remains on the surface[31]; yet no further clean-up is planned.

Numerous other sites underwent soil removal (individual areas up to 1.5 km²), and/or contain disposal pits and burial trenches containing concentrations of radioactive and toxic material.[32] In 2011, a report obtained under Freedom of Information laws documented that only a decade on, a number of traditional burial pits have been subject to subsidence and erosion, requiring further remediation.[33]

Unresolved issues many decades later include remaining contamination, inadequate clean-up of test sites, indigenous dispossession, and inadequate compensation for Aboriginal people, ex-military personnel and civilians for their hazardous exposure, illness and loss. In 2006, 54 years after the tests began, the government announced provision of free care for

27 Alan Parkinson, Maralinga: Australia's Nuclear Waste Cover-up. Sydney: ABC Books, 2007

28 Parkinson 2002.

29 Parkinson 2002.

30 MARTAC 2003, p.366.

31 Parkinson 2002.

32 MARTAC 2003, Chapter 6.

33 Philip Dorling, "Ten Years after the All-Clear, Maralinga is Still Toxic", Sydney Morning Herald, 12 November 2011. At: https://www.smh.com.au/environment/ten-years-after-the-all-clear-maralinga-is-still-toxic-20111111-1nbsd.html

cancers to all test participants (military, public servant and civilian), and in 2010 military veterans were extended the same benefits as veterans involved in operational service or service recognized as "hazardous".[34] In 2017, a Veteran Gold Card supporting comprehensive health care was made available to all Australian participants in British nuclear tests, including certain civilians within limited areas within 10–40 km of test sites. This excludes for example, those subjected to the Black Mist. However, there is still no readily available compensation for those exposed. For survivors, time is running out. In 2001, 40 % of test participants were confirmed to have died.[35]

Unethical research

The conduct of much research and monitoring of fallout from nuclear tests has been seriously deficient in ethical conduct, respect for human rights, transparency and accountability. An Australian example is an extensive programme of sampling of human bones for strontium-90. From 1957 to 1978, hospital pathology services were paid to remove sometimes quite sizeable samples of bone from about 22,000 bodies at autopsy, particularly of infants and children. In the 1950s and 1960s, samples were sent to the United Kingdom or United States (under "Project Sunshine") for testing. Permission was not sought from families, who were not aware of the programme or the fact that many remains were kept without their knowledge or consent for decades.[36] There are disturbing reports of families being denied access to their dead children's bodies or not being able to bury them after bones had been removed, of foetuses having been discarded, and of children having been buried anonymously.[37]

This study was one of approximately 4,000 human radiation experiments conducted under the auspices of the US Atomic Energy Commission over the period 1944–74. Some involved significant health risk to subjects; in some experiments, patients were subjected to sufficiently high doses to develop acute radiation sickness, which was sometimes fatal.[38]

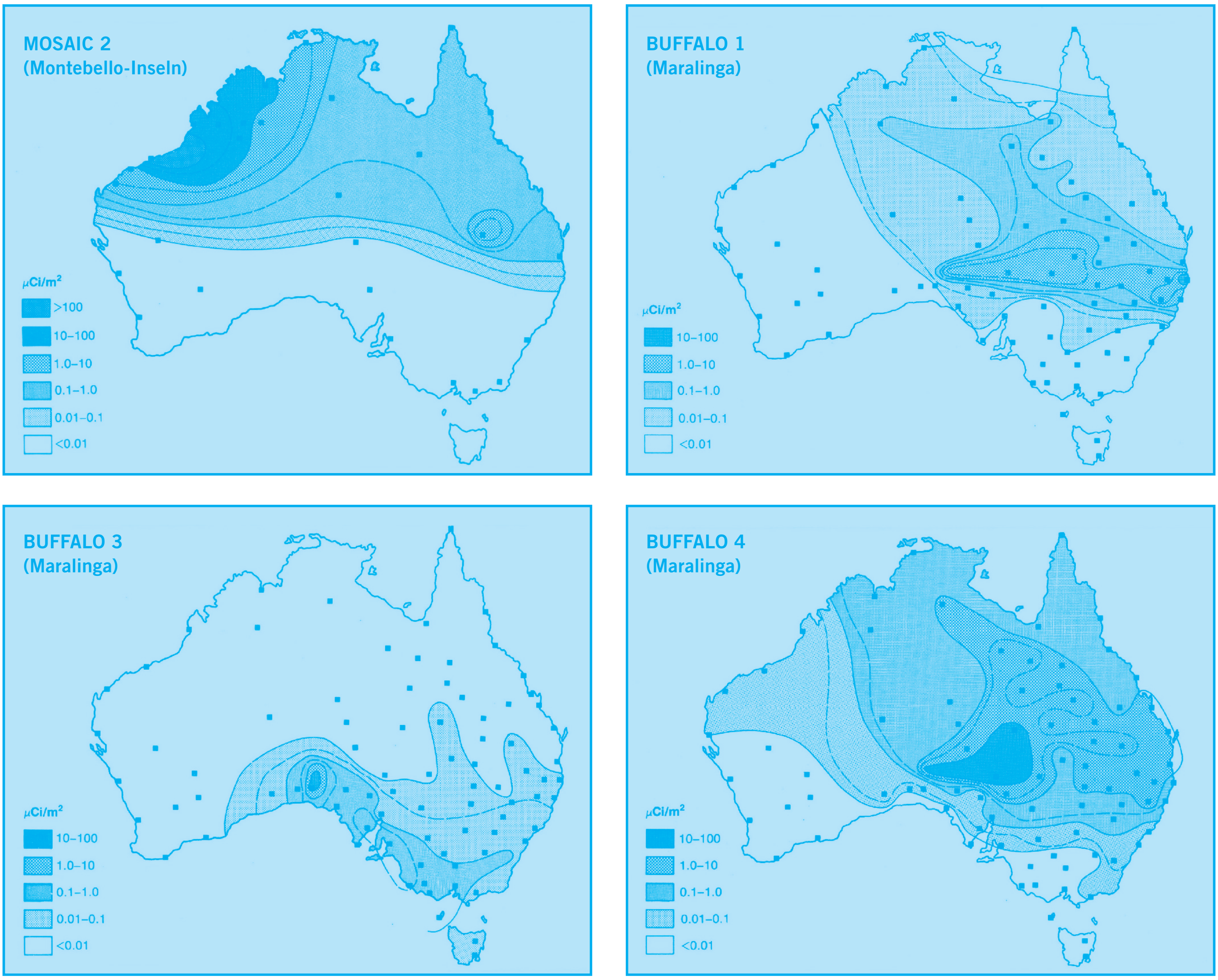
34 Department of Veterans' Affairs, Australian Government. Claims for nuclear test of bomb site exposure. 2022. At: https://www.dva.gov.au/financial-support/compensation-claims/claims-nuclear-test-or-bomb-site-exposure

35 Gun et al 2006, p. xvii.

36 Australian Health Ethics Committee, National Health and Medical Research Council. Ethical and Practical Issues Concerning Ashed Bones From the Commonwealth of Australia's Strontium 90 Program, 1957–1978. Advice of the Australian Health Ethics Committee to the Commonwealth Minister for Health and Ageing, Senator the Honourable Kay Patterson, Canberra, March 2002, pp. 4-6.

37 Walker 2014, p. 218-30.

38 Advisory Committee on Human Radiation Experiments. Final Report. Washington, DC: US Government Printing Office, October 1995, p. 779. At: https://bioethicsarchive.georgetown.edu/achre/final/report.html



Maps of measured radioactive fallout after the tests. 1 microcurie (µCi) = 37,000 Bq = 37 kBq. Square = test station

On July 25, 1946, the U.S. Army detonated the "Baker" nuclear test bomb with a yield of 21,000 tons of TNT equivalent underwater near the Bikini Atoll. 106 nuclear tests were carried out between 1946 and 1962 on the Marshall Islands.

Photo credit: U.S. Department of Defense, public domain

The U.S. nuclear weapons tests in the Marshall Islands

Arjun Makhijani

The tests and the test location

The United States carried out 23 nuclear weapon tests at Bikini Atoll between 1946 and 1958 with a total explosive power estimated at 76.8 Mt and 43 tests between 1948 and 1958 at Enewetak Atoll with a total explosive power of 31.7 Mt. Additionally, one other test was conducted within the Marshall Islands, in the stratosphere at about 26 km altitude, about 140 km northeast of Enewetak Atoll, for a total of 67 tests.[1] The total explosive power of 108.5 Mt was about 100 times the total yield of all surface, tower, and atmospheric tests conducted at the Nevada Test Site.[2] Another metric is that the Marshall Islands tests were equivalent to exploding one Hiroshima size bomb every day for about 20 years.

The first nuclear tests after World War II were conducted at Bikini Atoll in July 1946 during Operation Crossroads. The tests were proposed by the U.S. military to examine the impact of nuclear bombs in a naval environment, including on ships, since, as one general noted, "[w]e now have full information on the atomic bomb on land targets", evidently referring to the atomic destruction of Hiroshima and Nagasaki in August 1945.[3] Commodore Ben Wyatt recounted that he persuaded the people of Bikini to move on a Sunday after church services, because he "compared the Bikinians to the children of Israel whom the Lord saved from their enemy and led into the Promised Land."[4]

The matter was put more bluntly by Admiral William Blandy, who was the commander of an amphibious task force in the Pacific theater during World War II:

> *"We wish to acquire ... a few miserable islands of insignificant economic value, but won with the precious blood of America's finest sons, to use as future operating bases. All that can be raised on most of these islands is a few coconuts, a little taro, and a strong desire to be somewhere else"[5].*

The evacuation caused loss of ancestral homes, livelihood and tradition. The places of resettlement were not a "Promised Land"; in fact, the Bikinians preferred their own land and made that explicit when asked a few months after they had been moved.[6]

1 table: "United States Nuclear Tests By Date" in: Department of Energy: Nevada Operations Office. United States Nuclear Tests July 1945 through September 1992, DOE/NV--209-REV 15. Washington, D.C.: U.S. Department of Energy, December 2015, at https://www.nnss.gov/docs/docs_LibraryPublications/DOE_NV-209_Rev16.pdf

2 calculated from SCOPE 1999, Chapter 3, Table 3.1 – Frederick Warner, Rene JC Kirchmann (eds). Scientific Committee on Problems of the Environment, International Council of Science (SCOPE 59). Nuclear test explosions: Environmental and human impacts. Chichester, UK: John Wiley & Sons, 2000. Can be downloaded chapter by chapter at https://scope.dge.carnegiescience.edu/SCOPE_59/SCOPE_59.html

3 as quoted in Jonathan Weisgall, Operation Crossroads: The Atomic Tests at Bikini Atoll. Annapolis, Maryland: Naval Institute Press, 1994, p. 15.

4 as quoted in Weisgall 1994, op. cit., p. 107.

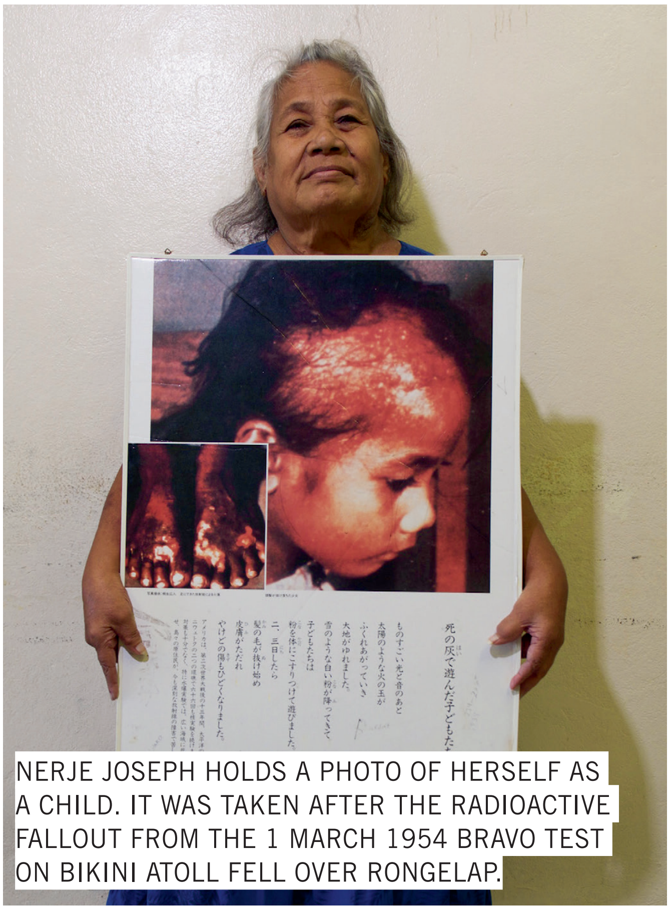
5 as quoted in Weisgall 1994, op. cit., p. 311.

6 Weisgall 1994, op. cit. p. 308 and p. 310.

The Marshall Islands were remote from large population centers – a factor in their selection. But they were not remote for the Marshallese people, they were home. And they were selected despite the fact that the military's own evaluation stated that the location did not "in the main" meet the meteorological criteria for safety. One of the criteria was that there should be "no possibility of subjecting personnel to radiological hazards or surrounding land or water area to unintentional radioactive contamination"[7]. The testing location was also contrary to the recommendation of Colonel Stafford Warren after the July 1945 test in New Mexico that similar tests should be done in a place that was "at least 150 miles" away from human habitation.[8] Ailinginae, Rongerik, and Rongelap Atolls are all less than 100 miles from Bikini Atoll. Later tests were also done at Enewetak Atoll; Bikini Atoll is well under 150 miles from Enewetak.

7 as quoted in IPPNW and IEER 1991, p. 72 – International Physicians for the Prevention of Nuclear War and Institute for Energy and Environmental Research. Radioactive Heaven and Earth: The Health and Environmental Effects of Nuclear Weapons Testing In, On, and Above the Earth. New York: Apex Press 1991, at http://ieer.org/wp/wp-content/uploads/1991/06/RadioactiveHeavenEarth1991.pdf

8 Stafford L. Warren. Memorandum to Major General Groves, Subject: Report on Test II at Trinity 16 July 1945; dated 21 July 1945, at http://ieer.org/wp/wp-content/uploads/2003/07/14_staffordmemo_trinity_1945.pdf



NERJE JOSEPH HOLDS A PHOTO OF HERSELF AS A CHILD. IT WAS TAKEN AFTER THE RADIOACTIVE FALLOUT FROM THE 1 MARCH 1954 BRAVO TEST ON BIKINI ATOLL FELL OVER RONGELAP.

Photo credit: Mark Edward Harris

Finally, it is important to note that the initial tests bore out the negative meteorological assessment. After the 1948 Operation Sandstone tests at Enewetak, James P. Cooney, who was a radiological safety officer, wrote that "Enewetak Atoll has proven to be a far from satisfactory site for atomic tests"[9]. Yet the United States persisted in testing in the Marshall Islands, including at Enewetak Atoll, with tragic results. In fact, about two-thirds of the tests were done at Enewetak Atoll.

Health impacts

Fallout occurred all over the Marshall Islands as a result of the 67 nuclear weapon tests carried out there; this is evident from the fallout map from just the 1954 CASTLE test series[10], based on measurements at the time and published by the U.S. Department of Commerce. Yet, most of the Marshall Islands is not yet operationally recognized as an affected area by the United States government.

In addition to Bikini and Enewetak, where the tests were carried out, the most severely impacted atolls were northern atolls to the east of these test sites, including Rongelap, Ailinginae, Rongerik, and Utrik atolls. Atolls to the southeast, like Ailuk Atoll, 300 miles from Bikini, also suffered high fallout, especially from the 15 megaton thermonuclear weapon test at Bikini called BRAVO, carried out on 1 March 1954.[11]

The BRAVO test showed an attitude that was worse than disregard of Warren's safety recommendation. The weather report in the days before the test indicated westerly winds, which meant that atolls to the east of Bikini were at risk. The outlook worsened a few hours before the test and indicated that Alinginae, Rongerik, and Rongelap would be directly in the path of the fallout. The test was carried out anyway.[12] The U.S. military

9 as quoted in IPPNW and IEER 1991, p. 72.

10 see maps below, from List 1955 – Robert J. List. Worldwide Fallout from Operation CASTLE. Washington, D.C.: U.S. Department of Commerce, 17 May 1955 at https://www.osti.gov/servlets/purl/4279860-EGhXto/

11 Moss-Christian 2021, p. 2 – Rhea Moss-Christian. Statement of Rhea Moss-Christian Chairperson of the Marshall Islands National Nuclear Commission Before the House Committee on Natural Resources Subcommittee on Oversight & Investigations Regarding the U.S. Nuclear Legacy in the Marshall Islands, October 21, 2021, at https://naturalresources.house.gov/download/testimony_rheamosschristian_102121pdf

12 Barbara Rose Johnston and Holly M. Barker. Consequential Damages of Nuclear War: The Rongelap Report, Walnut Creek, CA: Left Coast Press, 2008 and Ruff 2016, p. 21 – Tilman Ruff, "The humanitarian impact and implications of nuclear test explosions in the Pacific region", International Review of the Red Cross, Vol. 97 (899), July 2016 at https://international-review.icrc.org/sites/default/files/irc97_15.pdf ; the date is as per the website at https://international-review.icrc.org/articles/humanitarian-impact-and-implications-nuclear-test-explosions-pacific-region

chose not to evacuate those atolls immediately or even warn the people who lived there that they were at risk, unlike prior tests in the Marshall Islands.[13] In fact, atolls farther out, like Ailuk, were also impacted seriously but were never evacuated.[14]

The catastrophe that followed the BRAVO test is well documented. It was summarized by Dr. Tilman Ruff in an article for the International Review of the Red Cross:

> *"Two islands and part of a third were vaporized in the explosion, and fallout rained down on the food crops, water catchments, houses, land and bodies of children, women and men going about their daily activities. Children played with the unknown 'snow' and rubbed it in their hair and on their skin. The residents of Rongelap, Ailinginae and Utrik Atolls were finally evacuated two and a half days later, after having received near-lethal doses of radiation, the highest following a single test in the history of nuclear test explosions worldwide."*[15]

There were short-term somatic effects, like vomiting, damage to the mucosal lining of the gastro-intestinal tract, and radiation burns (called "beta burns") on the skin. Such acute radiation sickness occurs only with high exposures. The average exposure to 86 people on Rongelap was officially estimated at 1.9 Sv[16], creating a cancer risk of one in five in this population from this single test. Of course many had exposures in excess of this amount.

A Japanese fishing boat, the Daigo Fukuryu Maru (Lucky Dragon No. 5), was in the vicinity at the time of the 1 March 1954 BRAVO test: its crew also suffered high radiation exposures and acute radiation illnesses. One of the crew members died seven months later, others were hospitalized. It was not the only fishing boat contaminated in 1954. Monitoring by Japan during that year found contaminated fish in the holds of 683 boats; 457 tons of tuna caught by Japanese boats had contamination above then-prevailing limits.[17]

Doses from the Bravo test for the people who experienced high fallout were so high that the National Cancer Institute made the following, rather shocking statement in its 2004 assessment, after half a century of additional testing, fallout and the severe 1986 Chernobyl nuclear power plant accident: "Doses at Rongelap and Ailinginae were very high and were in a range for which there is little experience in dose estimation or health risk assessment."[18]

The same report concluded that the Marshall Islands population would suffer 500 excess cancers due to the radiation exposure from nuclear weapons testing. This is an enormous increase in cancer risk – 9 %, given the small population of the Marshall Islands[19]. This is comparable to about six million excess cancers on the mid-1950s population of the United States.

People all over the Marshall Islands were exposed by the testing, far beyond the three islands that have been recognized (Rongelap, Ailinginae, and Utrik) for medical monitoring by the U.S. government. Even Enewetak is not so recognized.[20] The radiation doses estimated by the U.S. government tell a different story. For instance, the official average thyroid dose estimate to people in Kwajalein, considered a "low-exposure atoll", was as high as 270 mGy. Several atolls were designated "very low exposure atolls"; one such was Majuro, where the capital of the Marshall Islands is located; the people there (and other "very low exposure atolls") had an average thyroid exposure of 75 mGy.[21]

The National Cancer Institute, based on what it called "a carefully considered analysis", later revised its estimate down to 170 excess cancers[22]; this would be equivalent to about 2 million excess cancers in the U.S. population. The revised dose estimates in the latter paper on which the lower estimate is based are far lower than independent estimates or even those of the Department of Energy itself.

13 Ruff 2016, pdf. p. 21.

14 Moss-Christian 2021, p. 2.

15 Ruff 2016, pdf p. 21, italics added.

16 IPPNW and IEER 1991, p. 76.

17 IPPNW and IEER 1991, p. 78.

18 NCI 2004, p. 9 – National Cancer Institute. Estimation of the Baseline Number of Cancers Among Marshallese and the Number of Cancers Attributable to Exposure to Fallout from Nuclear Weapons Testing Conducted in the Marshall Islands. Washington, D.C.: U.S. Department of Health and Human Services, September 2004, at https://marshall.csu.edu.au/Marshalls/html/Radiation/NCI-report.pdf

19 NCI 2004, p. 17.

20 Moss-Christian 2021, pp. 1-2.

21 NCI 2004, Table 1, p. 8.

22 NCI 2010 – National Cancer Institute. NCI Dose Estimation and Predicted Cancer Risk for Residents of the Marshall Islands Exposed to Radioactive Fallout from U.S. Nuclear Weapons Testing at Bikini and Enewetak, 2010, at https://dceg.cancer.gov/research/how-we-study/exposure-assessment/nci-dose-estimation-predicted-cancer-risk-residents-marshall-islands and Simon et al. 2010 – Steven L. Simon, André Bouville, Charles E. Land, and Harold L. Beck. Radiation doses and cancer risks in the Marshall Islands associated with exposure to radioactive fallout from Bikini and Enewetak nuclear weapons tests: summary, Health Physics, Vol. 99, No. 2, August 2010, at https://pubmed.ncbi.nlm.nih.gov/20622547/

BIKINIANS IN THE MARSHALL ISLANDS BEING EVACUATED FROM THEIR HOME ISLAND AFTER NUCLEAR TESTING IN THE AREA BY THE US IN MARCH 1946.

Photo credit: United States Navy, public domain

For instance, Simon et al. estimate that the total thyroid doses to adults on Utrik and Rongelap from all tests was 760 mGy and 7,600 mGy respectively; children's exposures were estimated to be about three times higher.[23] In contrast an 83-page-long 1985 Brookhaven National Laboratory report[24], which was a careful analysis of thyroid doses alone from the BRAVO test alone based on radiological measurements, estimated the Utrik and Rongelap thyroid doses (average of male and female exposures) to be 1,650 mGy and 12,000 mGy respectively. Six-year old children were estimated to have exposures about twice as high, while the doses to one-year-olds were estimated to be four times higher. These estimates would lead to cancer estimates closer to those in the 2004 NCI report, cited above.

Independent dose estimates are even higher than the above DOE estimates. For instance, a study prepared for Sanford Cohen & Associates, a company that undertakes radiation-related contracts with various U.S. government agencies, compared various dose estimates and cited thyroid doses to adults on Utrik as 27 Sv, about 17 times higher than the 1985 DOE estimate and 35 times higher than the estimate used by the National Cancer Institute in 2010. The dose estimates for children were similarly higher.[25]

The DOE dose estimates are high; the independent estimates are extremely high. Such estimates would indicate a much higher health toll, including but not only in terms of excess cancer mortality. Indeed, the findings of a Special Rapporteur for the United Nations Human Rights Council who investigated the impacts of testing on the Marshall Islands included the following[26]:

"30. The Special Rapporteur heard compelling testimony by women on their experience of returning from Rongelap Atoll, including on the alarmingly high rates of stillbirths, miscarriages, congenital birth defects and reproductive problems (such as changes in menstrual cycles and the subsequent inability to conceive, even in those who previously had no such difficulties). Some gave birth to babies that ultimately died from foetal disorders, and they still endured the shame and trauma they experienced as a result….

31. Several years after exposure, a high incidence of thyroid cancer was reported, as well as an unusually high prevalence of stunted growth among Marshallese children. The incidence of such cases was also supported by the number of claims before the Nuclear Claims Tribunal."

23 Simon et al. 2010

24 Edward T. Lessard, Robert P. Miltenberger, Robert A. Conard, Stephen V. Musolino, Janikiram R. Naidu, Anant Moorthy, and Carl J. Schopfer. Thyroid Absorbed Dose for People at Rongelap, Utirik, and Sifo on March 1, 1954, BNL 51882. Long Island, New York: Brookhaven National Laboratory, 1985, at https://www.osti.gov/servlets/purl/5547703

25 Bernd Franke, Review of Radiation Exposures of Utrik Atoll Residents. Heidelberg, Germany: ifeu-Institut für Energie- und Umweltforschung, GmbH, prepared for Sanford Cohen & Associates, 2002, p. 39

26 UN Human Rights Council 2012. At: https://documents-dds-ny.un.org/doc/UNDOC/GEN/G12/163/76/PDF/G1216376.pdf?OpenElement

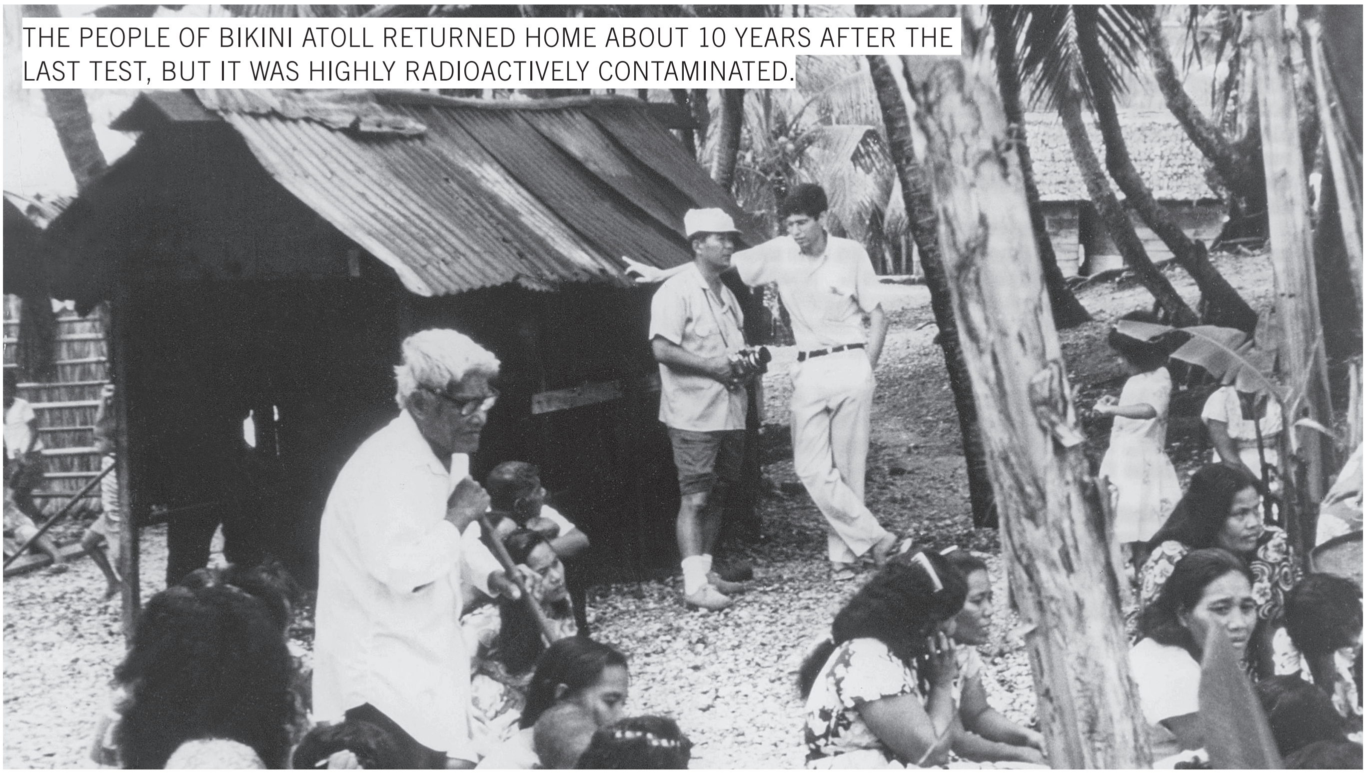

THE PEOPLE OF BIKINI ATOLL RETURNED HOME ABOUT 10 YEARS AFTER THE LAST TEST, BUT IT WAS HIGHLY RADIOACTIVELY CONTAMINATED.

Photo credit: U.S. Department of Energy, public domain

The use of the terms "low exposure" and "very low exposure" in the 2004 National Cancer Institute report should be put in context of exposures elsewhere, notably the United States. The National Cancer Institute has also done estimates of thyroid exposures in the United States due to atmospheric testing in Nevada[27], which roughly overlapped in time with the testing in the Marshall Islands.[28]

The highest exposures were in five counties, four in Idaho and one Montana (out of about 3,000 total counties in the United States). The average doses in these five counties were 120 mGy to 160 mGy; the average estimated exposure in the so-called "low exposure atolls" was approximately double that in the highest exposed U.S. counties. Given that these are averages over significant areas and populations, many individual doses would lower and many would be substantially higher, the latter bringing with it a correspondingly higher risk of cancer and other health problems. Children, especially female children, would be the most affected because their risk of cancer per unit of exposure is much higher than that of adults.[29] However, the United States government has never recognized any but three atolls as having been affected – Rongelap, Alinginae, and Utrik. No one else has been deemed exposed enough to merit health evaluations, much less care.[30] The opportunity to reduce the health impact by providing medical care or even to identify the health problems at the atolls deemed "low exposure" and "very low exposure" has been missed for all the decades since the tests. The fact that those Marshallese who were given checkups and some care were seen as experimental subjects should be noted. A 1956 U.S. Atomic Energy Commission document explicitly referred to them in the following words:

> *"While it is true that these people do not live, I would say, the way Westerners do, civilized people, it is nevertheless true that they are more like us than **the** mice."*[31]

The bold word "the" refers to the experimental mice in laboratories on whom a large amount of radiation research was, and

27 NCI 1997 – National Cancer Institute. Estimated Exposures and Thyroid Doses Received by the American People from Iodine-131 in Fallout Following Nevada Atmospheric Nuclear Bomb Tests. Washington, D.C.: U.S. Department of Health and Human Services, 1997, at https://www.cancer.gov/about-cancer/causes-prevention/risk/radiation/i131-report-and-appendix

28 Nevada Test Site atmospheric testing started and ended a few years later than Marshall Islands testing – 1951 to 1962 compared to 1946 to 1958 respectively.

29 table 6 and Figure 6, p. 38, summarize the risk factors, in: Arjun Makhijani, Brice Smith, Michael C. Thorne. Science for the Vulnerable: Setting Radiation and Multiple Exposure Environmental Health Standards to Protect Those Most at Risk. Takoma Park, Maryland: Institute for Energy and Environmental Research, 2006, at http://ieer.org/wp/wp-content/uploads/2006/10/Science-for-the-Vulnerable.pdf

30 Moss-Christian 2021, pp. 1-2.

31 as quoted in IPPNW and IEER 1991, p. 82, italics added.

is, done. In fact, the exposed people were enrolled in a secret human experiment without informed consent, as the Chair of the Marshall Islands National Nuclear Commission stated in her 21 October 2021 testimony to a Congressional oversight subcommittee:

> *"Following their evacuation after the Bravo event, the people of Rongelap and Utrōk were unknowingly enrolled by the U.S. Government in a top-secret medical experimentation program known as 'Project 4.1' to study the effects of radiation exposure on human beings. This study includes control populations whose bodies were similarly used by U.S. medical researchers to harvest bone marrow, teeth, organs, and blood to better understand the capabilities of U.S. weapons of mass destruction."*[32]

Nuclear testing in the Marshall Islands was a disaster from the very first test series in Bikini, Operation Crossroads, through the entire program until it ended in 1958. As the fallout maps, the impact was global, especially, but not only, in the Northern Hemisphere. It was also a disaster for the armed forces personnel who participated. The cumulative fallout from the 1954 test series as measured and estimated by the United States government is shown in the maps at the end of this article.[33]

Consider also Test Baker, the second test, on 25 July 1946, during Operation Crossroads at Bikini. It was exploded just underwater; it sent a million tons of radioactive spray 6,000 feet into the air, which came raining down on everything in the vicinity. Prior to the test, the radiation safety team had warned that "extremely serious" radiological conditions would be created if the water column did not rise to more than 10,000 feet. It also warned that the radiological problem "may remain dangerous for an interminable time thereafter." The advice was ignored and the test was carried out.[34]

A number of captured Japanese "target ships" were stationed in Bikini lagoon as part of the test. The lagoon itself became intensely radioactive, since some of the neutrons released from the underwater test converted the normal, non-radioactive sodium in sea salt into sodium-24, which is a very high energy beta-emitting radionuclide. Contrary to radiological safety advice, U.S. Navy ships were moved into the lagoon; the radioactive lagoon water was used, among other things, to wash down meat, to wash the decks, and in distillation equipment on board. Sailors scrubbed the decks to try to clean them, suspending radioactive material; there were hot spots scattered all over. As might be expected, naval officers did not know how to handle such situations, since this was their first encounter with atomic weapons and related radiation. The radiological safety team was led by Colonel Stafford Warren, who also led the team during the first-ever nuclear test in July 1945 in New Mexico. But their experience was largely ignored; indeed, one of the safety team members complained of "the blind 'hair-chested' approach to the matter [of radiological safety] with a disdain for the unseen hazard" among many naval officers.[35]

The existence of hot spots that could give many times the then-permitted daily dose limit to armed forces personnel of 1 mGy/day[36] was noted in the safety documents. Instruments to measure plutonium in the field were not available. Rather, gam-

APRIL/MAY 1948: PARTICIPANTS IN THE NUCLEAR TESTS ON ENIWETOK ARE MEASURED FOR RADIOACTIVITY.

Photo credit: U.S. Department of Energy, public domain

32 Moss-Christian 2021, p. 2.

33 from List 1955, pdf pages 20 and 21.

34 Operation Crossroads documents as quoted in Makhijani and Albright 1983, pdf, p. 3 – Arjun Makhijani and David Albright, Irradiation of Personnel at Operation Crossroads: An Evaluation Based on Official Documents. Washington, D.C.: International Institute for Radiation Research, 1983, at http://ieer.org/wp/wp-content/uploads/1983/05/crossroads.pdf

35 see Makhijani and Albright 1983 generally for this paragraph; the quote is from pdf p. 4.

36 The regulation at the time was 0.1 roentgen per day, which is approximately 1 mGy/day.

A HELICOPTER OVER UJELANG ATOLL. ON SEVERAL ISLANDS, INCLUDING ENWETOK, BIKINI, RONGELAP AND UTRIK, THE SOIL, LAGOON WATER, SEAFOOD, PLANTS AND AIR HAVE BEEN MONITORED TO ENSURE RADIATION DOES NOT EXCEED PERMISSABLE LEVELS.

Photo credit: U.S. Department of Defense, public domain

ma radiation and beta radiation were measured. Operation Crossroads' chief of radiological safety, Stafford Warren noted that "[e]very contaminated place as evidenced by the gamma or beta radiation on any surface of any vessel may be in fact the residence of many lethal doses of this alpha emitter [plutonium]"[37].

Besides the direct health impacts of radiation, there have also been other health impacts. Nuclear explosions have damaged coral reefs, which encourages the growth of a single-celled organism that produces a toxin and contaminates fish. Known as ciguatera poisoning, it does not impact the fish, but does impact the people who consume them, as it has the Marshallese. A 1982 survey found that over half of the Marshallese reported such poisoning in the prior year.[38]

There have also been serious impacts from dislocation and the concomitant loss of traditional work and diet, the consumption of processed food supplied, the long and costly distances to medical care, and the enduring stresses of loss of homelands to which many have not been able to return.[39]

Radiological contamination

Marshall Islands testing produced widespread radiological contamination. Nearly 80 % of the explosive power of 138.6 Mt of all U.S. atmospheric tests is accounted for by the tests on the Marshall Islands. Assuming rough proportionality of fission products, there would remain about 90 GBq of cesium-137 and 50 GBq of strontium-90, decay corrected to 2020, in addition to long-lived fission products like technetium-99 and iodine-129 which would be essentially undecayed from their initial amounts. About 160 kg of plutonium-239 would also remain.[40]

Bikini and Enewetak atolls, where the testing was done, would have been impacted the most in terms of residual radioactivity. In addition, the United States create a vast nuclear waste site on Runit Island in Enewetak Atoll in the 1970s in a crater created by one of the nuclear tests. The crater was not lined before tens of thousands of cubic meters of radioactive waste were dumped into it, including local U.S.-generated waste and waste sent to Runit from the Nevada Test Site. The waste pit was covered with a concrete dome.[41] The pit itself is unlined and is in communication with the ocean and its tides and currents. As a result it leaks radioactivity into the Pacific Ocean and Enewe-

37 as quoted in Makhijani and Albright 1983, pdf p. 20, italics added.

38 IPPNW and IEER 1991, pp. 86-88.

39 Moss-Christian 2021, pp. 6-7.

40 Calculated from data in IPPNW and IEER 1991, Chapters 2 and 3.

41 DOE 2020 – Department of Energy, Report on the Status of the Runit Dome in the Marshall Islands: Report to Congress. Washington, D.C.: U.S. Department of Energy, June 2020 at https://www.energy.gov/sites/prod/files/2020/06/f76/DOE-Runit-Dome-Report-to-Congress.pdf

Photo credit: US Defense Special Weapons Agency, public domain

AFTER THE TESTING ENDED, NUCLEAR WASTE WAS SEALED WITH AN EIGHT-METER-HIGH CONCRETE SARCOPHAGUS ON RUNIT ISLAND (ENIWETOK).

tak Atoll's lagoon. While Runit itself is uninhabited, people did move back to other parts of the atoll in 1980.

In its 2020 report to Congress on the Runit dome, the Department of Energy noted that there was damage to the concrete dome, including cracks in it; it nonetheless opined that "the dome is not in any immediate danger of collapse or failure"[42]. Independent researchers at the Center for Nuclear Studies, Columbia University, point to the reasons for far greater concern:

> *"The structural integrity of the Runit Dome, a concrete shell covering over 100,000 cubic yards of nuclear waste on an island of Enewetak Atoll, is at risk because of rising sea levels. Leakage from the dome—already occurring—is likely to increase and higher tides threaten to break the structure open in the coming decades."* [43]

The DOE report did note that leakage of radioactivity from the dome was entering the ocean and hence "the marine food chain"; but apart from some maintenance, monitoring and repair of the concrete, no remedial action is planned.[44] Of course, Enewetak lagoon and the inhabited islands are also contaminated; in fact the vast majority of the contamination is in these places.[45]

The Runit dome dramatically illustrates one of the major problems of remediation. If radioactive materials are gathered from exposed and dispersed locations, their disposal in a well-constructed site could temporarily lower risks, especially from radionuclides with relatively short half-lives. However, man-made structures are no match for the longevity of radionuclides like plutonium-239 (half-life more than 24,000 years), especially when subject to harsh conditions such as salty air and spray as well as the eroding impacts of tides and storms, exacerbated by global heating associated sea-level rise and increasing severity of storms and other extreme weather events. In the case of the Runit dome, the problem is much worse because the disposal site was an unlined crater created by a nuclear blast that would have severely damaged and fractured it, essentially guaranteeing leakage into the marine environment. In contrast, at about the same time that this unlined disposal site was created at Runit, the United States decided, in 1978, to spent vast sums of money to move tens of millions of tons of uranium mill tailings from unlined ponds where they were contaminating groundwater, to lined ponds. As of 1999, about 1.5 billion dollars had been spent to make such transfers to protect groundwater and the environment.[46]

Conclusions

The Marshall Islands tests, like others, were accompanied by evaluations of the military use of nuclear weapons in wartime. Among the most stark was the evaluation done after the very first tests, Operation Crossroads in 1946, conducted at Bikini. Radiological contamination due to second test of the series, Test Baker on 25 July 1946, was so severe that the Joint Chiefs of Staff evaluation considered the contamination itself as a possible major element of the use of nuclear weapons in war: the aim would be to produce "fear" in the civilian population. It is worth quoting at length because it puts in stark contrast the treatment and lack thereof afforded the people of the Marshall Islands who actually experienced the fallout:

42 DOE 2020, p. 4.

43 Hart Rapaport and Ivana Nikolic-Hughes, The U.S. Must Take Responsibility for Nuclear Fallout in the Marshall Islands: Congress needs to fund independent research on radioactive contamination and how to clean it up, Scientific American, April l 4, 2022, at https://www.scientificamerican.com/article/the-u-s-must-take-responsibility-for-nuclear-fallout-in-the-marshall-islands/

44 DOE 2020

45 Moss-Christian 2021, p.2.

46 Energy Information Administration. Uranium Mill tailing Sites Under the UMTRA Project: Remediation of UMTRCA Title I Uranium Mill Sites Under the UMTRA Project Summary Table: Uranium Ore Processed, Disposal Cell Material, and Cost for Remediation as of December 31, 1999. Washington, D.C.: U.S. Department of Energy, at https://www.eia.gov/nuclear/umtra/

"We can form no adequate mental picture of the multiple disaster which would befall a modern city, blasted by one or more bombs and enveloped by radioactive mists. Of the survivors in the contaminated areas, some would be doomed by radiation sickness in hours, some in days, some in years. But, these areas, irregular in size and shape, as wind and topography might form them, would have no visible boundaries. No survivor could be certain he was not among the doomed, and so added to every terror of the moment, thousands would be stricken with a fear of death and the uncertainty of the time of its arrival."[47]

The psychological element of the feat was also made clear in the same evaluation:

"In the face of ... the bomb's demonstrated power to deliver death to tens of thousands, of primary military concern will be the bomb's potentiality to break the will of nations and of peoples by the stimulation of man's primordial fears, those of the unknown, the invisible, the mysterious. We may deduce from a variety of established facts that the effective exploitation of the bomb's psychological implications will take precedence over the application of the destructive and lethal effects in deciding the issue of war."[48]

Despite some compensation as part of the Compact of Free Association, which ended the trusteeship of the United States and made the Marshall Islands an independent country, the Marshallese people continue to suffer. Adequate compensation and health care have not been forthcoming, as indicated by the October 2021 testimony of the Chair of the Marshall Islands National Nuclear Commission, Rhea Moss-Christian, to a congressional oversight subcommittee:

"The Nuclear Claims Tribunal remains open to receive any claims of personal injury and property damage caused by the nuclear tests. Several claims remain pending, as well, dependent on Congress' replenishment of the Tribunal Fund. The last compensation award and initial payment were made in December 2008, leaving over $23 million in unpaid personal injury awards and over $2 billion in unpaid property damage awards, making it clear that by the end of 2008, the Tribunal would no longer be able to fulfil its mandate arising out of the Section 177 Agreement, 'to render final determination upon all claims past, present, and future….which are based on, arise out of, or are in any way related to the Nuclear Testing Program.' In this context, please recall that both the explosive force and the radiation doses suffered by the Marshall Islands were greater than the Nevada Test Site downwinders, but the awards for the Marshallese have been much lower."[49]

47 IPPNW and IEER 1992, p. 143, italics added.

48 IPPNW and IEER 1992, p. 144, italics added.

49 Moss-Christian 2021, p. 9.

More than six decades after testing ended and more than three decades after the Soviet Union collapsed, the Marshall Islands are still left pleading for justice:

"There is still so much work to do and through this Subcommittee's efforts, there is a chance for progress, but this requires an acknowledgment of the full scope of damages and injuries by the US Government. To this day there has never been an apology from the US Government for the ongoing hardships Marshallese endure. The Nuclear Claims Tribunal is the mutually-agreed established forum for addressing the harms of the U.S. nuclear testing program. People who have been granted awards deserve to get them in full; others, who are in process or who may apply in the future, deserve a chance to be heard and have their claims fairly adjudicated. The Runit Dome and all that it represents about radiation still present in our environment requires closer attention and a reassessment and revision of DOE's mandate. People require health care beyond our means to provide in the RMI; they deserve a U.S. standard of health care to treat illnesses linked to U.S. activities on our islands. And people need the tools and knowledge to be able to participate and contribute to research that seeks to enhance our understanding of how radiation is impacting our lives and livelihoods."[50]

50 Moss-Christian 2021, pp. 9-10.

Further References:

Calin Georgescu. Report of the Special Rapporteur on the implications for human rights of the environmentally sound management and disposal of hazardous substances and wastes, Addendum: Mission to the Marshall Islands (27-30 March 2012) and the United States of America (24-27 April 2012), at https://documents-dds-ny.un.org/doc/UNDOC/GEN/G12/163/76/PDF/G1216376.pdf?OpenElement

In Operation Buster-Jangle, the U.S. military practiced ground operations following nuclear weapons deployments. The soldiers were sometimes only about 9 km away during the explosions. After the explosions, they came as close as 900 m to ground zero. The exercises were intended to show the psychological effects that the use of nuclear weapons had on the troops and their deployment.

Photo credit: Federal Government of the United States, public domain

The U.S. nuclear weapons tests in Nevada

Arjun Makhijani

The Nevada Test Site (NTS)[1] had the largest number of nuclear explosions of any nuclear test site in the world. 100 of them were atmospheric tests, starting on 27 January 1951. Six of the 828 underground tests had significant venting of radioactive materials, notably in the early underground testing period; the last of these was the Baneberry test, on 18 December 1970.[1]

Choice of the Nevada Test Site

The location of the test site in terms of protection of the public from fallout was contrary to the recommendation of the Chief of Radiological Safety at the very first nuclear weapons test conducted in the New Mexico desert on 16 July 1945. Noting that there was fallout as much as 200 miles (320 km) away from the test location on the fourth day after the test, Colonel Stafford L. Warren recommended that future similar tests be done at a site "preferably with a radius of at least 150 miles without population…."[2]. The choice of the Nevada Test Site disregarded this recommendation. In general the atmospheric tests were conducted when the winds were blowing away from the Los Angeles and Las Vegas metropolitan areas. As a result, prevailing westerly winds meant that almost the entire country that lay east of NTS suffered fallout, much of it in hot spots, including some that were as far as New York State, about 4,000 km away. The Nevada Test Site is on Western Shoshone land.[3]

Health impacts

A detailed study of health impacts of atmospheric testing was published by the National Cancer Institute in 1997.[4] The health impact assessment was partial by design since the study focused on doses from short-lived iodine-131 alone and on thyroid cancer. Yet, the study illustrated how widespread the fallout had been and the great difference that hot spots, often created by rainout of radioactivity, made to radiation doses and cancer risk. NCI 1997 estimated that about 5.5 million TBq of I-131 was released[5] – roughly 10 million times more than the I-131 release officially estimated for the 1979 Three Mile Island nuclear power plant accident.[6]

The estimated collective radiation dose to the thyroids of the 160 million people in the United States exposed to the fallout was about 3 million person-Gy, with an average individual dose of about 0.02 Gy. Doses to large numbers of young people

1 IPPNW and IEER 1991, Chapter 4 – International Physicians for the Prevention of Nuclear War and Institute for Energy and Environmental Research. Radioactive Heaven and Earth: The Health and Environmental Effects of Nuclear Weapons Testing In, On, and Above the Earth. New York: Apex Press 1991, at http://ieer.org/wp/wp-content/uploads/1991/06/RadioactiveHeavenEarth1991.pdf

2 Stafford L. Warren, Memorandum to Major General Groves, Subject: Report on Test II at Trinity 16 July 1945; dated 21 July 1945, at http://ieer.org/wp/wp-content/uploads/2003/07/14_staffordmemo_trinity_1945.pdf

3 Nuclear Princeton. Nevada Test Site. Princeton, NJ 2022, at https://nuclearprinceton.princeton.edu/nevada-test-site

4 NCI 1997 – National Cancer Institute. Estimated Exposures and Thyroid Doses Received by the American People from Iodine-131 in Fallout Following Nevada Atmospheric Nuclear Bomb Tests. Washington, D.C.: U.S. Department of Health and Human Services, 1997, at https://www.cancer.gov/about-cancer/causes-prevention/risk/radiation/i131-report-and-appendix

5 NCI 1997, p. ES.1.

6 TMI Commission. Report of the President's Commission on the Accident at Three Mile Island – The Need for Change: The Legacy of TMI, October 1979, p.31. At: https://www.osti.gov/servlets/purl/6986994

under 20 years old averaged five times higher. The number of thyroid cancers that resulted was estimated to be between 11,300 and 212,000, with a central estimate of 49,000 thyroid cancers.[7]

Four of the five most affected counties were in Idaho, while the fifth was in Montana. All were largely rural and 1,000 or more kilometres away from the test site. The average estimated thyroid dose in these counties (all ages) was between 0.12 Gy and 0.16 Gy as can be seen on the accompanying map. These doses are county averages; in general, it is likely that there would be considerable variation within counties, especially as some of them are very large. For example, Meagher County, Montana has an area of more than 6,000 km^2. Most of the fallout was due to tests conducted in 1952, 1953, 1955, and 1957.[8]

It was known during the 1950s that I-131, when deposited on vegetation and consumed by grazing animals (cows, goats, and sheep), became concentrated in their milk. Since I-131 has a half-life of only about eight days, the fresher the milk, the higher the dose to those who drank it, all other things being equal. As a result farm families, especially children, and among children, girls, were disproportionately impacted. Despite the knowledge, milk producers were given no information to help protect the country's milk supply. In contrast, the photographic film industry, which at the time packaged film in crop residues, was given advance notice of expected fallout patterns so that it could protect its film supply from radiation-caused fogging.[9]

The National Cancer Institute did not make estimates of radiation dose or cancer incidence for the people of Canada and Mexico, though some of their people also experienced fallout from atmospheric testing at NTS, as is clear from fallout at their respective borders in maps in NCI's report.[10]

A follow-up National Cancer Institute study examined the feasibility of estimating doses from all radionuclides and all atmospheric to the U.S. public. The study estimated that 22,000 cancers, resulting in 11,000 deaths in the United States would be caused by fallout; about 10 % of these deaths were estimated to be from leukemia. In view of the risk of leukemia, this study also estimated dose to the bone marrow of children born on 1 January 1951 (the month that testing started at NTS), as an illustration of children who would be most affected due to their date of birth. Essentially all children born then would have received bone marrow doses of 1 mGy or more. Children in large parts of the county, notably in areas to the northwest of NTS and also in the Midwest were estimated to have bone marrow doses of more than 3 mGy.[11] The full study was never completed.

Worldwide radioactive fallout

Atmospheric testing fallout was deposited all over the world; the contamination from long-lived radionuclides remains. US atmospheric testing (both at NTS and the Pacific Ocean region), deposited on the order of 260 kg of unfissioned plutonium-239 in fallout, essentially all of which remains in the environment. This represents almost half of the total plutonium in fallout from tests by all nuclear weapon states.[12] As a reference, the Natural Resources Defense Council has estimated that the Nagasaki bomb contained slightly more than 6 kg of plutonium.[13] US tests (both at NTS and the Pacific Ocean region) also resulted in the deposition of over a quarter of a million terabecquerels (TBq) of strontium-90 and over 400,000 TBq of cesium-137. More than three-fourths of these two radionuclides have decayed away in the decades since the last U.S. atmospheric test.

7 NCI 1997, p. ES.2 and Institute of Medicine. Exposure of the American People to Iodine-131 from Nevada Nuclear-Bomb Tests: Review of the National Cancer Institute Report and Public Health Implications. Washington, D.C.: National Academy Press, 1999, at https://nap.nationalacademies.org/login.php?record_id=6283&page=https%3A%2F%2Fnap.nationalacademies.org%2Fdownload%2F6283

8 NCI 1997

9 Pat Ortmeyer and Arjun Makhijani, "Worse than We Knew," Bulletin of the Atomic Scientists, Vol. 53, No. 6, 1997, at https://www.tandfonline.com/doi/pdf/10.1080/00963402.1997.11456789?needAccess=true

10 NCI 1997, Figures 3.21 and 3.22 for the border with Canada and Figures 3.28 and 3.30 for the border with Mexico

11 NCI 2005, Summary and Chapter 3 – National Cancer Institute. Report on the Feasibility of a Study of the Health Consequences to the American Population of Nuclear Weapons Tests Conducted by the United States and Other Nations. Washington, D.C.: U.S. Department of Health and Human Services, May 2005, zip file with all chapters at https://www.cdc.gov/nceh/radiation/fallout/feasibilitystudy/Technical_Vol_1_PDF.zip

12 based on data in Chapters 2 and 3 of IPPNW and IEER 1991.

13 Thomas B. Cochran and Christopher E. Paine. The Amount of Plutonium and Highly Enriched Uranium Needed for Pure Fission Weapons. Washington, D.C.: Natural Resources Defense Council, 1995, at https://nuke.fas.org/cochran/nuc_04139501a_144.pdf

Testing also resulted in uneven deposition of radionuclides on the NTS area itself. Besides bomb tests, plutonium dispersal tests were also conducted. Some of areas in the NTS have been used as radioactive and hazardous waste disposal sites.[14]

Underground testing impacts

Underground testing at NTS has left a larger inventory of long-lived radionuclides below the test site. An estimated 50,000 TBq of Sr-90, 80,000 TBq of Cs-137 and 1,700 kg of plutonium-239 remain on the site as of approximately 2020.[15] There are also very long-lived fission products, including technetium-99, cesium-135, and iodine-129 in the underground inventory that will last essentially forever (half-lives: about 210,000 years, 2.3 million years and 15.7 million years respectively). It is as yet unclear what long-term ecological damage to the underground environmental will be over such time frames.

The U.S. Department of Energy estimates that some of the groundwater on the site has been contaminated by the tests.[16]

"Corrective action sites"

There are about 2,200 "corrective action sites" at NTS at or near the surface; some remediation actions have been taken on almost all of them. Over 90 % of 878 deep underground "corrective action sites" are the subject of long-term monitoring. A transition to long-term monitoring indicates no current plans for corrective actions. Long-term modeling of groundwater flows covering a period of 1,000 years is among the methods being used to assess possible future risk.[17]

14 DOE 2021, Chapter 10 – Nevada National Security Site. Environmental Report 2020. Washington, D.C. National Nuclear Security Administration, Department of Energy, DOE-NV-03624--1210, September 2021, at https://www.nnss.gov/docs/docs_LibraryPublications/Nevada%20National%20Security%20Site%20Environmental%20Report%202020%20-%20Final.pdf

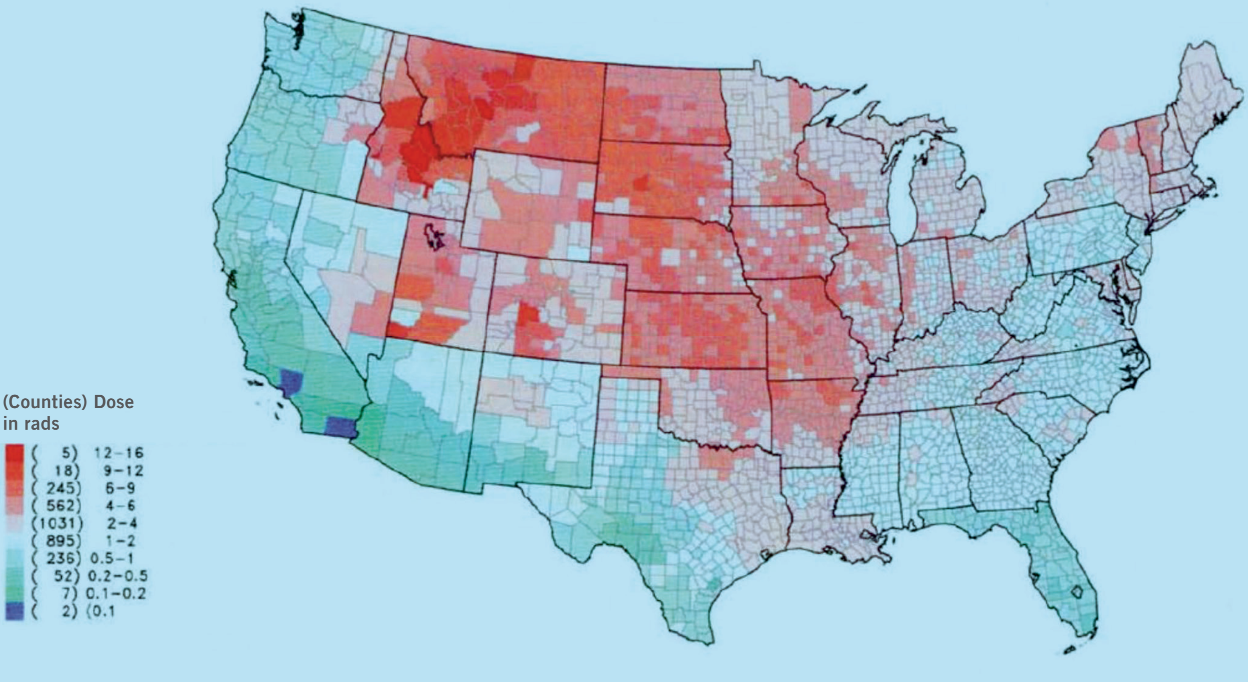
15 decay-corrected estimates, based on IPPNW and IEER 1991.

16 DOE 2021

17 DOE 2021, p. 11-1, 11-4 and 11-5.

Further References:
National Nuclear Security Administration. Nevada National Security Site Environmental Monitoring Report: 2020. Washington, D.C.: Department of Energy, September 2021, at https://www.osti.gov/biblio/1822366-nevada-national-security-site-environmental-report

Thyroid doses per inhabitant from atmospheric nuclear tests on the NTS



Novaya Zemlya Island is located in the Arctic Ocean. Despite the harsh climatic conditions, it has been inhabited since early times, mainly by the indigenous Nenets population. In addition, the island offers a diverse flora and fauna, and the north has been a national park since 2009 to protect Arctic nature. The latter was also severely affected by the 130 nuclear weapons tests conducted from 1955 to 1990. The largest test was the 50-megaton "Tsar Bomba" bomb, the most destructive nuclear bomb of all time.

Photo credit: Nixette, creativecommons.org/licenses/by-sa/4.0/deed.en

The Soviet nuclear weapons tests at Novaya Zemlya

Arjun Makhijani

The test site location

The Soviet government selected a northern site in Novaya Zemlya for nuclear testing in 1954; the nearest village, Amderma, was 280 km away. A southern site was also selected; the atmospheric tests were done at the northern site. Only seven of the tests on Novaya Zemlya were done at the southern site; all were underground, between 1973 and 1975.[1]

Radioactivity dispersal

The plan for Novaya Zemlya was to do far more powerful tests than those at the Semipalatinsk Test Site. One hundred and four indigenous Nenets families were evacuated 1,000 km away to the Archangelsk area.[2] More than 100 atmospheric tests were conducted on Novaya Zemlya with a cumulative explosive power of about 239 Mt[3], about 36 times more than the total explosive power of atmospheric tests at the Semipalatinsk Test Site. Using standard coefficients for generation of strontium-90 and cesium-137 and assuming 30 % of the total power was from fission (the rest being from fusion),[4] the inventory of these two radionuclides in fallout would be 266,000 TBq and 426,000 TBq respectively, dispersed over vast areas, given the immense power of many of the tests. The largest test ever, "Tsar Bomba" in 1961, was 58 Mt. More than three-fourths of this radioactivity would have decayed away by 2020. Unfissioned plutonium-239, essentially all still dispersed in the environment, would be roughly 170 kg.

There was also intense deposition of fallout in the sea as a result of the atmospheric tests at Novaya Zemlya. For instance, concentrations of strontium-90 in the Kara sea in 1963 reached as high as 39 Bq/m^3, which decreased to 5 Bq/m^3 by 1994[5] in part due to decay and in part due to dispersal.

1 Nils Bøhmer, Alexander Nikitin, Igor Kurdik, Thomas Nilsen, Michael H. McGovern, Andrey Zolotov. The Arctic Nuclear Challenge: Bellona Report Volume 3. Oslo, Norway: The Bellona Foundation, 2001, at https://bellona.org/publication/the-arctic-nuclear-challenge

2 IPNNW and IEER 1991, p. 101 – International Physicians for the Prevention of Nuclear War and Institute for Energy and Environmental Research. Radioactive Heaven and Earth: The Health and Environmental Effects of Nuclear Weapons Testing In, On, and Above the Earth. New York: Apex Press 1991, at http://ieer.org/wp/wp-content/uploads/1991/06/RadioactiveHeavenEarth1991.pdf

3 compiled from V. N. Mikhailov, head of editorial board. USSR Nuclear Weapons Tests and Peaceful Nuclear Explosions 1949 through 1990. Sarov, Russia: The Ministry of the Russian Federation for Atomic Energy, and Ministry of Defense of the Russian Federation, 1996, at https://web.archive.org/web/20060622055801/http://npc.sarov.ru/english/issues/peacef ul/peaceful_e.pdf

4 The fission-fusion split from IPPNW and IEER 1991 is used along with an updated value for total explosive power from Mikhailov 1996.

5 Remus Prăvălie "Nuclear Weapons Tests and Environmental Consequences: A Global Perspective", Ambio, 2014, at https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4165831

Lack of health studies

There are no health studies of the population impacted by atmospheric testing on Novaya Zemlya comparable to the assessments available for the Semipalatinsk Test Site in Kazakhstan. Yet there are clear indications of serious impacts far and wide. For instance, the peak measured deposition of beta radioactivity (characteristic of many fission products) in 1962 at Naryan Mar near Archangelsk, about 1,000 km away was over 1,300 MBq/km^2, about 460 times more than the peak in 1988. The peak deposition levels in Amderma, the village 280 km from the site, were more than 20 times higher than at Naryan Mar.[6]

There was venting of underground tests at Novaya Zemlya. Iodine-131, exposure to which is a cause of thyroid cancer, was detected in the 1980s in both the air and milk.[7]

Underground pollution

There is a vast inventory of underground pollution in the former Soviet Union, at the main test sites but also at the 100 or so "peaceful nuclear explosion" sites. The total inventories of strontium-90 and cesium-137 in 2020 would be on the order of 40,000 and 70,000 TBq respectively (decay-corrected values based on IPPNW and IEER 1991, Table 13, p. 104). About 1,200 kg of plutonium-239 also remains underground, about 500 kg of which is underground at the Semipalatinsk Test Site.[8]

The largest underground test of all time, more than 4 Mt, was also conducted at Novaya Zemlya in 1973. According to Columbia University's Lamont-Doherty Earth Observatory, that "explosion had a seismic magnitude of 6.97 and triggered an 80 million-ton rockslide that blocked two glacial streams and created a two kilometer-long lake."[9]

6 IPNNW and IEER 1991, p. 102, Table 12.

7 Bøhmer et al. 2001, PDF p. 64.

8 While critically important to understanding the ecological impact of nuclear activities, the radioactivity that has been dumped and discharged in the general area of the Arctic Ocean around Archangelsk region is a significant issue discussed in Bøhmer et al. 2001.

9 Lamont-Doherty Earth Observatory, "Frozen in Time: A Cold War Relic Gives up its Secrets," Columbia University News, New York, 28 November 2005, athttps://web.archive.org/web/20200916080615/https://www.ldeo.columbia.edu/news/2005/11_28_05.htm

A crater on the Semipalatinsk Test Site in the steppes of Kazakhstan. After the country's independence in 1991, the Kazakh government closed down the site and returned its nuclear weapon stockpiles to Russia – at that time the fourth largest nuclear arsenal in the world.

The Soviet nuclear weapons tests in Semipalatinsk

Arjun Makhijani

Atmospheric tests by the former Soviet Union at the Semipalatinsk Test Site resulted in significant radiation doses to nearby settlements, though there are differences in various accounts about the number of people exposed and the doses received. Testing was conducted with high levels of secrecy. Data on exposure of local people apparently began to be collected only in 1956 when a surface burst test caused "an emergency situation"; no protective measures for the exposed population were undertaken except for an evacuation of about two weeks of some nearby residents in 1953.[1] Various accounts are in agreement that communities near the test site suffered significant exposures to radiation over the atmospheric testing period that lasted from 1949 to 1962. There is also evidence of significant fallout hundreds of kilometres from the test site.

Various estimates of health impacts

The official Tsyb Commission, appointed in 1989, estimated that average exposures to people in nearby villages from the very first test ranged from 20 mSv to 1.6 Sv, with the total population dose being about 2,500 Sv, or an average of 400 mSv per person to almost 6,300 people in the villages of Dolon, Kainar, Sanhal, Karual, and Semyonovka.[2] This implies almost 300 excess cancers and almost 150 excess cancer deaths from just the first test at the Semipalatinsk test site, not including people who lived farther away than the closest villages.[3]

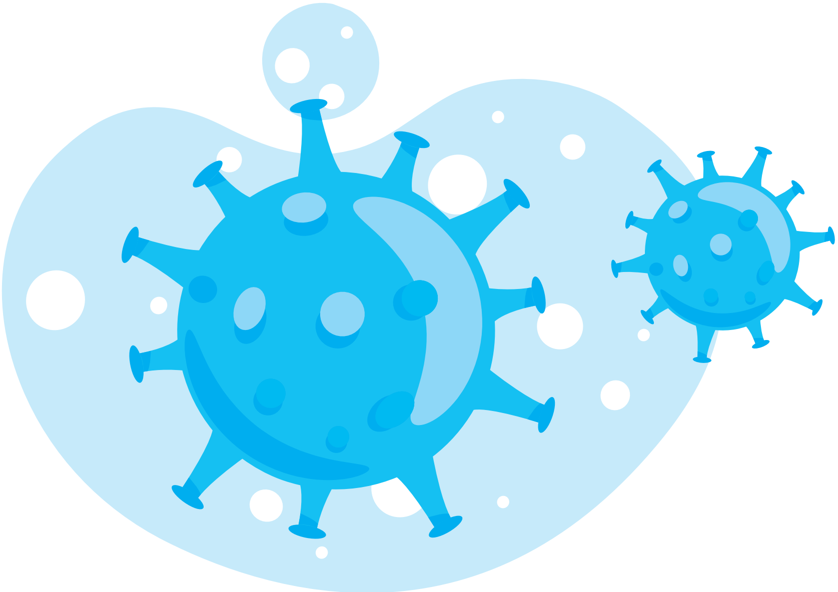
Kazakh Professor Saim Balmukhanov presented a broader estimate of exposed people at a 1990 European regional conference of International Physicians for the Prevention of Nuclear War. According to his data, between 100,000 and 200,000 people were exposed to less than 0.1 Sv, 30,000 to 40,000 to an average of 1.6 Sv and 1,000 people in the nearby village of Dolon to 2.8 Sv.[4] Using 0.05 Sv for the first set of people, this population dose estimate would be about 66,000 Sv, resulting in an estimated 7,500 excess cancers in the region. The cancer mortality in the village of Dolon would be expected to be nearly double the normal rate of roughly 20 %.

1 Roman Vakulchuk and Kristian Gjerde with Tatiana Belikhina and Kazbek Apsalikov. Semipalatinsk nuclear testing: the humanitarian consequences. Oslo, Norway: Norwegian Institute of International Affairs, 2014 at http://large.stanford.edu/courses/2014/ph241/powell2/docs/vakulchuk.pdf

2 based on Tsyb Commission data in IPPNW and IEER 1991, Chapter 6 – International Physicians for the Prevention of Nuclear War and Institute for Energy and Environmental Research. Radioactive Heaven and Earth: The Health and Environmental Effects of Nuclear Weapons Testing In, On, and Above the Earth. New York: Apex Press 1991, at http://ieer.org/wp/wp-content/uploads/1991/06/RadioactiveHeavenEarth1991.pdf

3 using risk estimates in the 2006 report of the United States National Academies known as the "BEIR VII" report – Committee to Assess Health Risks from Exposure to Low Levels of Ionizing Radiation, Board on Radiation Effects Research. Health Risks from Exposure to Low Levels of Ionizing Radiation: BEIR VII – Phase 2. National Research Council of the National Academies. Washington, DC: National Academies Press, 2006, at https://nap.nationalacademies.org/resource/11340/beir_vii_final.pdf

4 IPPNW and IEER 1991, p. 95



A third estimate can be made from data compiled by a commission appointed in 1990 by the USSR Congress of People's Deputies. This commission estimated that in the nearby population of 10,000 people, cancer deaths had increased by 39 %.[5] This implies an average individual dose of about 1.4 Sv. This is consonant with the average dose of 1.6 Sv to 30,000 to 40,000 people though, obviously, the two estimates of the numbers of people exposed to this level differ substantially.

A detailed cohort study was published in 2005 examining the medical records of 19,545 exposed and relatively unexposed people in order to compare medical outcomes, including cancer mortality. The authors' estimates of exposures were between 20 mSv and about 4 Sv, with an average of 630 mSv to an exposed population of nearly 10,000 people. Significant increases in total solid cancer deaths were found, with risks per unit of exposure exceeding those in the Hiroshima-Nagasaki cohorts. Significant increases were also found in many specific cancers including stomach and lung cancer, and, in the case of women, breast and esophageal cancer.[6]

Non-cancer Impacts

Both the Tsyb Commission and the 1990 Commission of People's Deputies found elevated levels of non-cancer health impacts as well. According to the latter report, as quoted in IPPNW and IEER 1991, p. 99,

» the average life expectancy in the oblast [region] decreased by three years compared with 1970;

» a certain increase by 1.5 to 4.5 times of the average spontaneous level of chromosomic changes in the lymphocytes of the peripheral blood system was detected;

» 40 to 50 % of the examined people showed an immunological status down to the lowest level of the norm;

» from 1986 to 1988 the birth defects in children increased from 6.4 % to 8.6 %. Fatal birth defects increased from 2.3 % to 7.3 %;

» there was a steady growth in cases of nervous disorder among children suffering from mental retardation;

» the analysis of the situation in the areas adjacent to the test site showed an increase in suicides by 2.5 times compared with all Soviet Union averages;

» every nuclear test caused a dramatic increase in the number of people seeking help at local medical facilities of the city and oblast.

These kinds of non-cancer impacts are to be expected especially among children whose mothers were exposed to radiation doses of hundreds of millisieverts to a few sieverts during pregnancy. For instance, the International Commission on Radiological Protection[7] estimated that there would be an excess severe central nervous system defect in the form of "severe

5 as quoted in IPPNW and IEER 1991, p. 97

6 Suzanne Bauer, Boris I. Gusev, Ludmilla M. Pivina, Kazbek N. Apsalikov, and Bernd Groshche. "Radiation Exposure due to Local Fallout from Soviet Atmospheric Nuclear Weapons Testng on Kazakhstan: Solid Cancer Mortality in the Sempalantinsk Cohort, 1960-1990", Radiation Research, Vol. 164, pp. 409-491, at https://www.jstor.org/stable/3581526.

7 International Commission on Radiological Protection, Developmental Effects of the Irradiation on the Brain of the Embryo and Fetus, ICRP 49, 1986 at https://www.icrp.org/publication.asp?id=ICRP%20Publication%2049, p. 20 and p. 31.

mental retardation" from exposure prior to 25 weeks of pregnancy for every 2.5 Sv of exposure, with no threshold.[8]

There were two ventings from underground nuclear tests at the Semipalatinsk Test Site in 1987. The tests impacted a larger population than the estimates discussed above. Vakulchuk et al. (2014) cite estimates of the exposed population as being between half-a-million and one million people, who lived within 160 km of the Semipalatinsk Test Site. In some cases, even more distant populations appear to have been seriously affected by hots spots:

"[There was] an emergency situation caused by a surface nuclear detonation on 16 March 1956, the radioactive cloud of which reached the city of Ust-Kamenogorsk, 400 km from the explosion epicentre. The city's population was exposed to nuclear fallout with radiation doses so high as to cause acute radiation poisoning. In response, the Soviet leadership established a special medical institution and hospitalized 638 persons suffering from radiation poisoning.[9] No information about the fate of these people is available, however."[10]

This experience of serious distant impacts is not surprising in view of the fact that research in recent decades both from civilian accidents and atmospheric testing has established the importance of hot spots, including distant hot spots in human exposure. For instance, the beta radiation deposition in Almaty in 1962 (known as Alma Ata at that time) over 800 km from Semipalatinsk was 16,000 MBq/km^2 compared to a measurement of just 8 MBq/km^2 in 1988.[11] Population doses and health impacts from these intense distant hot spots remain to be estimated.

Vakulchuk et al. (2014) also report high infant mortality and an increased rate of congenital malformations, also to be expected for pregnant women at the levels of exposure that have been

8 Discussion of risks of radiation exposure and some related research issues in the early part of pregnancy can be found in: Arjun Makhijani, Memorandum to Committee on Developing a Long-Term Strategy for Low-Dose Radiation Research in the United States, National Academies of Sciences, Engineering, and Medicine, 10 January 2022, at https://ieer.org/wp/wp-content/uploads/2022/01/Arjun-Makhijani-memorandum-to-National-Academies-committee-on-low-level-radiation-2022-01-10.pdf.

9 Symptoms of acute radiation sickness signify exposure to more than 0.3 Gy.

10 Vakulchuk et al. 2014, p. 10

11 IPPNW and IEER 1991, Table 12, p. 102

KARIPBEK KUYUKOV WAS BORN WITHOUT ARMS. HIS MOTHER WAS EXPOSED TO RADIOACTIVITY FROM THE NUCLEAR TESTS IN SEMIPALATINSK. TODAY, AFTER FINISHING HIS UNIVERSITY EDUCATION, HE IS ENGAGED IN THE GLOBAL EFFORT TO ABOLISH NUCLEAR WEAPONS AND IS ACTIVE IN THE NEVADA-SEMIPALATINSK MOVEMENT.

Photo credit: BANg

estimated for people near the test site.[12] Reviewing the various studies up to about 2013, Grosche et al. (2015) concluded that

"…data are available for more than 100,000 persons forming a large cohort which needs to be further investigated. Furthermore, the range of external doses as described in the study of cardiovascular diseases (i.e. 0–630 mGy) is wide enough to conduct meaningful health studies. Lastly, the data from the 3-generation studies are of high interest to study transgenerational effects. Overall, this line of research has great relevance not only for the region of Central Asia but also to countries around the world affected by nuclear testing."[13]

The total explosive power of the tests at the Semipalatinsk Test Site was about 6.6 Mt.[14] Using standard coefficients for strontium-90 and cesium-137, an estimated 266,000 and 425,000 TBq, respectively, of these radionuclides would have been present in fallout due to these tests. More than three-fourths of these amounts would have decayed away since that time. Almost all the unfissioned plutonium-239, roughly 170 kg, still remains in the environment due to dispersal in atmospheric testing fallout.

12 Arjun Makhijani, Memorandum to Committee on Developing a Long-Term Strategy for Low-Dose Radiation Research in the United States, National Academies of Sciences, Engineering, and Medicine, 10 January 2022, at https://ieer.org/wp/wp-content/uploads/2022/01/Arjun-Makhijani-memorandum-to-National-Academies-committee-on-low-level-radiation-2022-01-10.pdf.

13 Bernd Grosche, Tamara Zhunussova, Kazbek Apsalikov, Ausrele Kesminiene. "Studies of Health Effects from Nuclear Testing near the Semipalatinsk Nuclear Test Site, Kazakhstan", Central Asian Journal of Global Health, Vol. 4, No. 1, 2015, at https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5661192/.

14 compiled from: V. N. Mikhailov, head of editorial board. USSR Nuclear Weapons Tests and Peaceful Nuclear Explosions 1949 through 1990. Sarov, Russia: The Ministry of the Russian Federation for Atomic Energy, and Ministry of Defense of the Russian Federation, 1996, at https://web.archive.org/web/20060622055801/http://npc.sarov.ru/english/issues/peaceful/peaceful_e.pdf

Environmental contamination

The more than 300 underground tests have left a vast legacy of underground contamination.[15] The total amount of residual plutonium underground is estimated to be almost 800 kg.[16]

About 100 underground tests vented significant amounts of radioactivity, including two in 1987 and one in 1989. The ventings in 1987 were detected in the city of Semipalatinsk; in one case, on May 7, 1987, the radiation levels were 35 to 50 times natural background radiation. After a 1989 venting, radiation levels at the village of Chagan were more than 300 times background.[17]

15 IPPNW and IEER 1991, p. 102

16 IPPNW and IEER 1991, p. 103

17 IPPNW and IEER 1991, p. 103

Photo credit: Martin Deeken

Bernard Lown (left), a founding co-president of IPPNW, and Olzhas Suleimenov (right), a famous Kazakh poet, in Karaul/Semipalatinsk. In 1990, the International Physicians for the Prevention of Nuclear War and Suleimenov's Nevada-Semipalatinsk Movement joined ranks in order to convince President Gorbachev of the need for a nuclear testing moratorium.

The Lop Nur desert is located in the autonomous Xinjiang province in Western China. It was here that China detonated its first nuclear bomb in 1964. In the following years, 22 more atmospheric and 22 underground tests were conducted.

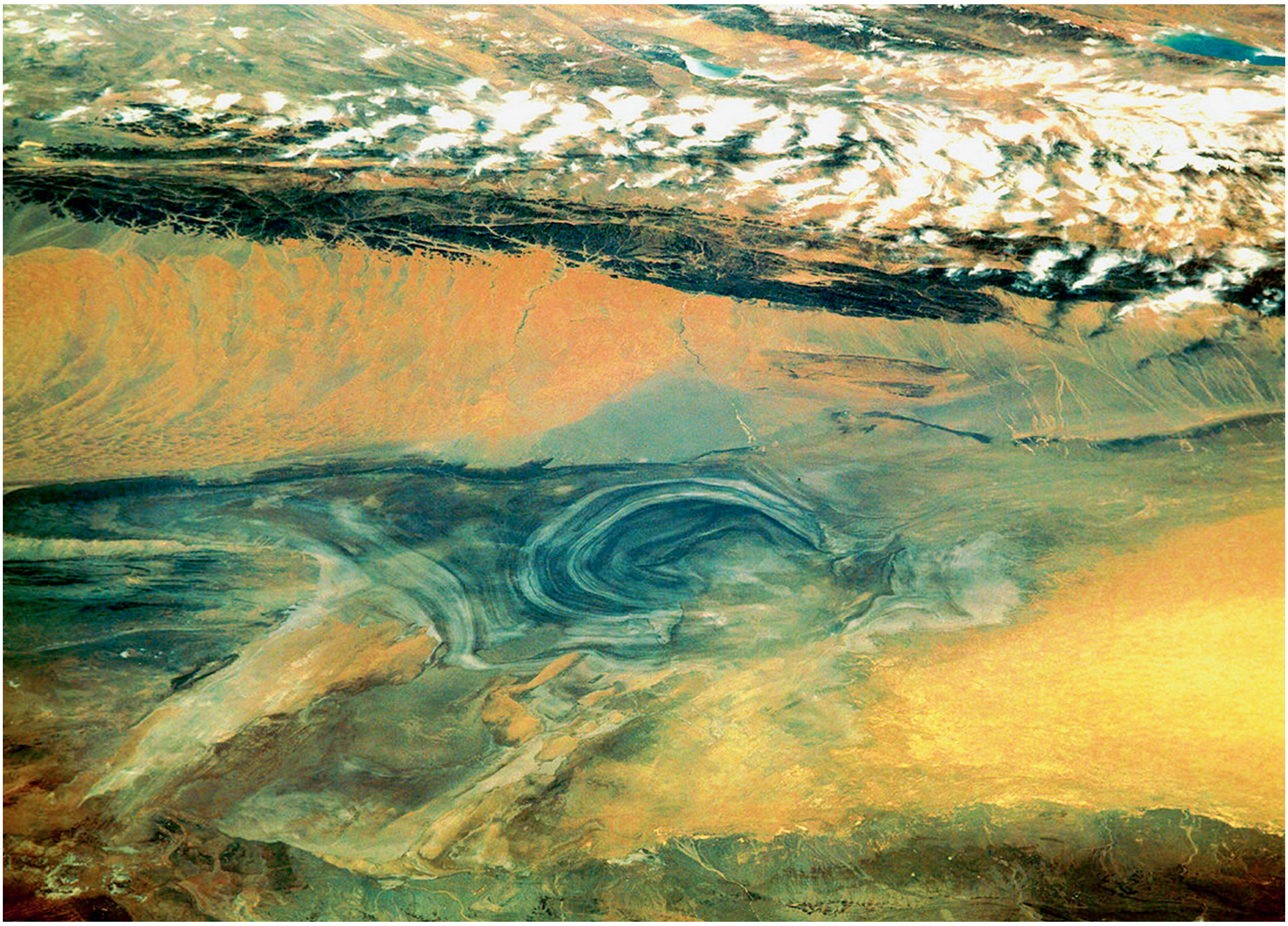


Photo credit: PD-USGov-NASA

China's nuclear weapons tests in Lop Nur

Arjun Makhijani, Tilman Ruff

The nuclear test explosions

China conducted 45 nuclear weapon tests, all at the Lop Nur site in Xinjiang province officially called Xinjiang Uygur Autonomous Region. 23 were atmospheric tests and 22 were underground. They ranged in explosive power from 1 kiloton to 4 Mt.[1] The estimated total yield of the atmospheric tests was 20.7 Mt; the fission portion of this yield is estimated at 12.7 Mt[2], undoubtedly leading to health impacts, as indicated by the radiation dose estimates cited below.

Health impacts and radiation doses

There are no official health studies or estimates of health impact or environmental damage due to Chinese nuclear weapons testing. There has, however, been some official indication that people died as a consequence of the testing, as indicated by the following 1989 statement of a senior Chinese military official[3]:

> *"Facts are facts. A few deaths have occurred, but generally China has paid great attention to possible accidents. No large disasters have happened."*

No quantitative interpretation of the phase "few deaths" is possible. It should, however, be noted, that the statement that China has "paid great attention" is about accidents and does not refer to the exposure that is to be expected from the very nature of nuclear testing in the atmosphere. Some of this expected exposure is at least indirectly being acknowledged by the Chinese government: it has reportedly begun making "payments to 'some military personnel and civilians' who took part in nuclear tests…."[4]

Information about the fallout from Chinese nuclear tests was presented at a 'mini-workshop' in Beijing in 1996 under the auspices of the Scientific Committee on the Problems of the Environment (SCOPE) of the International Council for Science (ICSU), and summarised in SCOPE 1999. China's Ministry of

1 CTBTO 2012, "16 October 1964 – The First Chinese Nuclear Test", Comprehensive Test Ban treaty Organization, 2012, at https://www.ctbto.org/specials/testing-times/16-october-1964-first-chinese-nuclear-test/

2 IPPNW and IEER 1991, Table 2, p. 35 – International Physicians for the Prevention of Nuclear War (IPPNW) and Institute for Energy and Environmental Research (IEER). Radioactive Heaven and Earth: The Health and Environmental Effects of Nuclear Weapons Testing In, On, and Above the Earth. New York: Apex Press 1991, at http://ieer.org/wp/wp-content/uploads/1991/06/RadioactiveHeavenEarth1991.pdf

3 as quoted in IPPNW and IEER 1991, p. 151

4 David Lague, "China Starts Payments to Atom Test Personnel," New York Times, 7 February 2008, at https://www.nytimes.com/2008/01/27/world/asia/27iht-china.2.9526066.html

THE REGION AROUND LOP NUR IS HOME TO ABOUT 20 MILLION PEOPLE. MANY OF THEM LIVE IN CLOSE PROXIMITY TO THE HIGHLY CONTAMINATED TEST SITE. THE INHABITANTS OF THE REGION COME FROM A NUMBER OF DIFFERENT ETHNIC GROUPS, MOST NOTABLY THAT OF THE UIGHURS.

Health reportedly established a network of 45 stations in the early 1960s, spread across the country, for monitoring environmental radioactivity in the early 1960s.[5] A large peak in gross beta deposition (around 125 Bq/m^2) occurred in 1962, 2 years before China began testing, due to tests by the former Soviet Union. Soviet and U.S. atmospheric tests ceased in 1963. Smaller peaks in 1966, 1971, 1973 and 1977 were due to Chinese atmospheric tests.[6] Environmental contamination by I-131 following nuclear explosions was described as 'significant' in some regions such as Lanzhou, Xining and Shenyang. I-131 deposition in Lanzhou was as high as 10 kBq/m^2 after the atmospheric test on 17 June 1974; that level was also found in Xining after the atmospheric test on 16 October 1980.[7]

Susceptibility to high uptake of radioactive iodine was present for people of some provinces affected by fallout from Lop Nur because of low dietary iodine intakes.[8] Higher radiation exposure was reported in rural communities, but "potentially critical groups living in the north of China and in Inner Mongolia had not been investigated"[9]. Herders living in areas contaminated by fallout were likely at risk of higher radiation exposure through outdoor exposure, consuming snow meltwater and high milk intake, particularly for children (who both absorb more ingested iodine and are more radiation-sensitive than adults).[10]

Outdoor air absorbed doses in urban areas between 400 and 800 km downwind of Lop Nur were measured between 0.024 and 0.45 mGy, with an average of 0.18 mGy, resulting in an estimated mean effective dose of 0.044 mSv from external irradiation.[11] Thyroid doses from internal radiation by I-131 for adults ranged from 0.06 mGy in Taiyuan to 2.5 mGy in Lanzhou; thyroid doses to infants would be about 10 times higher.[12] The

5 SCOPE 1999, Chapter 4, p. 74 – Frederick Warner, Rene JC Kirchmann (eds), Scientific Committee on Problems of the Environment, International Council of Science (SCOPE 59). Nuclear test explosions: Environmental and human impacts. Chichester, UK: John Wiley & Sons, 1999. Can be downloaded chapter by chapter at https://scope.dge.carnegiescience.edu/SCOPE_59/SCOPE_59.html, Publication dates in the original are variously indicated at 1999 and 2000. We have used the publication cataloging date, which is 1999.

6 SCOPE 1999, Chapter 4, p. 76

7 SCOPE 1999, Chapter 4, pp. 76-77

8 SCOPE 1999, Chapter 5, p. 109

9 SCOPE 1999, Chapter 5, p. 106

10 SCOPE 1999, Chapter 5, p. 109

11 SCOPE 1999, Chapter 6, p. 159-60

12 SCOPE 1999, Chapter 6, p. 159-60

average thyroid dose for the whole Chinese population as a result of the Lop Nur tests was estimated to be about 0.14 mGy.[13]

Though average deposition of strontium-90 "seems to have been lower" than in the rest of the northern hemisphere, the internal doses (mostly from tests not conducted in China) are estimated to be higher in China, related to dietary factors.[14]

Environmental contamination

The Lop Nur test site is in a desertic area, as with other test sites such as the Nevada Test Site in the United States, Maralinga in Australia (UK testing) and in Algeria (French testing). The fallout from at least some Chinese atmospheric tests spread far and wide as indicated by the detection of radioactivity from a 1976 Lop Nur test in Pennsylvania.[15]

The region of the Lop Nur test site in is location is rather similar to the region most impacted by atmospheric testing at Nevada: a large desertic area that nonetheless is populated by millions of people, many of who engaged in grazing activities. The total fission yield of China's atmospheric tests, the primary determinant of the amount of radioactivity in fallout out, was roughly a tenth of the tests at the Nevada Test Site.[16]

Roughly 14,000 TBq of strontium-90 and 23,000 TBq of cesium-137 remain in the environment from China's atmospheric testing[17] along with roughly 50 kg of plutonium-239. The same order of magnitude of contamination can be expected to be in the underground environment as a result of the underground tests, the last of which took place in 1996.

13 SCOPE 1999, Chapter 6, p. 160-1

14 SCOPE 1999, Chapter 6, p. 161

15 IPPNW and IEER 1991, p. 153

16 IPPNW and IEER 1991, Table 2, p. 35

17 IPPNW and IEER 1991, p. 153, decay-corrected to 2020

India's nuclear weapons tests all took place underground at a test site in Pokhran, in the west of the country. The like-named city is located only 45 km away. It is situated in the Thar Desert, but people still live here. And they have been living here for a long time: the Pokhran fortress was built as early as in the 14th century. Also, it is not the only settlement in the region. The village of Khetolai is even located only 4 km away from the test site.

India's nuclear weapons tests in Pokhran

Arjun Makhijani

The nuclear test explosions

All of India's nuclear tests – one explosion in 1974 and five explosions on 11 and 13 May 1998 – were conducted underground at the Pokhran test site in the western state of Rajasthan. The 18 May 1974 test was officially a 'peaceful nuclear explosion'. While it was not a deliverable device, it was clearly part of India's nuclear weapons development. Raja Ramanna, a scientific leader of the preparation for that test, was explicit about that in his memoir: he wrote about the 1974 test that he had "been involved in the development of a prototype weapons"[1]. The device contained five to seven kilograms of plutonium; independent estimates of yield are generally lower than the official figure of 12 kt.[2]

Three explosions were conducted at the same time on 11 May 1998 and two at the same time on May 13; the latter were experimental devices with yields less than 1 kt. The three 11 May 1998 explosions included a 45 kt thermonuclear weapon, a 12 kt fission weapon and an experimental 0.2 kt device, according to official yield estimates.[3] The tests were reportedly conducted at 200 to 300 meters depth.[4]

1 as quoted in M.V. Ramana, "La Trahison des Clercs", in M.V. Ramana and C. Rammanohar Reddy, eds., Prisoners of the Nuclear Dream. New Delhi, India: Orient Longman, 2003, pp. 233-234.

2 M.V. Ramana, The Power of Promise. New Delhi: Penguin Books India, 2012, p.28.

3 Department of Atomic Energy, "Press Statement by Dr. Anil Kakodkar and Dr. R. Chidambaram on Pokhran-II tests", Government of India, 24 September 2009, at https://pib.gov.in/newsite/PrintRelease.aspx?relid=52814

4 M.V. Ramana and Surendra Gadekar, "The Price We Pay", in M.V. Ramana and C. Rammanohar Reddy, eds., Prisoners of the Nuclear Dream. New Delhi, India: Orient Longman, 2003, p. 438.

Radioactivity dispersal and underground pollution

The official position of the Government of India is that there was no venting from the tests – and thus no atmospheric releases of radioactivity. No independent confirmation of this statement is available. As a result, the health complaints of people in nearby villages cannot be linked to the test.[5] The Department of Atomic Energy has acknowledged that the 1998 tests were just 5 km from a nearby village, Khetolai.[6]

Fission products and residual unfissioned plutonium from the tests remain underground. About 140 TBq of strontium-90, 230 TBq of cesium-137, and 33 TBq of plutonium-239 (about 14 kg) remain underground as of 2020[7], posing a long-term threat to the underground environment.

5 M.V. Ramana and Surendra Gadekar, "The Price We Pay", in M.V. Ramana and C. Rammanohar Reddy, eds., Prisoners of the Nuclear Dream. New Delhi, India: Orient Longman, 2003, p. 438.

6 Department of Atomic Energy 2009

7 values for Sr-90 and Cs-137 are decay-corrected values, based on M.V. Ramana and Surendra Gadekar, "The Price We Pay", in M.V. Ramana and C. Rammanohar Reddy, eds., Prisoners of the Nuclear Dream. New Delhi, India: Orient Longman, 2003, p. 439.

In the Baluchistan region, Pakistan conducted several underground nuclear tests. The region not only covers Pakistan, the western part is in Iran. Little is known about the Pakistani tests. Health studies have not been conducted, so the consequences for the local population can only be assumed.

Photo credit: Michael Foley, creativecommons.org/licenses/by-nc-nd/2.0/

Pakistan's nuclear weapons tests in Balochistan

Arjun Makhijani

The nuclear test explosions

Pakistan conducted five nuclear explosions on 28 May and one on 30 May 1998 in Balochistan, using highly enriched uranium as the fissile material. The total yields of the tests are a matter of some debate. The official claim of total yield for the 28 May tests is 30 to 35 kt and for the 30 May test is 15 to 18 kt. Zia Mian cites independent estimates of the yields on the two days of 10 to 15 kt and 2 to 8 kt respectively.[1] The Nuclear Weapon Archive's page for Pakistan's tests cites a variety of estimates, generally along the lines of the lower estimates cited by Mian.[2]

Radioactivity dispersal and underground pollution

Pakistan's nuclear weapon tests were all underground, tunnel tests. No information is available on venting of radionuclides and no health studies have been carried out.[3] As a result, the complaints of nearby villagers[4] about a variety of health problems cannot be validated by data.

The distribution of fission products for uranium-235 (the fissile part of highly enriched uranium) is somewhat skewed toward the lighter end of the periodic table than that for plutonium-239. A total yield of the six tests of 20 kt gives an inventory of roughly 60,000 TBq of strontium-90 and 70,000 TBq of cesium-137.

Pakistan's inventory of highly enriched uranium in 2020 was about 3.9 metric tons, not including an estimated 100 kg that was used in the nuclear weapon tests.[5] The radioactivity of the residual uranium would be dominated by uranium-234, rather than the fissile uranium-235, due to the much shorter half-life of the former. The total estimated residual uranium activity would be on the order of 0.2 TBq.[6]

1 Zia Mian, "A Nuclear Tiger by the Tail", in M.V. Ramana and C. Rammanohar Reddy, eds., Prisoners of the Nuclear Dream. New Delhi, India: Orient Longman, 2003, p. 91

2 Nuclear Weapon Archive, Pakistan page, Pakistan's Nuclear Weapons Program – 1998: The Year of Testing. Nuclear Weapon Archive Website at http://nuclearweaponarchive.org/Pakistan/PakTests.html, viewed on 10 May 2022

3 Zia Mian, personal email communication, 2 May 2022

4 Shah Meer Baloch, "The Fallout From Pakistan's Nuclear Tests", The Diplomat, May 29, 2017, at https://thediplomat.com/2017/05/the-fall-out-from-pakistans-nuclear-tests/

5 SIPRI Yearbook 2021: Armaments, Disarmament and International Security. Stockholm, Sweden: Stockholm Peace Research Institute, 2021, chapter on "World Nuclear Forces" at https://sipri.org/sites/default/files/2021-06/yb21_10_wnf_210613.pdf, Table 10.11 and Note g to that table, p. 406.

6 Residual radioactivity amounts estimated by the author.

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