Radiation Exposures and Compensation of Victims of French Atmospheric Nuclear Tests in Polynesia

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ABSTRACT

Between 1966 and 1974, France conducted 41 atmospheric nuclear weapon tests in French Polynesia, exposing local populations to radioactive fallout. Under French law, individuals who were present at the time and later developed certain radiogenic cancers are eligible for compensation from the government—unless it is proven that they could not have received effective doses greater than 1 mSv in any given year. Using new information available from recently declassified documents, as well as atmospheric transport modeling of radioactive fallout, this article shows that upper-bound government estimates of effective doses received by the public have been underestimated by factors of 2 to 10. As a result, approximately 110,000 people, representing 90% of the French Polynesian population at the time, could have received doses greater than 1 mSv per year. Integrating updated dose estimates into the claim adjudication process would enlarge the pool of eligible claimants by a factor of 10.

Introduction

At least 6 of the 41 nuclear devices France detonated over the atolls of Moruroa and Fangataufa in French Polynesia between 1966 and 1974 led to significant radioactive fallout on populated islands, including in the Gambier archipelago, Tureia atoll, and Tahiti, and to possible adverse health effects, including increased risks of developing radiation-induced cancers.[1] Recognition of incidental exposures of military personnel, test site workers, and downwind communities in French Polynesia led the French national assembly in 2010 to pass a law, known as the "Loi Morin," that created a compensation mechanism to be managed by a dedicated

committee, the Comité d'Indemnisation des Victimes des Essais Nucléaires (CIVEN).[2]

Under French law, those present in French Polynesia during the nuclear testing period who develop certain radiogenic cancers are eligible for compensation from the government—unless it is determined that the effective dose of radiation received from nuclear tests was less than 1 mSv per year, in all potential years of exposure.[3] Given that in cases of uncertainty the presumption of causation provided for by law favors claimants, upper bound estimates of doses are a key determinant of compensation outcomes.[4]

For members of the public who were not directly involved with the testing program, compensation decisions are based on retrospective dose calculations performed by the French Atomic Energy Commission (CEA) in 2006.[5] These calculations were done for the six atmospheric nuclear tests considered to be the most impactful on the downwind populations, including the 1974 Centaure test that contaminated Tahiti, home to two-thirds of the Polynesian population at the time.

While the 2006 government studies represented a significant advance in the understanding of the radiological consequences of key French nuclear tests, they also had significant shortcomings. First, they could not be independently verified or peer reviewed. For example, the reports provide no direct reference to the primary source material used as a basis for estimating external and internal doses. CIVEN recently recognized that it had never verified the studies' results and calculations.[6] The only outside evaluation, upon which CIVEN has relied, was qualitative and assumed all data and computations were correct.[7] Second, the authors did not include with their results any uncertainty or sensitivity analysis and relied upon exposure and contamination assumptions that can at times underestimate doses.[8] Third, the reports only concerned three islands and atolls out of more than 50 that were inhabited and known to have been impacted by fallout at the time.[9] Thus, comprehensive and independently-verified effective dose estimates are still unavailable to the French Polynesian public. In the absence of uncertainty analyses or quantitative reviews of the assumptions behind the 2006 estimates, the upper bound of doses received by local populations at the time of atmospheric testing may have been underestimated.

In this study, we reevaluate the upper bound of effective dose estimates from six French nuclear tests to the French Polynesian public and study the possibility of additional population exposures on islands and atolls for which no historical radiological surveillance data is available.

The article begins with a review of the legal background in which our study is anchored. It then proceeds with the review and reevaluations of the 2006 dose estimates beginning with the 1974 Centaure test, which impacted the island of Tahiti, followed by the analysis of five other tests

that impacted the Gambier archipelago and the atoll of Tureia—two communities located less than 450 km from the test site.

Our reevaluation of doses is based on declassified French government documents, including historical archives of the Joint Radiological Safety Service (SMSR) and the Joint Biological Control Service (SMCB), that provide measurement data relating to the internal and external radiation exposures of local populations during the period of atmospheric testing as well as technical information about the size and composition of French radioactive debris clouds. In particular, we used the latter to reconstruct the trajectory of the radioactive cloud generated by the 1974 Centaure test over French Polynesia using atmospheric transport modeling techniques and available historical meteorological data. This allows us to assess the impact of this test on islands for which no or limited historical radiological surveillance data is available.

Our results show how possible errors and omissions in the 2006 dose reconstruction studies may have resulted in significant underestimation of French Polynesian population exposures and resulting doses. As CIVEN relies on these studies in the adjudication process, such underestimations adversely impact individuals bringing compensation claims. In particular, our analysis of the 1974 Centaure test shows that over 90% of the French Polynesian population at the time could have received effective doses greater than the current compensation threshold of 1 mSv/yr. Finally, we discuss the legal and policy implications of these findings.

Legal background

In January 2010, the French government created a single unified compensation mechanism for victims under the "Law regarding the recognition and compensation of victims of French nuclear testing," colloquially known as the "*Loi Morin*."[10] The Law established a committee, the *Comité d'Indemnisation des Victimes des Essais Nucléaires* (CIVEN), for processing compensation claims from veterans, former workers at the test sites, and members of the public.[11] The *Loi Morin* stipulates that individuals suffering from a designated list of 23 (originally 21) potentially radiation-induced cancers who lived or sojourned in specific geographic areas where France conducted nuclear tests in Algeria and French Polynesia during the period of testing should benefit from a presumption of causality between the tests and their illnesses. The original version of the law stated that this presumption of causality should be upheld *unless* CIVEN considers the probability of such a causal link to be "negligible" due to the nature of the claimant's disease and their level of exposure.[12]
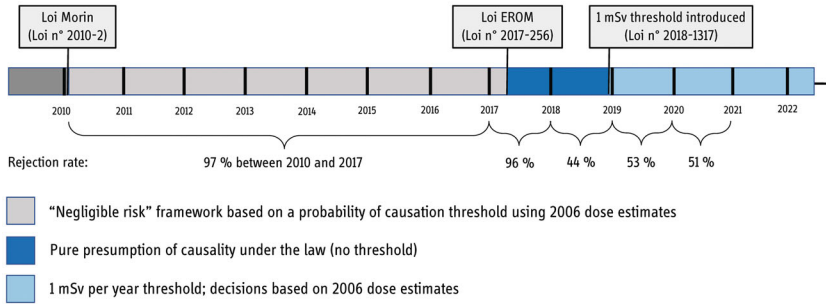
Figure 1. Timeline of the different methodologies in force for the compensation of victims from French nuclear tests and corresponding claim rejection rates. These rates reflect all claims submitted to CIVEN, not just those from residents of French Polynesia. Between 2010 and 2021, the overall CIVEN rejection rate was 77% (reduced to 67% after judicial decisions favoring claimants). For residents of French Polynesia, the overall rejection rate was 59% over the same period (reduced to 53% after judicial decisions). Claimants who submitted applications and who were rejected under the "negligible risk" framework were eligible to resubmit their claims to CIVEN through 31 December 2020, effectively extending the pure presumption of causality standard backwards to cover all submissions prior to the Loi EROM amendments.

Between 2010 and 2017, the French Ministry of Defense and CIVEN received a total of 1,039 applications and awarded compensation in 31 cases—an overall rejection rate of 97% (Figure 1).[13] In light of these statistics, the French legislature amended the *Loi Morin* through the "Loi EROM" to eliminate the "negligible risk" exception in February 2017.[14] Shortly thereafter, in June 2017, the French *Conseil d'Etat,* France's highest court for matters of public administration, issued an opinion stating that the presumption of causality could only be overturned if the pathology in question resulted *exclusively* from a cause other than ionizing radiation, or if the claimant was not exposed to *any* amount of ionizing radiation.[15] This decision effectively mandated the compensation of all applicants meeting the *Loi Morin*'s basic eligibility criteria—that is, all persons who were present in French Polynesia during the period of nuclear testing suffering from one of the enumerated cancers.

The 2017 *Loi EROM* tasked a parliamentary commission with developing a new methodology designed to limit compensation to "only those cancer cases which were caused by French nuclear tests."[16] Based on the commission's recommendations, CIVEN replaced the original "negligible risk" exception with an annual effective dose threshold requirement of 1 mSv in one year—the maximum annual level of ionizing radiation exposure attributable to nuclear activities set for the general public under the French Public Health Code. This change was made official through another law voted in December 2018.[17]

The 1 mSv threshold has been the subject of significant controversy, and currently applies only to the adjudication of applications filed *after* 28 December 2018. In June 2020, in the wake of a January 2020 Conseil D'État decision that the 1mSv threshold should *not* be understood to

function retroactively, the French legislature voted to extend this 1 mSv/ year threshold to all compensation claims, including those submitted prior to the December 2018 law.[18] In December 2021, however, the *Conseil Constitutionnel*, France's highest constitutional authority, effectively nullified this legislative action by declaring the 2020 law unconstitutional.[19]

Therefore, CIVEN today adjudicates claims brought by two distinct pools of applicants, governed by two different adjudicatory standards (Figure 1): claimants who filed between March 2017 and December 28, 2018 benefit from a pure presumption of causality (no threshold), and claimants who filed from January 2019 onwards (or in the very last days of December 2018) benefit from the presumption of causality unless CIVEN shows that they could not have been exposed at or above 1 mSv in any given year during the period of atmospheric testing. For individuals who submitted their claims in 2019 and onwards, estimates of maximum possible exposures (based, for example, on their location after particular tests) can therefore play a key role in determining compensation outcomes.

Methodology

To reevaluate the upper bounds of effective doses to the public, we started from available data and dose computations produced by the French atomic energy commission in 2006.[20] For each test, the CEA produced estimates for adult populations as well as for five age groups of children (babies, 1–2 years, 2–7 years, 7–12 years, and 12–17 years old). Table 1 presents the summary results for adults and children 1–2 years old. These effective doses (over the whole body) are the result of the sum of the effective doses received from four pathways: (1) inhalation of radioactive aerosols, (2) external irradiation by the plume (immersion in the radioactive cloud or *cloudshine*), (3) external irradiation by ground deposits (or *groundshine*), and (4) ingestion of contaminated food products.

For the first three pathways (inhalation, cloudshine, and groundshine), the effective doses are all calculated from the cumulative deposition of radionuclides on the ground (surface activity expressed in Bq/m^2) following a linear relationship. For the last pathway (ingestion of contaminated products), the effective dose is calculated from measurements of radioactivity in a selection of everyday consumer products.

To review the CEA estimates, we began by checking all assumptions and input data including air activity, ground deposition, and dose rate as well as water, milk and foodstuff consumption and contamination levels used in the computations and compared them from information available in declassified primary sources comprising over 200 documents issued by the SMSR and SMCB. For cases where we found errors and omissions, we corrected

Table 1. CEA 2006 reconstruction of effective (whole-body) dose ranges received by members of the public from French atmospheric tests in Polynesia.

Place	Year	Test	Effective dose child age 1–2 (mSv)	Effective dose Adult (mSv)
GAMBIER	1966	ALDEBARAN	3–10	3–7
	1966	RIGEL	0.4–0.71	0.1–0.23
	1971	PHOEBE	0.5–7.9	0.2–2.6
TUREIA	1966	RIGEL	0.1–0.23	0.06–0.15
	1967	ARCTURUS	0.9–4	0.79–3.2
	1971	ENCELADE	1.5–3.5	1.3–1.9
TAHITI (key districts)				
Pirae (Papeete)	1974	CENTAURE	1.2	0.5
Hitiaa	1974	CENTAURE	5.3	2.6
Teahupoo and Taravao	1974	CENTAURE	4.5	3.6

Effective doses reconstructed by the CEA in 2006 are the basis upon which CIVEN assess whether a claimant meets the effective dose threshold of 1 mSv/yr. under the conditions of the *Loi Morin*. They include "minimum" and "maximum" bounds (with the exception of the Centaure test) and are calculated over a six-month time frame.[21]

individual computations for effective (whole body) doses with respect to external exposure from groundshine and cloudshine as well as internal contamination from inhalation and ingestion of radionuclides.[22] When no data was available in primary source documents to verify the 2006 dose computations, we assumed the original results to be correct.

For the Aldebaran, Rigel, Arcturus, Phoebe and Encelade tests, which concerned the Gambier archipelago and the Tureia atoll, the CEA produced a confidence interval for its estimates in the form of a range of doses between a minimum dose and a maximum dose. This was not the case with the 1974 Centaure test, for which the CEA calculated three different doses corresponding to three distinct zones of the island of Tahiti: the Pirae-Papeete zone, the Hitiaa zone, and the southern zone of Teahupoo/Taravao Plateau. In particular, the CEA considers that "the Pirae-Papeete zone corresponds to the minimum doses received by the populations" and that the most affected zone Teahupoo/Taravao is not inhabited (despite government census showing the contrary).[23]

Although the Pirae-Papeete zone concentrates the majority of the population present in French Polynesia at the time of the atmospheric tests (approximately 80,000 inhabitants in 1974), no range of doses, no interval of confidence or uncertainty linked to this effective dose was calculated by the CEA. The dose estimate used by CIVEN for this area cannot be considered a maximum for this population. By following the CEA methodology and using new data and information from documents declassified in 2013, we produce a new upper bound for the effective dose received by the inhabitants of the Pirae-Papeete area in 1974.

Finally, we found radiological survey data in historical documents showing that other islands in French Polynesia had also been impacted by the Centaure fallout. To investigate whether even more islands had been impacted despite the absence of historical measurement data, we modeled the Centaure radioactive cloud trajectory over French Polynesia. To do so,

we used a modern atmospheric particle transport code together with historical weather data, open-source information about radioactive debris ("mushroom") clouds, as well as data on the composition and particle sizes of the fallout from the Centaure test gleaned from declassified documents (see details of the modeling in Appendix A).

Results

Effective dose to the public from the 1974 Centaure test fallout on the society islands

On July 17, 1974, at 17:00 UTC France detonated an experimental plutonium-based nuclear device that generated an energy equivalent of 4 kt of TNT. The experiment codenamed "Centaure" took place under a dirigible balloon anchored 270 m above Moruroa (21° 47′ 13″ S 138° 53′ 32″ W).[24] Twelve hours before the test, French radiological safety services predicted that fallout from the explosion would occur northward from the test site over the atolls of Hao and Tureia, but the potential impact was deemed small enough that the decision to conduct the test was nevertheless approved. After the explosion, French technicians realized the radioactive debris cloud did not reach the expected altitude (the top of the cloud reached 5,200 m instead of the predicted 8,500 m). Meanwhile, the winds had shifted toward the west pushing the cloud in the direction of Tahiti.

Our atmospheric transport simulation of Centaure shows the radioactive cloud traveling from Moruroa to Tahiti and the rest of the Society islands in a straight line reaching the island of Tahiti about two days after the explosion (Figure 2 and the supplementary video). The significant deposition of fission products and transuranics including plutonium-239 on the most inhabited islands of French Polynesia is consistent with a low stabilized radioactive cloud height (well below the tropopause), the relatively small (micron size diameter) but high-density metallic particles in the cloud, and heavy rain in the days following the test. Figure 2 shows the reconstruction of the 1974 Centaure cloud trajectory over French Polynesia. Air activities in pCi/m^3 (1 pCi = 0.037 Bq) between 0 and 500 m were obtained using the HYSPLIT atmospheric transport code (see Appendix A). We find that the cloud traveled directly from Moruroa to Tahiti in about two days before reaching the leeward islands (including Huahine, Raiatea, Taha'a, Bora-bora and Maupiti). Early time steps of the cloud trajectory are consistent with the CEA map of the fallout simulated for approximately the first 24 hours.

At the main radiological station of Tahiti, located at Mahina, the measured dose rate peaked at 390 microrad/h between H + 48 and H + 54.5. Declassified documents show the total cumulative deposition reached
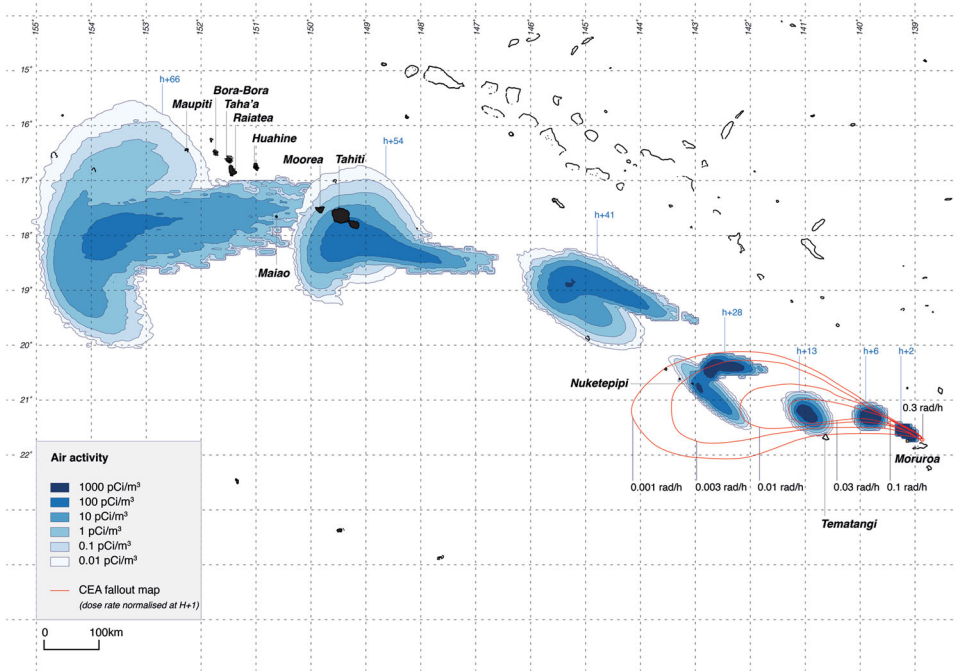
Figure 2. Reconstruction of the 1974 Centaure cloud trajectory over French Polynesia. Air activities in pCi/m³ (1 pCi = 0.037 Bq) between 0 and 500 m were obtained using the HYSPLIT atmospheric transport code (see Appendix A).

$3.4 \times 10^6 \, \text{Bq/m}^2$ $(9 \times 10^7 \, \text{pCi/m}^2)$.[25] Another recent study, independent from our work, obtained the same cumulative value from the same declassified government documents.[26] According to a 1974 map we found in the archival documents, the fallout on Tahiti was uneven with ratios of deposited activity in various parts of the island ranging from 0.1 to 11 times the value measured at the Mahina radiological station. Figure 3. Shows the measurements of ground activity in Tahiti following the 1974 Centaure fallout. Both maps provide deposition values in relation to the reference data at the Mahina Radiological Control Station. The 2006 official map on the right is the reproduction of the original 1974 map on the left. The highest activity values in Taravao (9.6 times) and Teahupoo (11 times) do not appear on the 1997 and 2006 versions but are considered in the 2006 dose estimates, albeit assuming locals only spent 4 h outside per day (equivalent to receiving no dose from groundshine 83% of the time). More importantly, the upper bound for activity in the western part of the main island is modified from 0.3 to 0.2. The CEA 2006 Centaure reconstruction study assume a 0.13 ratio between the Pirae/Papeete zone and Mahina, and as the histogram of the daily deposition measured in Mahina shows, does not consider ground deposition after 19 July.
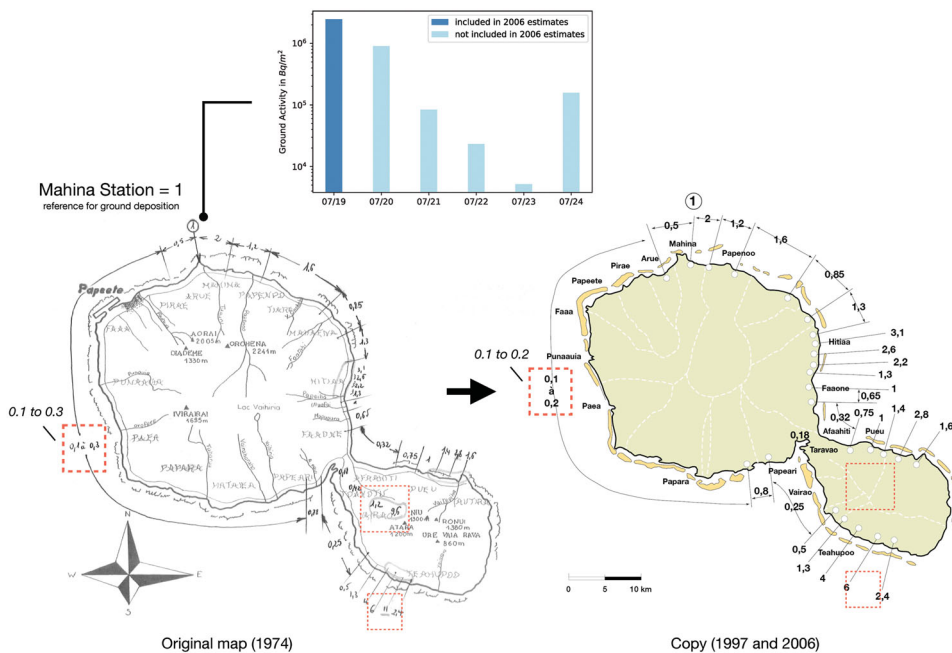
Figure 3. Measurements of ground activity in Tahiti following the 1974 Centaure fallout. Both maps provide deposition values in relation to the reference data at the Mahina Radiological Control Station.

Through analysis of primary sources, we also found information suggesting multiple errors or omissions were made in the 2006 retrospective dose reconstruction of the Centaure test that have important implications for the computed results: First, the government study used a cumulative deposition of 2.5×10^6 Bq/m^2 at Mahina, corresponding to the activity measured on 19 July 1974 only (see Figure 3).[27] Because of this lower value, all groundshine, cloudshine and inhalation doses were underestimated by a factor of $3.4/2.5 = 1.36$. Second, a careful comparison of the 1974 original map representing the deposited activity on the island of Tahiti and subsequent copies published in official French government publications.[28] Figure 3 shows that the ground activity measured on the road surface for the Papeete/Pirae zone ranged from 0.1 to 0.3 times the value measured at the Mahina station and not 0.1 to 0.2 as more recent government maps suggest. In the dose reconstruction, official studies used a ratio of 0.13, which is 2.3 times lower than the historical upper bound ratio of 0.3 for this zone as found on the 1974 map. While the declassified report associated with the original 1974 map suggests that deposition activity was relatively independent from the road surface condition at the points of measurements, activity measured away from the roads was typically higher—up to 30%. This suggest the upper bound for ground deposition in the Papeete/Pirae could also be

higher: up to ~0.39 the value measured at Mahina or 3 times the value used by the 2006 CEA study.

Combined, these possible errors mean that the groundshine, cloudshine, and inhalation upper dose estimates for the Pirae/Papeete zone, which was home to ~80,000 inhabitants (2/3 of the total French Polynesia population) at the time, were underestimated by a factor of ~4.08.

Regarding internal contamination, the 2006 study acknowledges the limited contamination data for foodstuffs, including the absence of radioactivity measurements for vegetables from the Papeete market in July 1974.[29] As a proxy, activities for the Papeete/Pirae region were taken from the Paea market, which had the lowest contamination values on the island. Given the possibility of sourcing vegetables elsewhere, it is equally plausible to assume that vegetables could have originated from nearby Hitiaa (which had the highest measured contamination). Using the latter values raises the maximum effective doses and thyroid doses equivalent from vegetable consumptions by a factor of 2.73 for Papeete. Given the lack of data in declassified government documents, it is difficult to estimate the validity of reconstructed doses from other foodstuffs (e.g., meat or fish). For the purposes of this reevaluation, we assume they are valid.

Based on these findings, we corrected the 2006 computations for effective doses from groundshine, cloudshine, inhalation, and ingestion received by the inhabitants of Tahiti after the Centaure test using the CEA methodology but accounting for errors and omissions.

To produce a confidence interval for our new effective dose estimates, we also assigned a 25% standard deviation to the Mahina ground deposition measurements from which groundshine, cloudshine and inhalation doses are computed. This value is found in CEA reports and is typical for this type of measurement.[30] To a first order, the ground deposition measurement error propagates to groundshine, cloudshine and inhalation dose estimates. This allows us to compute a new upper bound corresponding to a 95% confidence interval (1.96–σ) assuming doses are normally distributed and all other sources of errors to be zero.[31] (The latter being a conservative assumption.) The results are given for different age groups and presented in Table 2 for the Pirae/Papeete area. Results for the Hitiaa and Taravao areas are available in Appendix B, Table B1. They suggest that, for the Centaure fallout alone, the entire population of Tahiti (~87,500 people at the time) could have received effective (whole-body) doses above 1 mSv. Interestingly, declassified documents show that the effective doses computed in the 1970s and assigned to Papeete were also greater than 1 mSv for the year 1974 (see Appendix C, Table C1).

The 2006 study did not evaluate the impact of Centaure beyond the island of Tahiti. However, we found in primary sources that ground

Table 2. Original and revised sum of external and internal effective dose estimates in mSv for the Pirae/Papeete area due to the CENTAURE fallout.

	Age (years)	Newborn	1–2	2–7	7–12	12–17	Adult
Original estimate (2006)	Inhalation	0.032	0.050	0.046	0.049	0.048	0.046
	Cloudshine	0.002	0.002	0.002	0.002	0.002	0.002
	Groundshine	0.053	0.053	0.053	0.053	0.053	0.053
	Ingestion	0.680	1.086	0.611	0.508	0.487	0.352
	Total	0.77	1.19	0.71	0.61	0.59	0.45
Revised estimate	Inhalation	0.195	0.304	0.280	0.298	0.292	0.280
	Cloudshine	0.012	0.012	0.012	0.012	0.012	0.012
	Groundshine	0.335	0.335	0.335	0.335	0.335	0.335
	Ingestion	0.680	1.686	1.121	0.948	0.827	0.612
	Total	1.22	2.34	1.75	1.59	1.47	1.24

The revised upper bound estimates only include measurement uncertainties with regards to the Mahina station ground deposition measurement and nothing else, as taking other sources of uncertainty would increase these values further.

contamination measurements were conducted on other islands including Moorea, Bora-Bora, Raiatea, and Huahine. The average ground contamination for these islands was ∼0.3 times the value measured at the Mahina reference station. All islands had hotspots reaching up to 0.4–0.6 times the reference value, except for Huahine, which showed values up to 2.5 times the reference point.[32]

This suggests that inhabitants from these islands could have received effective doses from external exposure and inhalation ranging from ∼0.3 to 2.5 mSv, similar to the doses computed for the Pirae/Papeete and Hitiaa areas on Tahiti (see Table S7). No information about the consumption of contaminated foodstuffs is available for these islands. Adding this contribution would raise the effective dose. Given known estimates of doses from ingestion for Tahiti (ranging from 0.6 to 3.5 mSv depending on the age of the individual), it is also possible that all the inhabitants of Moorea, Bora-Bora, Raiatea and Huahine (∼17,100 people) could have received an effective dose greater than 1 mSv.

For the other Society islands where no measurement data is available, our simulation of the Centaure cloud pathway over French Polynesia (Figure 2) shows that all, including Maiao, Tahaa, and Maupiti (∼4,200 people), were impacted by the Centaure fallout. Our simulation suggests that Tahaa and Maupiti were subjected to similar levels of deposition as Huahine, Raiatea, and Bora-Bora, which is consistent with their geographic proximity (see Figure 2).[33] In our simulation, Maia finds itself, as Taravao on Tahiti, located directly on the trajectory of the cloud's center of mass where the activity is the highest. We find that the island could have received levels of deposition ∼8 times higher than those measured at Mahina. Given these results and the upper bound doses available for Tahiti, the populations of Maiao, Tahaa, and Maupiti could also have received doses greater than 1 mSv.

Effective dose from other tests on the Gambier archipelago and the atoll of Tureia

In addition to the Centaure case study, the French government has produced six dose reconstruction reports for the Aldebaran (1966), Rigel (1966: two reports, one for the consequences on the Gambier archipelago and one on Tureia atoll), Arcturus (1967), Encelade (1971), and Phoebe (1971) tests, which concerned residents of the Gambier archipelago and the Tureia atoll (for a total of ~600 individuals) who lived less than 450 km away from the test site and were the most impacted by French nuclear testing.

The first three of these tests were detonated from barges anchored on the lagoon of Moruroa and Fangataufa atolls, while the latter two were suspended under balloons to limit the interaction of the expending fireball with the lagoon water. In all five tests, either the Gambier islands, Tureia or both were impacted by direct fallout (see Figure 4).

The dose reconstructions for these tests present again issues with key assumptions that impact the resulting dose estimates to the local population. These include, among others, assumptions about the source of drinking water utilized by residents, which can affect estimates of internal exposure to ionizing radiation, as well as errors in extracting available measurement values from historical documents and accounting for measured dose rates from ground deposition when available. There is also an issue with using generalized extrapolation of foodstuff and water contamination levels from measurements taken from other nuclear tests or other places, when such data is unavailable for a given location or test, which can lead to underestimation of the internal exposure of inhabitants. In addition, dose calculations for the Arcturus and Phoebe tests could not be fully verified as key primary sources related to these tests are still publicly unavailable. Figure 5 present the 2006 data and our reevaluation of the upper bound dose estimate for a child (see details and data for other age groups in the Appendix B including Tables B3–B8).

Overall, we find that maximum effective whole-body doses could have been underestimated for the Aldebaran, Arcturus, Encelade, and Phoebe tests by factors of 1.5–4. Dose estimates for the Rigel test, based on fewer measurements, are much more uncertain and could have been underestimated by a factor of ~10.

Discussion

Our results show that upper bound estimates of effective doses received by the French Polynesian population during the period of French atmospheric testing have been under-appreciated by factors of ~2 to 10, even without considering all measurement and model uncertainties.
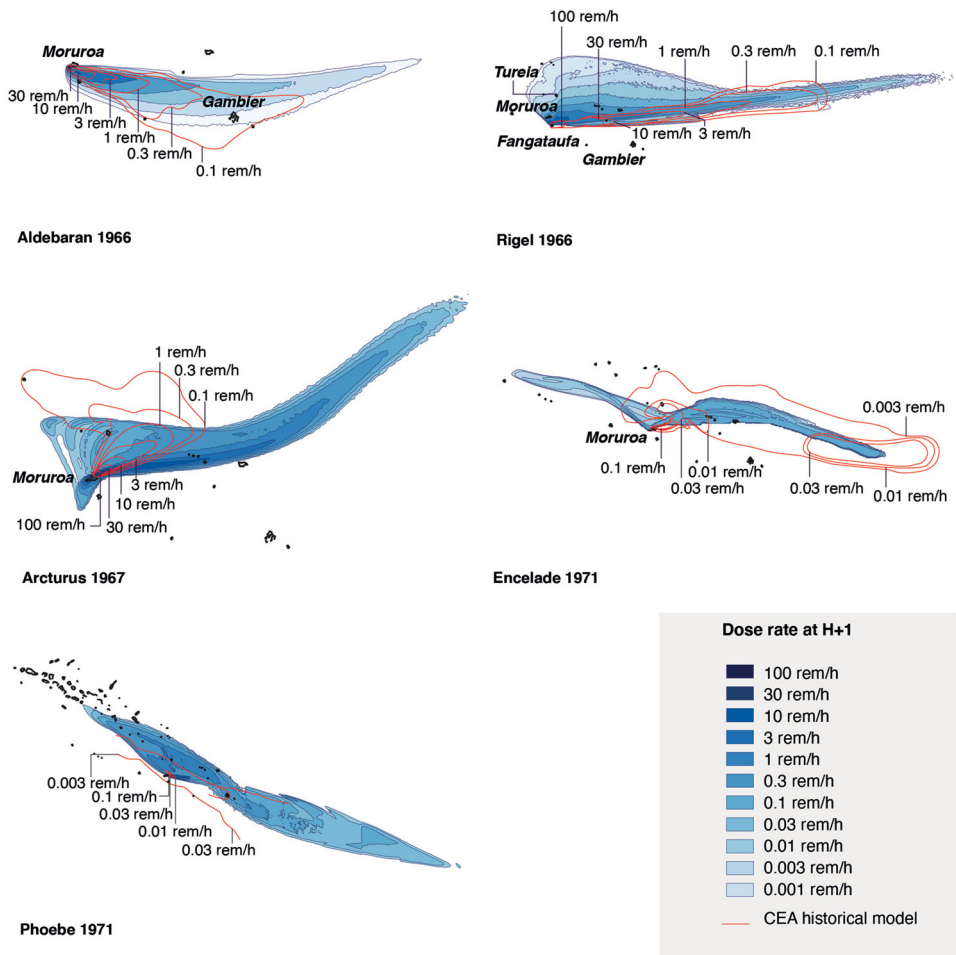
Figure 4. Reconstruction of the fallout from key atmospheric nuclear tests that impacted the Gambier archipelago and the atoll of Tureia between 1966 and 1971. Dose rate contours are normalized to H + 1 after the explosion and expressed in rem/h (1 rem = 0.01 Sv) to allow for direct comparison with historical simulations (red contours). Our results (solid blue) were obtained using the atmospheric transport code HYSPLIT (see Appendix A). We find our results to be in relatively good agreement with historical simulations further confirming the usefulness of our approach for reconstructing local fallout from shallow water or balloon bursts.

Taking our new findings into account, as well as population census data from 1967, 1971, and 1977,[34] we estimate that the total number of inhabitants who may have received doses greater than 1 mSv/yr. to be ∼110,000, about 90% of the total French Polynesian population in 1974. This estimate includes 87,500 inhabitants in Tahiti, 6,000 in Moorea, 16,000 in the Leeward Islands, and 600 in Gambier and Tureia, and is about ten times more people than the original 2006 estimates suggest.[35]

These findings introduce the possibility of much broader compensation for victims of radiogenic cancer who resided in French Polynesia at the
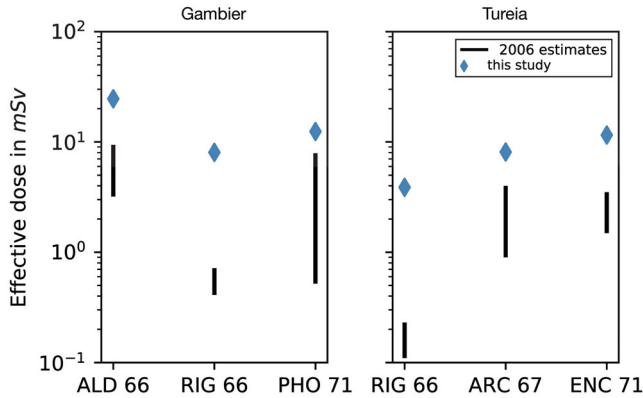
Figure 5. Estimates of effective doses received by a 1–2 year-old child during the most important fallout events on the Gambier archipelago and the atoll of Tureia. The name of the tests are abbreviated as follows: ALD for Aldebaran, RIG for Rigel, ARC for Arcturus, ENC for Encelade, and PHO for Phoebe. Our results (in blue) show that existing government dose reconstruction studies (black lines spanning from minimum to maximum doses) may have consistently underestimated upper-bounds of doses received by the public by up to an order of magnitude.

time of the French atmospheric tests. We estimate the total number of cancers between 1975 and 2020 of types that are recognized under French law to be radiogenic among the 110,000 people residing in the Society Islands in 1974 (the majority on Tahiti) to be $\sim$10,000.

We obtained this number by assuming an average population death rate of 0.54% and an average recognized cancers incidence of $\sim$0.2% per year over this period.[36] Furthermore, based on available cancer incidence data from the French Polynesian government, we find that the current average incidence of radiogenic cancers among people born before 1975 in French Polynesia is about 0.4% per year.[37] Thus we might expect at most about 350 new cases of radiogenic cancers per year among the 1974 residents who are still alive today. Beyond that, projections would have to account for age-related increases in rate of cancer in a population declining due to all causes of mortality. We note that this total number of cancers is two orders of magnitude greater than what would be expected from estimates of lifetime attributable risk of solid cancer based on available effective dose estimates (assuming a population similar to the United States in 1999).[38] It is impossible to attribute excess cancers to specific individuals, however.

Our results have implications for both past and future claimants' compensation claims. French Polynesians living in Tahiti in the summer of 1974 whose compensation claims have been rejected by CIVEN on the grounds that they were not exposed to 1 mSv of radiation in a twelve-month period, for example, should have the opportunity to seek renewed review of their claims.

Conclusion

In the context of French compensation law for victims of past nuclear testing, upper bound estimates of effective doses to the public are of key legal and policy importance. For claimants, who have developed radiogenic cancers and were present in French Polynesia during the period of atmospheric testing, they are the scientific basis upon which compensation is denied. For the French and French Polynesian governments, they also dictate the total number of eligible claimants and therefore the possible cost of compensation incurred from past nuclear testing.

On the basis of dose reconstructions based on a review of declassified French government source material and atmospheric transport modeling for six nuclear tests, we estimate that the number of French Polynesians who may have received effective doses greater than 1 mSv/yr, and would therefore be eligible for compensation should they develop one of the 23 legally-recognized radiogenic cancers, to be 110,000—about 90% of the total French Polynesian population in 1974. Additional exposure and contamination from atmospheric tests, which also impacted French Polynesian islands but were not reevaluated in this study, could increase this number further.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Data and code availability statement

All data generated or analyzed during this study are either included or cited in the published article and are available from the corresponding author upon reasonable request. The relevant primary source documents can be accessed online (https://moruroa-files.org/en/declassified-documents/). The source code for the HYSPLIT transport and dispersion model is available upon request from the NOAA Air Resources Laboratory (https://www.ready.noaa.gov/HYSPLIT_linux.php). The open-source code for Onix is available online (https://github.com/jlanversin/ONIX).

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20. See the seven reports cited in endnote 6.

21. Table reproduced from Ministère de la Défense, La dimension radiologique des essais nucléaires français en Polynésie, 293.

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24. Martin, Les atolls de Mururoa et Fangataufa, 271.

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28. The original 1974 map is available in SMSR, Retombées consecutives au tir CENTAURE, Report 101/SMSR.PAC/CD (September 7, 1974): figure 7, https://moruroa-files.org/documents/02-44-58. The latter (edited) versions appeared in multiple documents starting in 1998. See: Ministère de la Défense, La dimension radiologique des essais nucléaires français en Polynésie, 217, Martin, Les atolls de Mururoa et Fangataufa, 427, and G. Bourges, Study of the Radiological Situation at the Atolls of Mururoa and Fangataufa. Radiological Consequences of the Atmospheric Tests on the Islands of French Polynesia from 1966 to 1974 (CEA/DAM/DRIF/DASE, Paris, 1997), 947.

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31. Including this 25% measurement uncertainty, the upper bounds for groundshine, cloudshine, and inhalation contributions to the effective dose for the inhabitants of the Pirae/Papeete are corrected by the following factor $(1.36 \times 0.3 \times 1.3) \ / \ 0.13 \ \times$

$(1 + 1.96 \times 0.25) = 4.08 \times 1.49 = 6.08$ times the values originally estimated by the CEA.

32. The range of deposition values with respect to the Mahina reference station are 0.13–0.5 for Moorea, 0.15–2.5 for Huahine, 0.2–0.6 for Raiatea, 0.25–0.4 for Bora-Bora. See SMSR, Retombées consecutives au tir CENTAURE, figures 8–11.

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34. See INSEE, Polynésie Française: Comparaison des résultats des recensements de 1956, 1962 et 1971, et du dénombrement de 1967 (September 20, 1971): 1–14, and INSEE, Résultats du recensement de la population de la Polynésie française (April 29, 1977).

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Appendix A. ATMOSPHERIC transport simulation of nuclear test fallout

Fallout patterns and cloud trajectories from French nuclear tests were reconstructed using the US NOAA Hybrid Single-Particle Integrated Trajectory (HYSPLIT) particle transport and dispersion model.[39] Following previous studies,[40] we modeled the dispersion and deposition of fallout from a stabilized nuclear cloud using data available in historical declassified documents or French government publications and meteorological data from the NCEP/NCAR Reanalysis (1948–present) project.[41]

Initial clouds are represented as a segmented vertical linear source with activity distributed among the cap, skirt, and stem of the cloud as 0.775/0.15/0.075 for barge surface tests and 0.9712/0.0283/0.0005 for balloon tests. Cloud dimensions were obtained from government sources (see Table A1). In general, the base of the mushroom cap is ∼0.7 time the altitude of the top. The base of the skirt is 1/2 and 2/3 the altitude of the base of the cap for ground (barge) and air (balloon or airdrop) bursts respectively.

For Centaure, the corresponding altitudes were taken as 5200 m, 3640 m and 1815 m with the stem extending to ground level. The cloud particle sizes were assumed to be log-normally distributed with parameters (d = 73.6 μm, s = 1.51) for barge tests and (d = 0.15 μm, s = 2.5) for balloon tests. Particles were equally distributed in 100 diameter bins of equal activity (according to the 2.5 and 3rd moment respectively) and summed to a unit release. Particle density was kept constant over time and was assumed to range from 1.30–2.16 to 4.8 g/cm^3 for barge and balloon tests respectively. For Centaure, the particle density was obtained from a granulometric measurement of particles collected at the Tahiti Mahina radiological measurement station.[42]

HYSPLIT calculations were run on a 12-core Linux machine with MPI and involved the release of 3,000,000 particles each. The meteorological data is provided on a 2.5 by 2.5 degrees global grid with a 6-hour time resolution. The output data include particle air concentration between 0 and 500 m and ground deposition on a 22 by 22 degrees grid with 0.05 by 0.05 degrees resolution. Air and ground activity were then computed assuming no fractionation of fission products using the con2rem HYSPLIT routine. The source code of con2rem was modified to allow for the use of more than 500 nuclides in the source term and to account for the beginning of decay at the time of the explosion and not at the beginning of the simulation. Different source terms were used for activity concentration maps or dose rate contour calculations normalized at H + 1 using uranium-235 and plutonium-239 ENDF8 fission product yields at 500 keV and 14 MeV.[43] Decay of the source term was conducted at different time interval with Onix, an open-source depletion code developed at Princeton University.[44] Activity to dose ratios for groundshine, cloudshine, and inhalation were obtained from the US FGR12 and ICRP Publication 72.[45] A Python routine was written to generate relevant con2rem activity input files.

Overall fallout dose contours were found to be in good agreement with those produced historically by the French government (see Figure 4 of main text) despite known uncertainties associated with the chosen particle size distribution, the cloud dimensions, and the meteorological reanalysis dataset. Similarly, air activity concentrations computed by HYSPLIT were

found to be within an order of magnitude of historical measurements. They were often underpredicted by a factor of 5 to 10, however, depending on the test (for example, between the measured and the predicted air activity concentration at the Mahina station following the Centaure fallout). Underprediction for similar type of HYSPLIT computation have been noted elsewhere.[46] In our case, they may be the result of multiple assumptions and models included in HYSPLIT. For example, HYSPLIT typically overestimates wet deposition from light rain,[47] which could deplete the debris cloud faster as it travels for several days. In addition, we assume particle sizes and densities to remain constant over time and may be underestimating their settling velocity once they reach lower altitudes.[48]

Table A1. List of French atmospheric nuclear and safety tests in the Pacific (1966–1974) with relevant data for atmospheric transport simulations.

#	Date DD/MM/YYYY	Time (UTC)	Name	Location	Type	Height (m)	Yield (kT)	Type	Cloud top (m)	Cloud bottom (m)
1	02/07/1966	15:34	**ALDÉBARAN**	21°52′07″S 139°00′07″W	Barge	10	28	Fission, Pu	9,000	5,000
2	19/07/1966	15:05	TAMOURÉ	21°46′32″S 138°24′52″W	Air drop	1000	50	Fission, Pu	150,00	13,000
3	21/07/1966	12:00	GANYMÈDE	21°46′49″S 138°54′16″W	Tower	12	0	Safety, Pu	n.a.	n.a.
4	11/09/1966	17:30	BÉTELGEUSE	21°47′30″S 138°53′33″W	Balloon	470	110	Fission, Pu	18,000	10,000
5	24/09/1966	17:00	**RIGEL**	22°14′24″S 138°43′22″W	Barge	3	125	Fission, Pu	13,000	6,000
6	04/10/1966	21:00	SIRIUS	21°52′18″S 139°00′12″W	Barge	10	205	Fission, Pu	22,000	12,000
7	05/06/1967	19:00	ALTAÏR	21°47′11″S 139°53′33″W	Balloon	295	15	Fission, Pu	11,000	8,000
8	27/06/1967	18:30	ANTARÈS	21°52′08″S 139°00′02″W	Balloon	340	120	Fission, Pu	20,000	8,500
9	07/02/1967	17:30	**ARCTURUS**	21°47′11″S 138°53′33″W	Barge	3	22	Fission, Pu	15,000	7,100
10	07/07/1968	22:00	CAPELLA	21°47′24″S 138°53′32″W	Balloon	463	115	Fission, Pu	16,700	11,400
11	15/07/1968	19:00	CASTOR	21°47′24″S 139°00′13″W	Balloon	650	450	Fission, HEU	21,000	14,800
12	03/08/1968	21:00	POLLUX	21°47′26″S 138°53′32″W	Balloon	490	150	Fission, Pu	17,600	10,400
13	24/08/1968	18:30	CANOPUS	22°14′36″S 138°43′30″W	Balloon	520	2,600	Fission + Fusion	24,000	14,800
14	08/09/1968	19:00	PROCYON	21°52′36″S 139°00′18″W	Balloon	700	1,280	Fission + Fusion	24,000	15,500
15	15/05/1970	18:00	ANDROMÈDE	21°47′03″S 138°53′34″W	Balloon	220	13	Fission, Pu	10,000	7,500
16	22/05/1970	18:30	CASSIOPÉE	21°52′34″S 139°00′14″W	Balloon	500	224	Fission + Fusion	17,000	13,500
17	30/05/1970	18:00	DRAGON	22°14′21″S 138°43′26″W	Balloon	500	945	Fission + Fusion	21,000	15,000
18	24/06/1970	18:30	ERIDAN	21°47′03″S 138°53′34″W	Balloon	220	12	Fission, Pu	12,000	85,00
19	03/07/1970	18:30	LICORNE	21°52′34″S 139°00′14″W	Balloon	500	914	Fission + Fusion	24,000	15,000
20	27/07/1970	19:00	PÉGASE	21°47′03″S 138°53′34″W	Balloon	220	0.05	Fission, Pu	2,400	1,680 (estimate)
21	02/08/1970	19:00	ORION	22°14′02″S 138°43′01″W	Balloon	400	72	Fission + Fusion	16,500	10,500
22	06/08/1970	19:00	TOUCAN	21°52′34″S 139°00′14″W	Balloon	500	594	Fission + Fusion	19,000	14,000
23	05/06/1971	19:15	DIONÉ	21°47′15″S 138°53′34″W	Balloon	275	34	Fission, Pu	13,400	11,200
24	12/06/1971	19:15	**ENCELADE**	21°52′34″S 139°00′14″W	Balloon	450	440	Fission, HEU	17,000	13,500

Table A1. Continued.

#	Date DD/MM/YYYY	Time (UTC)	Name	Location	Type	Height (m)	Yield (kT)	Type	Cloud top (m)	Cloud bottom (m)
25	04/07/1971	21:30	JAPET	21°47′10″S 138°53′33″W	Balloon	230	9	Fission, Pu	9,000	5,500
26	08/08/1971	18:30	**PHOEBÉ**	21°47′10″S 138°53′33″W	Balloon	230	4	Fission, Pu	4,800	1,800
27	14/08/1971	19:00	RHÉA	21°52′39″S 139°00′38″W	Balloon	480	955	Fission + Fusion	20,000	15,500
28	25/06/1972	19:00	UMBRIEL	21°47′09″S 138°53′34″W	Balloon	230	0.5	Fission, Pu	2,400	1,680 (estimate)
29	30/06/1972	18:30	TITANIA	21°52′00″S 139°00′22″W	Balloon	220	4	Fission, Pu	5,800	2,600
30	27/07/1972	18:40	OBÉRON	21°52′00″S 139°00′22″W	Balloon	220	6	Fission, Pu	8,500	6,500
31	31/07/1972	22:30	ARIEL	21°46′50″S 138°54′02″W	Tower	10	0.001	Safety, Pu	n.a.	n.a.
32	21/07/1973	18:00	EUTERPE	21°52′00″S 139°00′22″W	Balloon	220	11	Fission, Pu	n.a.	n.a.
33	28/07/1973	23:06	MELPOMÈNE	21°47′12″S 138°53′34″W	Balloon	270	0.05	Fission, Pu	2,300	1,800
34	18/08/1973	18:15	PALLAS	21°47′12″S 138°53′34″W	Balloon	270	4	Fission, Pu	5,500	1,800
35	24/08/1973	18:00	PARTHÉNOPE	21°52′00″S 139°00′22″W	Balloon	220	0.2	Fission, Pu	2,500	1,400
36	28/08/1973	18:30	TAMARA	21°48′50″S 139°15′19″W	Air drop	250	6	Fission, Pu	n.a.	n.a.
37	13/09/1973	15:42	VESTA	21°46′48″S 138°53′57″W	Tower	4.1	0	Safety, Pu	n.a.	n.a.
38	16/06/1974	17:30	CAPRICORNE	21°51′58″S 139°00′03″W	Balloon	220	4	Fission, Pu	6,900	4,830 (estimate)
39	01/07/1974	17:30	BÉLIER	21°46′48″S 138°53′57″W	Tower	5.6	0	Safety, Pu	n.a.	n.a.
40	07/07/1974	23:15	GÉMEAUX	21°52′08″S 139°00′07″W	Balloon	312	150	Fission + Fusion	15,250	10,668
41	07/17/1974	17:00	**CENTAURE**	21°47′13″S 138°53′32″W	Balloon	270	4	Fission, Pu	5,200	3,640 (estimate)
42	25/07/1974	17:30	MAQUIS	21°58′50″S 139°11′15″W	Air drop	250	8	Fission, Pu	10,700	7,490 (estimate)
43	28/07/1974	17:30	PERSÉE	21°46′48″S 138°53′57″W	Tower	5.6	0.001	Safety, Pu	n.a.	n.a.
44	14/08/1974	0:30	SCORPION	21°52′08″S 139°00′07″W	Balloon	312	96	Fission + Fusion	17,500	12,250 (estimate)
45	24/08/1974	23:45	TAUREAU	21°47′13″S 139°53′32″W	Balloon	270	14	Fission, Pu	10,000	7,000 (estimate)
46	14/09/1974	23:30	VERSEAU	21°52′20″S 139°00′12″W	Balloon	433	332	Fission + Fusion	19,000	13,300 (estimate)

Only tests with their name in bold were the focus of government dose reconstruction studies. Data was extracted from French government documents.[49] For cloud top and bottom, "n.a." means the data is not available. For a few tests, the altitude of the cloud bottom was estimated to be 0.7 time the altitude of the top.

Appendix B. Reevaluation of effective doses to the public—supplementary data

Reevaluation of doses from the 1974 Centaure test

Table B1. Corrected effective dose estimates for the Centaure fallout on Tahiti.

Effective dose	Child age 1–2 years			Adult		
	Pirae	Hitiaa	Taravao	Pirae	Hitiaa	Taravao
Groundshine	**0.32**	**1.70**	**6.22**	**0.32**	**1.70**	**6.22**
Cloudshine	**0.01**	**0.03**	**0.12**	**0.01**	**0.03**	**0.12**
Inhalation	**0.30**	**0.78**	**2.86**	**0.28**	**0.71**	**2.58**
Water	0.05	0.10	0.02	0.02	0.03	0.00
Milk	0.36	2.10	0.36	0.03	0.20	0.03
Vegetables	**0.95**	0.95	0.56	**0.41**	0.41	0.24
Meat	0.08	0.04	0.04	0.04	0.02	0.02
Eggs	0.02	0.01	0.01	0.01	0.00	0.00
Fish	0.15	0.15	0.15	0.07	0.09	0.09
Mollusk	0.02	0.07	0.07	0.01	0.06	0.06
Shellfish	0.06	0.06	0.06	0.03	0.03	0.03
Ingestion	1.69	3.48	1.26	0.61	0.84	0.47
Internal	1.99	4.25	4.11	0.90	1.55	3.06
External	0.33	1.73	6.35	0.33	1.73	6.35
Total (mSv)	**2.32**	**5.98**	**10.46**	**1.23**	**3.28**	**9.40**
CEA 2006	1.19	5.27	4.55	0.45	2.59	3.56
Ratio	1.95	1.14	2.30	2.73	1.27	2.64

Updated values in bold reflect higher ground deposition for the reference station (Mahina), higher upper bound for deposition in the Pirae/Papeete zone, absence of data from the Papeeete/Pirae market for vegetables. Groundshine was corrected for one year (instead of six months) and we assumed time spent outdoor to be 2/3 for Teahupoo/Taravao (as is assumed by the CEA for Pirae and Hitiaa) as opposed to the 1/6 coefficient chosen by CEA for this area, which was the most impacted by fallout.

Table B2. Corrected thyroid dose equivalent estimates for the Centaure fallout on Tahiti.

Thyroid dose equivalent	Child age 1–2 years			Adult		
	Pirae	Hitiaa	Taravao	Pirae	Hitiaa	Taravao
Groundshine	**0.32**	**1.61**	**5.91**	**0.32**	**1.61**	**5.91**
Cloudshine	**0.01**	**0.04**	**0.13**	**0.01**	**0.04**	**0.13**
Inhalation	**3.47**	**8.70**	**32.91**	**1.64**	**4.22**	**14.96**
Water	0.60	1.30	0.22	0.20	0.30	0.05
Milk	4.50	25.00	4.50	0.40	1.70	0.40
Vegetables	**11.90**	11.90	6.90	**4.50**	4.50	2.60
Meat	1.10	0.54	0.54	0.50	0.20	0.20
Eggs	0.18	0.14	0.07	0.07	0.05	0.03
Fish	1.90	1.90	1.90	0.80	1.00	1.00
Mollusk	0.30	0.84	0.84	0.12	0.66	0.66
Shellfish	0.66	0.66	0.66	0.30	0.30	0.30
Ingestion	21.14	42.28	15.63	6.89	8.71	5.24
Internal	24.61	50.98	48.54	8.53	12.93	20.20
External	0.33	1.65	6.04	0.33	1.65	6.04
Total (mSv)	**24.94**	**52.63**	**54.58**	**8.86**	**14.57**	**26.24**
CEA 2006	14.11	48.68	39.83	4.36	11.81	16.24
Ratio	1.77	1.08	1.37	2.03	1.23	1.62

Updated values in bold include groundshine and cloudshine contributions to the Thyroid dose equivalent and address the absence of data for vegetables from the Papeeete/Pirae market.

Reevaluation of doses for tests that impacted the Gambier and Tureia

This section provides details on our dose reevaluations for the five tests that impacted the Gambier archipelago and the atoll of Tureia. For each test, we provide a table with a breakdown of external and internal doses with a description of the corrections we implemented after our review of French government documents. For two of these tests (Aldebaran and Rigel), we provide additional background to show how limited data and poor assumptions about the source of drinking water utilized by residents of Tureia and the Gambier archipelago can lead to underestimations of internal exposure to ionizing radiation.

Aldebaran on Gambier (1966)

The first French nuclear test conducted in French Polynesia, codenamed "Aldebaran," took place on 2 July 1966. The plutonium device was fired at 15:34 (UTC) from a barge anchored on the surface of the Moruroa lagoon (altitude $\sim$10 m, water depth = 30–40 m) and generated a $\sim$28 kt fission yield. The radioactive debris cloud (a mixture of slurry droplets comprising a saturated solution of sodium chloride in water with sodium chloride crystals and small radioactive particles in suspension) reached an altitude of 9000 m and was pushed away by winds coming from the west-north-west direction.[50] Meteorological data reproduced in a 1967 declassified document indicates general wind directions were measured and known three hours before the test.[51] Gamma detection buoys meant to measure the primary axis of the fallout were deployed in an arc whose sector covered the Gambier archipelago.[52] The fallout from Aldebaran reached the Gambier islands 10 hours and 45 minutes after the test. Dry deposition of radioactive particles took place for about one hour and 20 minutes, leading to a ground deposition of 6.2×10^7 Bq/m^2 (single measurement of 1.67 mCi/m^2).[53] The dose rate at the end of the fallout reached 0.25 mGy/h (25 mrad/h),[54] which is in good agreement with our fallout predictions (see Figure 4 of main text). It rained on the island shortly after, leading to the contamination of rainwater collection systems.

Despite ample time for issuing warnings, the population was not alerted about the risks of radiation exposures. Authorities in charge of measuring environmental and foodstuff contamination on the islands suggested that it might be necessary to minimize the true dose estimates to avoid losing the trust of local inhabitants.[55] The 1966 estimates concluded that the population received effective whole-body and thyroid doses of 7.12 mSv (0.712 rem) and 15.4 mSv (1.54 rem).[56] These numbers were obtained using methodologies and models available at the time and were computed for adults only.

In the 2006 dose reconstruction study of the event, the CEA computed effective (whole-body) dose and thyroid doses equivalent from groundshine, cloudshine, inhalation, and ingestion of radionuclides for multiple age groups.[57] The study developed minimum and maximum estimates of the whole-body and thyroid doses to the local population based on different assumptions.

For groundshine, a dose rate of 0.14 mSv/h was computed at H + 11 (i.e., 11 hours after detonation) from the ground deposition data and a radionuclide source term, without providing details and assumptions about how such source term was produced. This dose rate was considered consistent with the measured ground activity and was chosen to compute the dose estimates, despite producing half the dose rate measured on Gambier at the time. The CEA then calculated the corresponding external dose up to six months (and not up to a year). The result was then multiplied by 2/3 to account for time typically spent outside

rather than inside during the day, as opposed to a factor of 0.75 found in declassified historical documents (and without a quantitative estimate of the shielding provided by local houses). One such document shows that significant radioactivity was measured on the clothes of a local inhabitant who was sleeping outside,[58] highlighting the problem of using a correction factor in this particular context to produce a maximum dose estimate.

For cloudshine and inhalation, two different values of deposition velocity ($V_d = 10^{-2}$ and 10^{-1} m/s) were used by the CEA to generate a minimum and maximum total integrated activity in air. These values are consistent with the dry deposition velocities for particles in the range of 6 to 20 μm in diameter with density $\sim$2 g/cm^3. Given that the test occurred on a barge anchored at the surface of the Moruroa lagoon and the relative proximity of the Gambier islands to ground zero, it is likely that a wider range of particle sizes reached the atoll, yet no uncertainties associated with this parameter were considered.

For exposure from the ingestion of contaminated water, the CEA assumed that either no contaminated water was consumed by the inhabitants in the case of the minimum exposure dose estimate or that contaminated water from the main village stream water collection system (814 Bq per liter measured on 8 July, corresponding to 14,000 Bq/l at H + 11) was consumed to compute the maximum dose. While the report of the radiological survey team dispatched to the island described some French government employees drinking bottled water,[59] the local population, who were not made aware of the fallout, had no access to uncontaminated sources of drinking water. Furthermore, isolated households typically relied on rainwater collected in barrels and cisterns from their roofs as their primary source of drinking water in 1966 and as late as 1977.[60]

We estimated the contamination of rainwater from the Aldebaran test from two different type of measures, both obtained from historical documents. First, the radiological survey team, measured the contamination levels of rainwater samples collected on 8 July 1966 and 9 July 1966 and found values of 16,650 Bq/l and 14,800 Bq/l respectively.[61] These correspond to values at H + 11 ranging from $(14{,}000/814)\times14{,}800 = 2.54 \times 10^5$ Bq/l to $(11/(7 \times 24 + 11))^{-1.2}\times14{,}800 = 4.2 \times 10^5$ Bq/l depending on methodologies to account for decay between H + 11 and the sampling time. This gives a factor of $\sim$20 difference between the water contamination measured in the central water supply in Rikitea and the contaminated rainwater. Second, on 3 July, activity in rainwater samples collected from the SMSR pluviometer ranged from 5.48×10^5 to 1.39×10^6 Bq/l.[62] Correcting for decay this gives 2.19×10^6 to 5.56×10^6 Bq/l at H + 11. The pluviometer collection area was 1 m^2 and it rained 13 mm. Typical individual household water collection involved surfaces of 30 m^2 and cisterns of 15,000 liters capacity.[63] Remembering that the measured total deposited activity was 6.2×10^7 Bq/m^2, this means that to a first order about 390 liters of contaminated water $(6.2 \times 10^7/(0.013 \times 1{,}000) = 4.77 \times 10^6$ Bq/l at H + 11) would have been collected on the first day. Assuming a cistern half full, this activity would have been diluted by a factor of $\sim$20 (note that the cistern could have been at lesser capacity) to $\sim$2.5 $\times 10^5$ Bq/l or 20 times the activity of the Rikitea water system.

By considering rainwater consumption and following the CEA methodology used in other reports where this contamination pathway is computed, we find that the maximum effective and thyroid dose estimates from water consumption for the first month after the fallout could have been underestimated by a factor of 20. Using this set of information, we reevaluate the 2006 CEA effective dose and thyroid dose equivalent to adults and children on the Gambier Islands. Our results shown in Table B3 suggest that maximum dose estimates could have been underestimated by a factor of $\sim$2.5.

Table B3. Effective and thyroid dose estimates for the Aldebaran fallout on the Gambier archipelago.

	Effective dose (mSv)				Thyroid dose equivalent (mSv)			
	Child age 1–2 years		Adult		Child age 1–2 years		Adult	
	Min	Max	Min	Max	Min	Max	Min	Max
Groundshine	**3.02**	**8.14**	**3.02**	**8.14**	**2.87**	**7.74**	**2.87**	**7.74**
Cloudshine	0.06	0.29	0.03	0.67	**0.07**	**0.30**	**0.03**	**0.71**
Inhalation	0.70	2.99	0.16	3.84	3.00	30.00	1.30	13.00
Water	**0.48**	**9.60**	**0.12**	**2.40**	**6.00**	**120.00**	**1.30**	**26.00**
Vegetables	0.10	1.70	0.09	1.40	1.30	19.00	1.00	14.00
Fish	0.00	0.64	0.00	0.32	0.02	7.00	0.01	3.20
Mollusk	0.00	1.24	0.00	0.48	0.00	15.80	0.00	5.40
Ingestion	0.58	13.18	0.21	4.60	7.32	161.80	2.31	48.60
Internal	1.29	16.17	0.37	8.44	10.32	191.80	3.61	61.60
External	3.08	8.43	3.04	8.82	2.93	8.04	2.89	8.45
Total (mSv)	**4.37**	**24.60**	**3.42**	**17.26**	**13.25**	**199.84**	**6.50**	**70.05**
CEA 2006	3.20	9.40	3.10	6.60	4.00	78.00	2.00	37.00
Ratio	1.36	2.62	1.10	2.61	3.31	2.56	3.25	1.89

Results are based on 2006 CEA data and our reevaluations (in bold) of the groundshine dose as well as doses from contaminated water consumption. Groundshine and cloudshine contributions to the thyroid, missing from the CEA analysis, were also included.

Rigel on Gambier and Tureia (1966)

The fourth French nuclear test in French Polynesia, codenamed "Rigel," took place on 24 September 1966 from a barge anchored on the lagoon of the Fangataufa atoll (22° 14′ 24″ S 138° 43′ 22″ W). The test involved an experimental thermonuclear device consisting of a plutonium core surrounded by a thick shell of lithium deuteride.[64] While no significant fusion reaction took place, the device generated a 125 kt yield. The test led to significant contamination of the Fangataufa test site, which required a major cleanup by military personnel.[65] After the explosion, the radioactive cloud head traveled eastwards over the uninhabited Acteon islands. Parts of the cloud stem, however, traveled northwards and landed on Moruroa and Tureia, a feature which our simulation reproduced (see Figure 4). Both Tureia and the nearby Gambier islands also experienced radioactive rains two days after the test.[66]

In the absence of comprehensive environmental and foodstuff radiological survey data, the 2006 CEA dose reconstruction for both the Gambier islands and Tureia are primarily built upon a single rain activity measurement at each location.[67] From these individual data points, dose estimates are computed for groundshine, cloudshine, inhalation, and ingestion using activity ratios constructed from data available from other tests. For example, the drinking water activity is calculated from the rainwater activity by using ratios of these two values from the Arcturus (1967) and Encelade (1971) tests, which both impacted Tureia and not the Gambier islands. On top of this, three major assumptions have important impact on the final dose estimates from water consumption, especially in the case of Tureia.

First, at least two different sets of measurements for the original rain contamination levels appear in two different historical documents. One in the report of the Rigel test, and one in the overall report on the 1966 campaign.[68] The 2006 dose reconstruction uses the lowest of the two. Using the largest values of activities raise the maximum dose estimate by ∼1.52 and ∼2.85 for Gambier and Tureia respectively. (We also discarded a third set of data points for rain activity, three orders of magnitude larger than the others, assuming the units were wrongfully reported.)

Second, assumptions about the ratios of activities between rain contamination and collected rainwater underestimate maximum doses. Tureia had two kinds of rainwater collection systems: a shared communal cistern and individual household cisterns. For the Encelade test, the latter were contaminated up to ~7.4 times more than the communal cistern.[69] The ratios used for the Rigel reconstruction, however, are based on measurements from two different type of cisterns (communal for Arcturus, and household for Encelade) that have different collection surfaces and capacities, leading to different dilution factors of the contaminated rain. In the case of Arcturus, no data is publicly available for the family cisterns.[70] Taking this possibility into account raises the maximum effective and thyroid doses for the local population by at least a factor of ~7. This does not mean that the cisterns were not contaminated with higher levels of fission products as dilution factors are affected by the amount of water already present in the cisterns when the fallout occurs, which remains unknown.

Third, for Tureia, the population is assumed to drink half the amount of water of other inhabitants in French Polynesia (the core assumption is that adults drink one liter of water and two liters of coconut water per day). This assumption, no longer used in recent dose reconstruction studies,[71] also leads to the underestimation of maximum doses by a factor of 2.

Together, changes in these three assumptions can affect the maximum dose estimates by a factor of ~10 to 20 depending on the age of individuals (see Tables B4 and B5). This result is not surprising given the large uncertainties involved when relying on such limited data. While the 2006 reconstruction studies present both "minimum" and "maximum" dose estimates, our analysis and results clearly show that they should not be understood as such nor as any type of confidence intervals. To our knowledge, any type of uncertainty and sensitivity analysis is still missing from the government studies available to date.

Table B4. Effective dose and thyroid dose equivalent estimates for the Rigel fallout on the Gambier archipelago.

	Effective dose (mSv)				Thyroid dose EQ. (mSv)			
	Child age 1–2 years		Adult		Child age 1–2 years		Adult	
	Min	Max	Min	Max	Min	Max	Min	Max
Groundshine	**0.02**	**0.05**	**0.02**	**0.05**	**0.02**	**0.04**	**0.02**	**0.04**
Cloudshine	0.00	**0.00**	0.00	**0.00**	0.00	**0.00**	0.00	**0.00**
Inhalation	0.00	**0.00**	0.00	**0.00**	0.01	**0.02**	0.01	**0.01**
Water	**0.38**	**7.91**	**0.10**	**2.10**	**4.40**	**90.21**	**1.00**	**21.01**
Vegetables	0.00	**0.05**	0.00	**0.04**	0.02	**0.59**	0.01	**10.93**
Fish and Mollusk	0.01	**0.02**	0.01	**0.02**	0.13	**0.20**	0.10	**0.15**
Ingestion	0.39	7.98	0.11	2.16	4.55	91.00	1.11	32.10
Internal	0.40	7.98	0.11	2.16	4.56	91.02	1.11	32.10
External	0.02	0.05	0.02	0.05	0.02	0.04	0.02	0.04
Total (mSv)	**0.42**	**8.03**	**0.13**	**2.20**	**4.58**	**91.06**	**1.13**	**32.15**
CEA 2006	0.41	0.71	0.13	0.23	4.61	7.81	1.11	2.11
Ratio	1.00	11.37	1.01	9.68	0.99	11.66	1.02	15.27

Results are based on 2006 CEA data and our reevaluations. Updated values in bold include corrections to the groundshine dose as well as doses from contaminated water consumption. Groundshine and cloudshine contributions to the thyroid, originally missing, were also included. The maximum groundshine dose was computed for one year instead of six months (factor of 1.04) and assumed 100% of time spent outside (factor of 1.5). Groundshine was also corrected to account for the availability of higher rain activity measurement value (5,000 pCi/cm^3) leading to an increase by a factor of 1.52 (note that deposition was estimated by the CEA from rainwater activity, the sole measurement available). The rain activity correction was also applied to cloudshine, inhalation as well as ingestion contributions from fish and vegetables consumption as they were all computed from this value. The contribution of water consumption to the maximum estimate was also corrected by a factor of $7.4 \times 1.67 = 12.3$ to account for both higher measured rain activity and the possibility of rain (cistern) water consumption on the Gambier Archipelago (based on Arcturus data corrected for possibly higher family cisterns activity). Note that, technically, the maximum value could be increased further if no contaminated rain dilution is assumed.

Table B5. Effective and thyroid dose estimates for the Rigel fallout on the Tureia atoll.

	Effective dose (mSv)				Thyroid dose (mSv)			
	Child age 1–2 years		Adult		Child age 1–2 years		Adult	
	Min	Max	Min	Max	Min	Max	Min	Max
Groundshine	**0.05**	**0.22**	**0.05**	**0.22**	**0.05**	**0.21**	**0.05**	**0.21**
Cloudshine	0.00	**0.00**	0.00	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Inhalation	0.00	**0.01**	0.00	**0.01**	0.03	**0.09**	0.02	**0.04**
Water	0.05	**3.37**	0.03	**0.84**	0.52	**37.12**	0.12	**8.44**
Fish and Mollusk	0.00	**0.27**	0.00	**0.21**	0.06	**3.14**	0.02	**2.08**
Ingestion	0.05	3.65	0.03	1.05	0.58	40.25	0.14	10.52
Internal	0.06	3.65	0.03	1.06	0.61	40.34	0.15	10.56
External	0.05	0.22	0.05	0.22	0.05	0.21	0.05	0.21
Total (mSv)	**0.11**	**3.88**	**0.08**	**1.28**	**0.66**	**40.55**	**0.20**	**10.77**
CEA 2006	0.11	0.23	0.06	0.15	0.61	2.01	0.15	0.95
Ratio	1.02	17.02	1.32	8.78	1.08	20.17	1.32	11.40

Results are based on 2006 CEA data and our reevaluations. Updated values in bold include corrections to the groundshine dose as well as doses from contaminated water consumption. Groundshine and cloudshine contributions to the thyroid, originally missing, are also included. The maximum groundshine dose was computed for one year instead of six months (factor of 1.04) and assumed 100% of time spent outside (factor of 1.5). Groundshine was also corrected to account for the availability of a higher rain activity measurement value (2,000 pCi/cm^3 measured on 9/26/1966) leading to an increase by a factor of 2.85. The rain activity correction was also applied to cloudshine, inhalation as well as foodstuffs consumption as they were all computed from this value. The contribution of water consumption to the maximum estimate was also corrected by a factor of $7.4 \times 2.85 = 21.09$ to account for higher measured rain activity and lower dilution of rainwater activity in family cisterns (based on Arcturus cistern data). Note that, technically, the maximum value could be increased further if no dilution took place. Finally, we correct water consumption for Tureia by a factor of 2 to be coherent with recent dose reconstruction studies (see main article).

Arcturus on Tureia (1967)

Table B6. Effective dose and thyroid dose equivalent estimates for the Arcturus fallout on the Tureia atoll.

	Effective dose (mSv)				Thyroid dose EQ. (mSv)			
	Child age 1–2 years		Adult		Child age 1–2 years		Adult	
	Min	Max	Min	Max	Min	Max	Min	Max
Groundshine	**0.73**	**3.28**	**0.73**	**3.28**	**0.69**	**3.11**	**0.69**	**3.11**
Cloudshine	0.00	0.01	0.00	0.01	**0.00**	**0.01**	**0.00**	**0.01**
Inhalation	0.02	0.11	0.01	0.07	0.23	1.38	0.10	0.63
Cistern (rain) water	0.11	**1.63**	0.03	**0.44**	1.24	**18.35**	0.29	**4.29**
Fruits	0.02	0.02	0.01	0.01	0.20	0.22	0.13	0.14
Fish	0.02	0.25	0.01	0.10	0.22	2.80	0.08	1.00
Mollusk	0.03	2.80	0.03	2.28	0.34	31.80	0.26	22.50
Ingestion	0.18	4.70	0.08	2.84	2.00	53.17	0.76	27.93
Internal	0.20	4.81	0.09	2.91	2.23	54.55	0.86	28.56
External	0.73	3.29	0.73	3.29	0.69	3.12	0.69	3.12
Total (mSv)	**0.93**	**8.09**	**0.82**	**6.19**	**2.92**	**57.67**	**1.55**	**31.68**
CEA 2006	0.90	4.00	0.79	3.20	2.23	37.44	0.86	24.56
Ratio	1.03	2.02	1.04	1.93	1.31	1.54	1.81	1.29

Results are based on 2006 CEA data and our reevaluations. Updated values in bold include corrections to the groundshine dose as well as doses from contaminated water consumption. Groundshine and cloudshine contributions to the thyroid, originally missing, are also included. The maximum groundshine dose was computed for one year instead of six months (factor of 1.04) and assumed 100% of time spent outside (factor of 1.5). Groundshine was also corrected to account for the availability of a measured dose rate (3 mrad/h measured on 7/2/1967), leading to an increase by a factor of 3 (note that another instrument measured 5 mrad/h).[72] The rain activity correction was also applied to cloudshine, inhalation as well as foodstuffs consumption as they were all computed from this value. The contribution of water consumption to the maximum estimate was also corrected by a factor of 7.4 to account for potentially lower dilution of rainwater activity in family cisterns (as measured after the Encelade test). Note that, technically, the maximum value could be increased further if no dilution took place. Finally, we correct water consumption for Tureia by a factor of 2 to be coherent with recent dose reconstruction studies (similarly to the Rigel test).

Encelade on Tureia (1971)

Table B7. Effective dose and thyroid dose equivalent estimates for the Encelade fallout on the Tureia atoll.

	Effective dose (mSv)				Thyroid dose EQ. (mSv)			
	Child age 1–2 years		Adult		Child age 1–2 years		Adult	
	Min	Max	Min	Max	Min	Max	Min	Max
Groundshine	**1.39**	**6.93**	1.39	**6.93**	**1.30**	**6.51**	**1.30**	**6.51**
Cloudshine	0.00	**0.02**	0.00	**0.02**	0.00	0.02	0.00	0.02
Inhalation	0.01	**0.12**	0.00	**0.05**	0.14	**1.64**	**0.04**	**0.50**
Cistern (rain) water	0.25	**3.82**	0.06	**0.95**	3.00	**44.73**	0.66	**9.96**
Coconut water	0.01	0.01	0.00	0.00	0.02	0.02	0.01	0.01
Vegetables (papaye)	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01
Vegetables (coprah)	0.01	0.01	0.00	0.00	0.03	0.03	0.01	0.01
Meat	0.00	0.01	0.00	0.00	0.01	0.06	0.00	0.02
Fish	0.01	0.24	0.01	0.10	0.13	2.25	0.05	0.84
Mollusk	0.07	**0.38**	0.06	**0.32**	0.54	**3.56**	0.41	**2.69**
Ingestion	0.35	4.46	0.13	1.38	3.74	50.66	1.14	13.53
Internal	0.36	4.59	0.13	1.43	3.88	52.30	1.18	14.03
External	1.39	6.94	1.39	6.94	1.30	6.53	1.30	6.53
Total (mSv)	**1.75**	**11.53**	**1.52**	**8.37**	**5.18**	**58.82**	**2.49**	**20.56**
CEA 2006	1.49	3.50	1.25	1.91	3.88	26.54	1.18	7.53
Ratio	1.18	3.30	1.21	4.38	1.34	2.22	2.10	2.73

Results are based on 2006 CEA data and our reevaluations. Updated values in bold include corrections to the groundshine dose as well as doses from contaminated water and mollusk consumption. Groundshine and cloudshine contributions to the thyroid, originally missing, were also included. The maximum groundshine dose was computed for one year instead of six months (factor of 1.04). It assumed 100% of time spent outside (factor of 1.5) and accounted for the first six hours of the fallout (+0.32 mSv). It was also corrected to account for the difference between the reconstructed and the measured dose rate (6 mrad/h measured on 6/13/1971),[73] leading to an increase by a factor of 3.33. Maximum inhalation and cloudshine were multiplied by 2 (as the CEA assumed a 0.5 factor because the fallout occurred at night). Internal dose from mollusk consumption was multiplied by 1.58 to account for the maximum activity measured in Benitier (measurement ref. 38628 A).[74] The maximum dose from water was multiplied by 1.06 to account for the maximum measured value.[75] Finally, we corrected water consumption for Tureia by a factor of 2 to be coherent with recent dose reconstruction studies (see main article).

Phoebe on Gambier (1971)

Table B8. Effective dose and thyroid dose equivalent estimates for the Phoebe fallout on the Gambier archipelago.

	Effective dose (mSv)				Thyroid dose EQ. (mSv)			
	Child age 1–2 years		Adult		Child age 1–2 years		Adult	
	Min	Max	Min	Max	Min	Max	Min	Max
Groundshine	**20.11**	**0.65**	**0.11**	**0.65**	**0.11**	**0.62**	**0.11**	**0.62**
Cloudshine	0.00	0.00	0.00	0.00	**0.00**	**0.00**	0.00	0.00
Inhalation	0.00	0.00	0.00	0.00	0.01	**0.04**	0.00	**0.02**
Cistern (rain) water	0.37	**10.99**	0.10	**2.83**	4.30	**138.47**	1.00	**30.46**
Fruits	0.03	0.72	0.03	0.64	0.34	9.00	0.27	7.10
Fish	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mollusk	0.02	0.05	0.01	0.02	0.18	0.58	0.06	0.20
Ingestion	0.41	11.76	0.13	3.49	4.82	148.05	1.33	37.76
Internal	0.41	11.76	0.13	3.49	4.83	148.09	1.33	37.78

(*continued*)

Table B8. Continued.

	Effective dose (mSv)				Thyroid dose EQ. (mSv)			
	Child age 1–2 years		Adult		Child age 1–2 years		Adult	
	Min	Max	Min	Max	Min	Max	Min	Max
External	0.11	0.65	0.12	0.65	0.11	0.62	0.11	0.62
Total (mSv)	**0.53**	**12.42**	**0.25**	**4.14**	**4.94**	**148.71**	**1.44**	**38.40**
CEA 2006	0.52	7.88	0.24	2.57	4.83	97.82	1.33	26.72
Ratio	1.01	1.57	1.02	1.61	1.02	1.52	1.08	1.44

Results are based on 2006 CEA data and our reevaluations. Updated values in bold include corrections to the groundshine dose as well as doses from contaminated water consumption. Groundshine and cloudshine contributions to the thyroid, originally missing, were also included. The maximum groundshine dose was computed for one year instead of six months (factor of 1.04). It assumed 100% of time spent outside (factor of 1.5). It was also corrected to account for the difference between the reconstructed and the measured dose rate (5 mrad/h measured on 8/8/1971),[76] leading to an increase by a factor of 3.8. The maximum dose from water consumption was multiplied by 1.57 to account for the maximum measured activity in Taku (1,800 Bq of iodine-131 per liter of water).[77]

Appendix C. 1970s declassified dose estimates

2013 Declassified documents provide original 1970s dose estimates

Recently declassified documents show that estimates of external and internal doses to populations were computed as early as the first atmospheric test (Aldebaran, July 1966). Two documents from 1974 and 1978 provide summaries of external and internal exposures for the atmospheric tests period.[78] Additional documents provide estimates of internal contamination due to the presence of long-lived fission products in the food chain from 1975 to 1988. We extracted these data and combined them to obtain the official dose estimates known in the 1970s (see Tables C1 and C2). Using doses for newborns and children, we also produced total dose estimates for children based on their birth year (see Table C3). All these previously classified estimates predate the first public estimates by twenty years. [79]

Overall, the historical data confirm the impact of atmospheric tests on the populations of Tahiti, Gambier, and Tureia. While the 2006 retrospective dose reconstructions led to higher dose estimates, this was not the case for Tahiti and Papetee who concentrated most of the Polynesian population at the time of atmospheric testing.

Table C1. Official annual effective dose (1970s estimates) to a newborn, a 7-year-old, and an adult in the islands of Tahiti (Papeete), Tureia, and Gambier for the 1966–1974 atmospheric test period.

	Papeete			Tureia			Gambier		
Effective dose (mSv)	Newborn	7-Year-old child	Adult	Newborn	7-Year-old child	Adult	Newborn	7-Year-old child	Adult
1966	0.11	0.03	0.02	0.95	0.95	0.67	3.97	7.01	4.94
1967	0.05	0.03	0.02	1.71	1.82	1.55	0.14	0.24	0.17
1968	0.05	0.02	0.02	0.21	0.19	0.19	0.03	0.03	0.03
1969	0.02	0.02	0.02	0.10	0.10	0.10	0.02	0.02	0.02
1970	0.08	0.03	0.02	0.18	0.21	0.19	0.21	0.21	0.21
1971	0.15	0.07	0.06	2.16	2.16	1.92	1.88	2.50	2.08
1972	0.02	0.02	0.02	0.09	0.09	0.09	0.02	0.02	0.02
1973	0.11	0.05	0.05	0.05	0.05	0.05	0.02	0.02	0.02
1974	1.46	1.21	1.16	0.12	0.12	0.12	0.04	0.04	0.04
Total (mSv)		1.48	1.39		5.69	4.88		10.11	7.54

The doses are obtained by summing official external and internal dose estimates.[80] Dose from inhalation were not computed. Internal doses include the ingestion of radionuclides such as cesium-137, strontium-90 and cobalt-60. Dose to newborn does not include exposure in utero.

Table C2. Official annual thyroid dose equivalent (1970s estimates) to a newborn, a 7-year-old child, and an adult in the islands of Tahiti (Papeete), Tureia, and Gambier for the 1966–74 atmospheric test period.

	Papeete			Tureia			Gambier		
Thyroid dose (mSv)	Newborn	7-Year-old child	Adult	Newborn	7-Year-old child	Adult	Newborn	7-Year-old child	Adult
1966	2	0.26	0.1	10.1	10.14	3.9	7.4	75.3	29
1967	0.69	0.09	0.03	7.36	9.88	3.8	0.23	2.3	0.89
1968	0.59	0.09	0.04	0.59	0.09	0.03	0	0.11	0.04
1969	0	0	0	0	0	0	0	0	0
1970	1.34	0.19	0.07	0	0.65	0.25	0	0	0
1971	2.13	0.28	0.11	8.46	8.49	3.27	1.52	15.45	5.94
1972	0.12	0.02	0.01	0	0	0	0	0	0
1973	1.42	0.2	0.08	0	0	0	0	0	0
1974	7.44	2.04	0.78	0	0	0	0	0	0
Total (mSv)		3.17	1.22		29.25	11.25		93.16	35.87

The doses are obtained by summing official external and internal dose estimates.[81] Dose from inhalation were not computed. Internal doses include the ingestion of radioiodine through contaminated water. Dose to newborn does not include exposure in utero.

Table C3. Total effective dose and thyroid dose equivalent (1970s estimates) to children born and raised in the islands of Tahiti (Papeete), Tureia, and Gambier during the 1966–1974 atmospheric test period.

	Total effective dose 1966–74			Total thyroid dose Eq.1966–74			Total effective dose 1966–88		
Birth year	Papeete	Tureia	Gambier	Papeete	Tureia	Gambier	Papeete	Tureia	Gambier
1965	1.48	5.69	10.11	3.17	29.25	93.16	1.54	5.89	10.19
1966	2.29	5.69	7.07	4.91	29.21	25.26	2.36	5.89	7.15
1967	1.80	4.62	3.00	3.51	16.59	15.79	1.87	4.82	3.08
1968	1.67	2.94	2.85	3.32	9.73	15.45	1.74	3.14	2.93
1969	1.47	2.72	2.82	2.73	9.14	15.45	1.53	2.92	2.90
1970	1.43	2.60	2.80	3.88	8.49	15.45	1.50	2.80	2.88
1971	1.74	2.42	1.96	4.39	8.46	1.52	1.81	2.62	2.04
1972	1.32	0.26	0.08	2.36	0.00	0.00	1.38	0.46	0.16
1973	1.32	0.17	0.07	3.46	0.00	0.00	1.39	0.37	0.15
1974	1.46	0.12	0.04	7.44	0.00	0.00	1.52	0.32	0.12
1975							0.07	0.20	0.08

The doses are obtained by summing the data from tables C1 and C2 per birth year. Dose from inhalation were not computed. Doses do not include exposure in utero.