INSTITUTE FOR ENERGY AND ENVIRONMENTAL RESEARCH
Democratizing science to protect health and the environment

Prepared for the International Campaign to Abolish Nuclear Weapons/June 2022

SUMMARY OF HEALTH AND ENVIRONMENTAL IMPACTS OF FRENCH NUCLEAR TESTING IN ALGERIA

Arjun Makhijani, Ph.D., President, Institute for Energy and Environmental Research

Nuclear test site selection and nuclear explosions

France conducted four atmospheric nuclear weapon tests in Algeria at Hammoudia, about 70 kilometres 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 (Barrillot 2008).

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 (Barrillot 2008). 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 grams of plutonium each, were also carried out at the Gerboise verte location between 1961 and 1963. Finally, five plutonium dispersal tests, containing between 20 grams and 200 grams of plutonium each were carried out between May 1964 and March 1966 at the Tan Afella underground testing location ((IAEA 2005, p. 16; 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).

The first atmospheric test, Gerboise bleue, had an explosive power of 70 kilotons; the other three were less than 5 kilotons each (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);

the total explosive power of the French atmospheric tests in Algeria is estimated at 73 kilotons (SCOPE 1999, Chapter 3, Table 3.4 pdf p. 15).

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 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 (Collin and Bouveret 2020, p. 12). There is clear technical evidence and personal testimony of high fallout and contamination from the participants in the testing.

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 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.

Contamination and exposure also occurred from the underground tests. Four tests were "not fully contained" according to a French Senate report on the country's testing program (Bataille and Revol 2002). 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 kilotons, 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", (letter of a participant, Michel R., quoted in Barrillot 2008, p. 11), and evident in photographs of the time (see, for example, Jarvis 2021, slide 18).

The official French Senate report on the impact of testing has estimated the following distributions of external exposures from the Beryl tests (Bataille and Revol 2002):

- 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 (read from a bar chart in Bataille and Revol 2002).

An official summary of total external doses from French testing in Algeria is as follows (Bataille and Revol 2002):

- 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 (Philippe 2021). Official U.S. dose estimates for Marshall Islands exposures are also much lower than independent ones (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).

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 kilometres away in Fort Lamy Bataille and Revol 2002), 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 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 (Lindblom 1961).

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 (ARCO 2021).

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 nuclear power plant accident. It is worth noting that, at 22 Bq/kg, the radioactivity in the sand that blew over France, as measured by ACRO (ACRO 2022), 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) (Duyssembaev et al. 2017; distances estimated from Figure 1).

ACRO also drew the following inference from its measurements (ACRO 2022, translated from the French by the author):

> 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.

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 (IAEA 2005, pp. 26-27). 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 (IAEA 2005, p. 7). 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 (calculated by the author from clearance coefficients in

Avtandilashvili et al. 2016). 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.

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 (IAEA 2005, p. 27).

Based on available data, this author estimates that about 10 kilograms of plutonium have been dispersed in the Algerian environment due to the atmospheric and subcritical tests in the Reggane area, with roughly 90 percent 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 kilograms 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 (the quote below is from Barrillot 2008, p. 12; see also Collin and Bouveret 2020).

> 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.

The "Pollen" tests, done about 30 km from Taourirt Tan Afella, presented their own risks, because they were meant to study plutonium dispersal (IAEA 2005, p. 16):

> 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.".

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.

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 (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).

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 (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 (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):

> **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.

End of quote

References

ARCO 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/
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
Avtandilashvili et al. 2016	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
Barrillot 2008	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
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
Collin and Bouveret 2020	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
Duyssembaev et al. 2017	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
Franke 2002	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

IAEA 2005	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
International Conference 2007	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.
Jarvis 2021	Jill Jarvis, "Terra Incognita: Mapping the Afterlives of French Nuclear Imperialism in the Sahara", *Maghrib in Past and Present*: Podcasts, Episode 112, 2021, at https://www.themaghribpodcast.com/2021/03/terra-incognita-mapping-afterlives-of.html
Lindblom 1961	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
Ministère de la Défense 2007	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
Parkinson 2004	Alan Parkinson. The Maralinga Rehabilitation Project: Final Report. *Medicine, Conflict and Survival*, Vol. 20, No. 1, 2004; 70-80.
Parkinson 2002	Alan Parkinson. Maralinga: The Clean-Up of a Nuclear Test Site. *Medicine & Global Survival*, Vol. 7, No. 2, 2002; 77-81.
Philippe 2021	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
SCOPE 1999	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 Links to the referenced chapters are provided in the text.
Véterans des essais nucléaires 2007	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

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.