ASSESSING RADIATION DOSES ATTRIBUTED TO RESIDUAL RADIOACTIVE MATERIAL

POTENTIAL DOSES AT THE ATOLLS

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Mururoa Atoll has been populated only occasionally in the past, and there is no evidence that Fangataufa has ever been inhabited. The lack of a water supply, and the vulnerability of the atolls to the sea, make it difficult for people to live there.

However, for the purposes of the International Study on the Radiological Situation at the Atolls of Mururoa and Fangataufa, the existence of a hypothetical population resident on Mururoa was assumed in order to determine potential radiation doses. The estimation of doses to more distant communities was also necessary in order to establish the significance of any releases of radioactive materials.

The assessment takes account of the dispersion of radionuclides both from the underground and atmospheric tests, and from accelerated releases of material due to disruptive events of natural or human origin, such as a landslide, or to changes in climatic conditions.

The assessment was concerned with the present and future radiation doses due to residues at Mururoa and Fangataufa Atolls. Doses received in the past as a result of the fallout at the time of the French atmospheric testing were not evaluated in the Study, although an estimate of such doses in the region was provided by the United Nations Scientific Committee on the Effects of Atomic Radiation. (UNSCEAR). *(See box, next page.)*

CATEGORIES OF EXPOSURE

The Study estimated dose rates due to exposure to the residual radionuclides from the French nuclear tests for critical groups of people, for both present and future conditions. Estimates were made for the following categories of groups:

- present exposure for hypothetical inhabitants of Mururoa and Fangataufa atolls;
- present exposure for inhabitants of Tureia Atoll, the nearest inhabited atoll in the region;
- future exposure for inhabitants of the region and any inhabitants of Mururoa and Fangataufa atolls as a consequence of the residual radioactive material now present in the environment and that part of the radioactive material contained underground which will migrate to the accessible environment in the future;
- potential exposure of inhabitants of the region and hypothetical inhabitants of Mururoa and Fangataufa atolls as a consequence of postulated disruptive events.

Pathways of Exposure. The major contribution to doses was assessed to be via the ingestion exposure pathway. Realistic diets were used for populations such as those dwelling on Tureia Atoll, the nearest inhabited atoll, and for hypothetical inhabitants of Mururoa and Fangataufa atolls. For hypothetical populations elsewhere, high consumption rates, in particular for seafood, were assumed to ensure that upper limit estimates of dose rates were obtained.

Where possible, the concentrations of radionuclides in foodstuffs were obtained by direct measurement. If direct measurement was not possible, as for hypothetical populations, concentrations in foodstuffs were estimated.

PRESENT DOSES AT THE ATOLLS

A population permanently resident on the atolls with a diet of local produce and seafood from the lagoons would not generally receive a radiation dose attributable to the residual radioactive material exceeding

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0.01 mSv per year. This is equivalent to a very small fraction (less than one part in 200) of the total dose that such a resident population would unavoidably receive from natural radiation sources. *(See table and box, next page.)*

The dose estimates are based on measured levels of man-made radionuclides in the environments of the atolls, which will include contributions from global fallout (i.e. fallout from all atmospheric nuclear weapon testing). Except in the case of seafoods, it is not possible to determine those contributions to the measured environmental levels, and therefore those fractions of the estimated doses that are due to global fallout.

The present average annual dose within the entire 20° to 30° southern latitude band of Mururoa Atoll due to global fallout is estimated to be of the order of 0.002 to 0.003 mSv.

PRESENT DOSES IN THE SOUTH PACIFIC OCEAN

Present annual doses to inhabitants of other South Pacific islands attributable to the residual radioactive material in the accessible environment were also estimated. There are some 5000 people living within 1000 kilometers of Mururoa. The Study estimated that only negligible doses (of less than 0.0001 mSv per year) are being received by the residents of Tureia Atoll, the nearest inhabited land to Mururoa and Fangataufa atolls (at about 130 kilometers from Mururoa, with a population of around 120), as a result of releases of radionuclides from Mururoa and Fangataufa.

Tureia Atoll did receive some fallout, however, at the time of the atmospheric nuclear tests carried out at Mururoa and Fangataufa atolls, over and above global fallout. The radiation doses being received by its residents as a result of all earlier fallout were estimated to be about 0.005 mSv per year. Again, the fraction of this dose that is due to fallout from the tests at Mururoa and Fangataufa atolls alone is indeterminate, since the dose estimates are based on measured levels of total man-made radionuclides in the environments of Tureia Atoll, which will include some contribution from global fallout. The dose of 0.005 mSv per year is very small in comparison with the total doses that Tureian inhabitants receive from natural sources of radiation and is similar to the dose rate calculated for the hypothetical population of Mururoa Atoll.

PAST RADIATION DOSES FROM FALLOUT

At the time of the French atmospheric tests between 1966 -74, about 5000 people were living within 1000 kilometers of the French test site, and local exposures did occur, for five tests in particular *(see table)* owing to unusual wind and rainfall conditions. Four tests caused effective doses of 1to 5 mSv to residents of Tureia (the closest inhabited atoll, at a distance of 130 kilometers to the north of Mururoa) and the Gambier Islands (400 kilometers southeast of Mururoa) in 1966–71. One test caused doses of up to 0.8 mSv to residents of Tahiti (1200 kilometers to the northwest) in 1974. Only a few individuals on these islands would have received the maximum estimated doses given in the table below. In Tahiti, for example, most people would have received external exposures only. Some internal exposures were estimated on the other islands resulting from the ingestion of green vegetables or lagoon molluscs.

Exposures at the time were due largely to the fallout of short-lived radionuclides, for example radioactive iodine (especially iodine-131 with a half-life of eight days). Measurements of iodine-131 concentrations in milk were made at many locations in the southern hemisphere during the period of atmospheric nuclear testing at the atolls of Mururoa and Fangataufa. Thyroid equivalent doses received by people as a result of the nuclear tests at the two atolls are believed not to have exceeded 10 mSv over the whole period of atmospheric testing from 1966–74.

PAST DOSES FOR MAXIMALLY EXPOSED INDIVIDUALS

Date of nuclear test	Location of exposure	Annual effective dose (mSv)			
		External	Inhalation	Ingestion	Total
2 July 1966	Gambier Islands	3.4	0.18	1.9	5.5
2 July 1967	Tureia Atoll	0.7	0.023	0.17	0.9
12 June 1971	Tureia Atoll	0.9	0.003	0.43	1.3
8 August 1971	Gambier Islands	0.9	0.002	0.24	1.2
17 July 1974	Tahiti (Mahina)	0.6	0.08	0.06	0.8

PRESENT DOSES TO ADULT INHABITANTS DUE TO RESIDUAL RADIOACTIVE MATERIAL & GLOBAL FALLOUT

Pathway	Annual dose *(hypothetical estimates at the Anemone Site on Mururoa Atoll)* (mSv)	Annual dose at Tureia Atoll (mSv)
External irradiation	~0.0011	<0.001
Inhalation	<0.0001	—
Ingestion: terrestrial foods	0.0009[a]	0.004[a]
Ingestion: seafood	0.0043[b]	0.00001[b]
Total	~0.006	~0.005

[a]An indeterminate part of this dose derives from global fallout.
[b]The contribution to the aquatic ingestion dose from seafood of 0.0004 mSv arising from global fallout is not included in this dose estimate.

It should be noted that there are differences in the contributions to doses by the different exposure pathways for Tureia Atoll and Mururoa Atoll. At Tureia Atoll, seafood consumption is high, but the contribution to dose by this pathway is insignificant since there is virtually no radioactive material due to fallout in the lagoon sediments. The consumption of terrestrial foods is the more important contributor to dose owing to the greater deposition on land at Tureia of caesium-137 from the atmospheric nuclear tests at the time than at Mururoa Atoll. For Mururoa Atoll, where there is plutonium in the lagoon sediments, seafood consumption is the more important pathway.

Doses to individuals consuming seafood caught in Pacific fishing areas further afield were also estimated. The dose rates are, in all cases, very much lower even than the dose rates calculated for Mururoa and Fangataufa atolls. Present annual doses to high consumers of seafood caught from areas neighbouring Australia and New Zealand and to individuals consuming similar quantities of seafood from areas neighbouring South America are all negligible; typical doses are many orders of magnitude below average doses due to natural background radiation.

COMPARISON OF RADIATION DOSES

Source of dose	Dose
Global natural background doses	*(mSv per year)*
■ Typical range	1 to10
■ Maximum	~ 100
■ Average	2.4
Mururoa and Fangataufa atolls	
■ Dose due to natural background radiation	1.4 to 3
Estimated current additional doses from remaining residual radioactive material at Mururoa and Fangataufa atolls	
■ Maximum at Tureia Atoll	<0.0001
■ Average at Mururoa and Fangataufa atolls	<0.01
■ Maximum at Kilo-Empereur region of Fangataufa Atoll	~0.25
Maximum additional dose at Tureia Atoll following a rock slide at Mururoa Atoll	0.007 (initial year)

PARTICULAR SITUATIONS

The Study in addition considered four particular situations at Mururoa and Fangataufa.

■ **Plutonium in the lagoons.** The inventory of plutonium in the sediments of the two lagoons is relatively large; some five kilograms at Mururoa Atoll and three kilograms at Fangataufa Atoll. However, this plutonium will deliver only very small doses owing to its low rate of transfer via feasible pathways to people. The availability of plutonium is also decreasing owing to the removal of the lagoon sediments over time to the ocean, and the gradual burial and dilution of lagoon sediments by the accumulation of fresh sediments.

■ **Tritium in the lagoons.** The concentration of tritium in the

lagoons is at present some ten times higher than the very low levels in the open ocean (of the order of 1000 Bq/m^3 respectively), as a consequence of releases from underground sources. However, tritium is one of the least radiotoxic of radionuclides. Continuous drinking of fresh water containing 1.6 x 10^8 Bq/m^3 would be required to lead to a dose of 2.4 mSv per year, the average annual dose received from naturally occurring sources of radiation. The radiation doses which would result from the tritium in the lagoon are therefore negligible.

■ **Potential exposure due to particulates containing plutonium.** The atmospheric safety trials that were conducted on the motus of Colette, Ariel and Vesta on Mururoa Atoll resulted in the explosive dispersion of plutonium (together with small quantities of americium). The Study found that the general surface activity of residual plutonium in the area was perhaps three times the French criterion for clean-up operations of 10^6 Bq/m^2 which was established to limit potential exposures via inhalation of finely divided coral containing plutonium. This enhanced level of general surface activity would, however, lead only to low doses; for example, less than 0.001 mSv per year to people such as fishermen who might spend 120 hours per year in the area.

Some of the dispersed radioactive material is in the form of discrete particles, however, ranging in size from the order of 0.1 millimeter up to perhaps 1 millimeter. Plutonium particles were found in samples of sand, coral and coral bedrock collected on Colette and in sand from a sand bank in the lagoon adjacent to the Colette area.

These particles provide another pathway for potential exposure in the Colette area. If an individual were to go to Colette motu or the smaller motus of Ariel and Vesta (which are on a remote part of the atoll rim and barely above sea level), there is a risk, albeit very small, that such a particle could be incorporated into the body via a cut and retained. The consequent exposure would persist unless the particle were removed (by natural process or human action) and a significant radiation dose could be accumulated. The assumption is that while the particle remained in the body it would be a continuous source of plutonium; the plutonium would slowly dissolve in body fluids and would be transported to critical organs and tissues (in particular bone) which would be continuously irradiated.

Information obtained from the Study's own survey and examination of collected particles was sufficient for an estimate of the overall radiological risk to be made. Data from experimental studies of the incorporation of similar active particles from the Maralinga nuclear test site in Australia were used. For a retained plutonium oxide particle, the estimated potential effective dose to an adult could range between 9 x 10^{-8} and 9 x 10^{-6} Sv/Bq.

If one of the most active particles of plutonium, of around 100,000 Bq, were to be retained in the body, doses over a lifetime of up to around 1000 mSv could result. This is about ten times the average dose accumulated in 50 years from natural radiation sources. The lifetime dose would depend on the age of the individual and on the solubility of the particle in body fluids. For a child, the lifetime dose could be higher by up to a factor of two. Given the protracted (chronic) nature of the exposure, it is unlikely that any immediately apparent health effect, apart from the production of a small nodule of dead tissue around the particle, would be experienced as a result of such an intake, even by highly active particles.

The chance of such an exposure actually occurring was estimated to be very remote, however. The probability of an individual living on Mururoa incurring fatal cancer in this way is estimated to be less than one in one million per year.

■ **Doses to a hypothetical critical group on Fangataufa.** The Study indicates that the highest doses that could be received as a result of residues from the French nuclear tests would be doses to a hypothetical and very small group of people consuming only local produce from a limited area of the Kilo-Empereur region of Fangataufa Atoll. This region is windward of the site where a 125 kiloton atmospheric barge test was carried out on 24 September 1966. The barge test left a narrow strip of land along three kilometers of the atoll rim with elevated levels of caesium-137 and other radionuclides in the soil, though the distribution is very patchy. The dose would be due mainly to the supposed

consumption of coconuts and other produce containing caesium-137, all grown in areas of the strip where the levels of this radionuclide are highest. The consequent effective dose rate would be less than 0.25 mSv per year. This is equivalent to about 10% of the annual background radiation dose that such a resident population would unavoidably receive from natural sources alone. However, this hypothetical scenario is considered highly unlikely to occur in practice, since Fangataufa Atoll is virtually uninhabitable by people adopting a traditional semi-subsistence lifestyle; the Atoll is on occasions inundated by seawater and has no fresh water and edible crops other than some coconuts.

ESTIMATED DOSES IN THE FUTURE

Three cases were considered in the estimation of doses to populations in the future.

■ **Doses in the future due to residual radioactive material presently in the accessible environment.** The estimated annual radiation doses to any possible future inhabitants of Mururoa and Fangataufa due to the general dispersion of radionuclides from nuclear tests in the environment are all small in absolute terms and insignificant on the basis of any existing criterion or comparison. Radiation doses due to radioactive material already in the accessible environment — principally arising from caesium-137 and plutonium-239,240 — will persist. But they will decline in magnitude owing to both radioactive decay and other processes that reduce the availability of these radionuclides in the environment.

According to the Study's predictions, the rate of leaching of the caesium-137, strontium-90 and plutonium-239,240 in the lagoon sediments, which are responsible for present levels of these radionuclides in lagoon water, will continue to decrease with time, as will the estimated radiation doses associated with these radionuclides. Estimated hypothetical future doses from the existing sources at Mururoa if the atolls were actually to be inhabited would initially decline over 100 years from the present maximum of no more than 0.01 mSv per year to about 0.001 mSv per year as the residual radioactive material at the surface decays and disperses. (It should be noted that these doses will rise in the long-term future as plutonium migrating from underground reaches the lagoons; however, they will never exceed present doses.)

■ **Potential exposure due to underground radionuclides.** The assessment of the likely future releases due to the migration of radionuclides from underground sources shows that the releases of caesium-137 and strontium-90 to the lagoon will decrease with time but that, after an initial decline, the plutonium release rate will increase to a maximum after 5000 to 6000 years. However, even at the time of this maximum, the associated estimated doses to hypothetical Mururoa residents would be less than those estimated to be received today by the same hypothetical residents, that is, less than 0.01 mSv per year. Similarly, exposures at other locations in the South Pacific in the future due to releases from underground radioactivity at Mururoa and Fangataufa are predicted to be less than those very low values from radionuclides currently present in the accessible environment.

■ **Potential exposure of inhabitants of the region as a consequence of postulated disruptive events.** The Study investigated the radiological consequences of postulated disruptive events. These included glaciation and a slide of carbonate rock leading to a release of radionuclides into the ocean. In the case of a rock slide, the highest hypothetical annual doses would be received by residents of nearby atolls, since any radionuclides so released would be carried away by ocean currents. For the residents of Tureia Atoll, the dose in the first year following such a rock slide would not be more than a few thousandths of a millisievert, even if it were pessimistically assumed that all the plutonium involved in the slide went into solution. This dose would only occur in the one year following the rock slide; subsequent doses would be progressively lower as the radioactive material was dispersed.

CONCLUSION

Overall, the Study analyzed potential radiation doses to present and future hypothetical population groups at the atolls. It found that — except in the hypothetical case on the Kilo-Empereur rim of Fangataufa — no group is likely to receive at any time a dose attributable to the residual radioactive material at Mururoa and Fangataufa which exceeds approximately 1% of the background radiation dose that the group will unavoidably receive from natural radiation sources. ❐