DISPERSION OF RESIDUAL RADIONUCLIDES FROM MURUROA AND FANGATAUFA THROUGH THE OCEAN

FROM THE ATOLLS TO THE SEAS

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Modelling the transport of radionuclides through the marine environment is a complex exercise. As part of the Study on the Radiological Situation at the Atolls of Mururoa and Fangataufa, scientists investigated the dispersion of radionuclides after their release from Mururoa and Fangataufa lagoons and from underground sources. The investigation covered mixing processes within the lagoons, discharge into the ocean, and transport to the shores of neighbouring islands and distant continents.

This article highlights work carried out through the Study to assess the dispersion of residual radionuclides through the ocean, and summarizes the major findings.

METHODOLOGY & APPROACHES

For modelling purposes, the area around the source of radioactivity (i.e. the point at which radionuclides are released into the marine environment) was divided into three major zones : the near field (the lagoons); the regional field (broadly, the area of French Polynesia); and the far field (the South Pacific beyond the regional field).

To understand the water and sediment dynamics in the near field, two models were developed by the Mururoa Study's Marine Modelling Working Group. A model of the mixing of water was used to estimate radionuclide concentrations in the lagoons for given releases from underground into the lagoons, and the flow rates of radionuclides from the lagoons into the surrounding ocean.

A sediment model was developed to predict the movement of sediment between the lagoons and the ocean. Estimates were made of the amount of sediment, and the corresponding quantity of plutonium, leaving the lagoons annually under average weather conditions, or with a severe storm.

The rates of release of radionuclides from the lagoon sediments were assessed, leading to estimates of the release rates of plutonium, caesium-137, strontium-90 and tritium from the lagoons to the oceans as a function of time.

Three compartment models were used to model dispersion of radionuclides in the regional field. These models cover different areas with different resolutions, and each has particular strengths and weaknesses. Taken together, they give an indication of the likely uncertainty in the dispersion estimates, and improve the robustness of the final conclusions.

Transport and dispersion in the far field was assessed using a predictive model of world ocean circulation.

The outputs from these models are estimates of radionuclide concentrations in the ocean as a function of time and location. These concentrations were used to estimate doses to real and hypothetical people at various locations and times in the future.

MODELLING OF THE LAGOONS

Radionuclides in the lagoon waters arise from the leaching of radioactive material from the lagoon sediments and from migration of material from the underground sources. Their concentrations in the lagoon waters will be determined by their rate of release into the lagoon and the rate at which the lagoon waters are exchanged with the ocean. If radionuclides are released into the lagoon, the first two stages in the dispersion process are mixing in the lagoon and the exchange of lagoon water with the ocean. A hydrodynamic model of circulation in the

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lagoons was developed and the average turnover time for exchange of water with the ocean was estimated. The turnover time, averaged over all seasons, was estimated to be 98± 37 days, and 33± 12 days for Mururoa and Fangataufa lagoons, respectively.

The ultimate fate of the unconsolidated sediments on the bottom of the lagoons (and the plutonium in them) is important in assessing the long-term implications of the radiological conditions at the atolls.

A sediment transport model was developed for Mururoa lagoon; it led to a tentative estimate for the average annual removal rate of bottom sediments through the pass to the ocean of 80,000 tonnes per year. A cyclonic storm is, however, capable of removing very large quantities of sediment from a lagoon — one such storm could remove about 4×10^6 tonnes of sediment, mostly over the rim of the atoll.

The annual equivalent release rate of plutonium from this source was estimated to be of the order of 0.1 TBq. The source term is expected to decrease with an effective half-life of about ten years because of the progressive burial of plutonium-bearing sediments by fresh sediment.

RELEASE RATES OF RADIONUCLIDES

Four radionuclides (tritium, strontium-90, caesium-137 and plutonium-239,240) were considered as the most important for modelling exercises. The analysts took into account the contributions from both leaching of the lagoon sediments and from underground sources.

For tritium (a half-life of 12.3 years), which is observed in the form of water, there is no contribution from the sediments. The observed concentrations (about 200 Bq/m^3, a factor of two above the oceanic background) are entirely due to underground sources. Tritium concentrations in the lagoons may remain fairly constant for the next few decades before declining slowly.

For strontium-90, expectations are that both leaching and underground sources are contributing to concentrations. Although a considerable scatter in the past data on strontium-90 was observed, it appears that the radionuclide's concentrations could rise above current levels for a few decades, though not more than by a factor of two.

In the case of caesium-137, the current release from underground sources is slightly related to leaching of sediments. Its concentrations in the lagoons have been decreasing with an apparent half-life of about seven years and it is unlikely that they will exceed present levels at any time in the future.

For plutonium, leaching of lagoon sediments is currently the only significant source. On the basis of observations it is estimated that plutonium concentrations in the lagoons will decrease with an effective half-life of about ten years.

On the basis of measurements of these radionuclides in the lagoons and the open ocean provided by the Marine Working Group, their present release rates from the lagoons were estimated and predictions for the future were made. No attempt was made to distinguish Mururoa and Fangataufa as separate sources since, on an oceanic scale, they are so close together as to be indistinguishable. The releases via the lagoons are considered to be surface releases; releases direct to the ocean are assumed to occur at a depth of 400 meters.

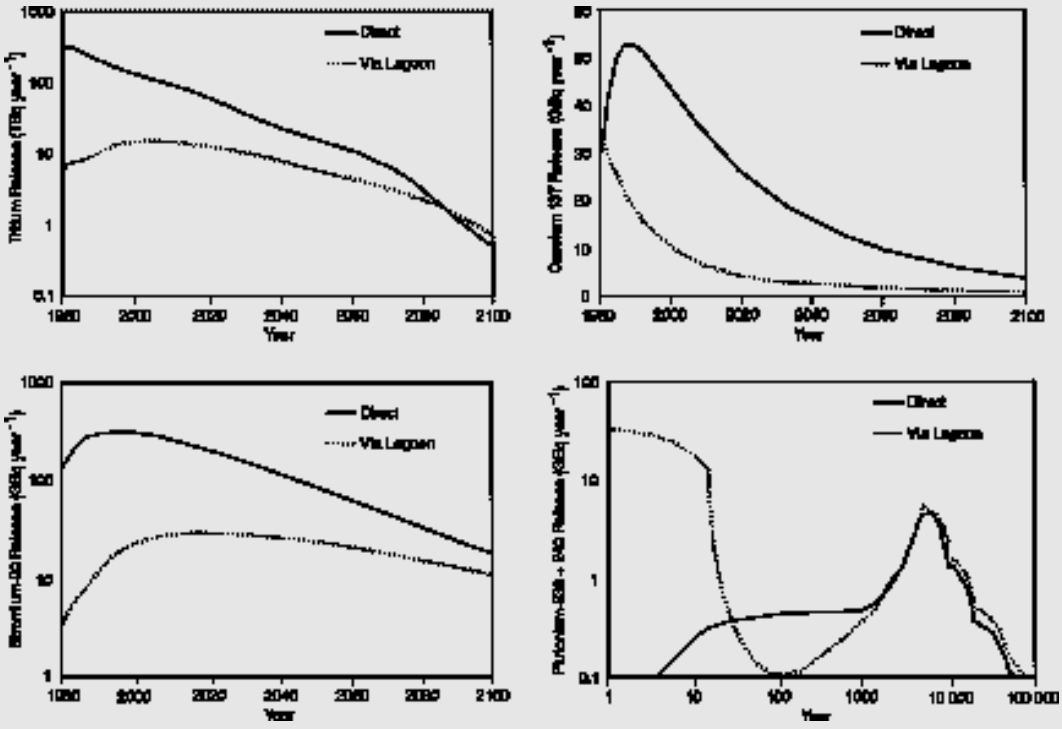
The total release rates of tritium, strontium-90, and caesium-137 will decrease with time, with the dominant contribution from underground sources coming from releases directly into the ocean. *(See graphs.)* On the other hand, in the case of plutonium, which will migrate very slowly, the underground contribution will peak after about 6000 years at a much lower peak value than at present.

In the case of the assumed disruptive event, i.e. a carbonate rock slide with an instantaneous release of radionuclides to the marine environment from underground sources, the estimated releases were 1PBq for tritium, 30 TBq for caesium-137, 10 TBq for strontium-90 and 10 TBq for plutonium-239,240.

REGIONAL MODELS OF DISPERSION

Three compartment models were developed to assess dispersion of radionuclides on the regional scale. This covered such neighbouring atolls as Tureia Atoll and those as far away as Tahiti, and considered dispersion over the long term. The three models differ in

RELEASE RATES OF RADIONUCLIDES AT MURUROA & FANGATAUFA



The graphs show the predicted time-dependent release rates of tritium, strontium-90, caesium-137, and plutonium-239,240 to the biosphere.

their spatial resolution, the degree to which vertical structure in the ocean is taken into account and the time over which it is convenient to follow the dispersion. The models were applied to "continuous" sources arising from geosphere migration and varying in source strength over time, and to "instantaneous" releases, when a major fraction of the source is released within a relatively short time of a year or so.) Both cases could conceivably arise as a consequence of disruptive events.

A number of hypothetical disruptive events were considered. They included extreme events and events due to climatic changes that could lead to enhanced release rates of radioactive material now in the cavity-chimneys or to enhanced rates of exposure to material in the environment (e.g. to the plutonium in the sediments). Events considered included glaciation, leading to falling sea levels and the exposure of the lagoon bed; and a slide of carbonate rock leading to an "instantaneous" release of the radionuclides exposed by the rock slide.

The only disruptive event that was found to warrant a thorough assessment was the hypothetical major breakaway and slide of the carbonate formations in the northern zone of Mururoa Atoll; this is in the area where underground safety trials and some nuclear tests that produced cavity-chimneys penetrating into the carbonate formations were carried out.

The compartment modelling of regional dispersion provides estimates of the surface water concentrations at various Pacific islands over different time periods for predicted releases from Mururoa and Fangataufa and for the instantaneous releases. The predicted concentrations at the atolls of French Polynesia were found to be lower than the present concentrations due to global fallout observed in the open ocean.

Only the plutonium release for a disruptive event (a rock slide) gives a higher concentration (by about two orders of magnitude) at the closest atoll (Tureia) than the present levels due to global fallout. However, after ten years the predicted concentrations will be below the present background concentrations.

FAR FIELD MODELLING

A far field general circulation model was used to estimate the concentrations in the ocean of radionuclides released from the atolls and transported and dispersed as far as the east coast of Australia and the west coast of South America. The model was applied to continuous and instantaneous sources and to cases in which the release occurs into the surface layer and in which it takes place at 400 meters depth, below the thermocline. In the latter case, the released material is trapped below the thermocline and dispersion is inhibited; higher concentrations will be found at farther distances from the points of release, but at depths of about 400 meters.

Only in the case of a hypothetical disruptive event — a rock slide, release at 400 meters depth —could sea level concentrations of tritium, strontium-90 and caesium-137 at Tureia Atoll reach the present levels observed in the South Pacific Ocean due to global fallout.

For example, for tritium the maximum predicted elevation in concentration is about 10 Bq/m^3 after five years halfway to Australia, and about 1 Bq/m^3 off the coast of Australia five years later. These compare with the background tritium level of 50-100 Bq/m^3 at 400 meters depth. The release of the plutonium would result in a predicted ocean concentration at Tureia Atoll of 100 mBq/m^3. This is about two orders of magnitude higher than the present very low ocean concentration there (about 1 $mBq/m^{3)}$ due to global fallout associated with all atmospheric nuclear testing. Plutonium concentrations in the ocean at Tureia would return to the background concentrations within ten years.

In the case of a more realistic time-dependent release of radionuclides, the predicted long-term concentrations of radionuclides will be below background oceanic levels beyond 100 kilometers from Mururoa and Fangataufa Atolls.

For example, for plutonium, in the case of a surface release, the predicted maximum surface concentrations, after ten years of release, would be about 0.2 mBq/m^3 in the vicinity of Mururoa. This is about an order of magnitude below present levels.

OVERALL CONCLUSIONS

In summary, the Study's marine modelling work reached the following conclusions:

- The estimated turnover time of the lagoon waters is 98 ± 37 days for Mururoa and 33 ± 12 days for Fangataufa.
- The transfer of particulate (sediment-bound) plutonium-239,240 from the Mururoa lagoon into the Pacific Ocean is estimated to be 8 GBq per year with mean winds and tides, and 0.7 TBq in the event of an extreme storm (per storm). The frequency of an extreme storm is estimated to be one in ten years. The source term due to storms is expected to decrease with time, due to depletion of plutonium-bearing sediments and gradual burial of these sediments. The source term due to plutonium from a storm is an order of magnitude below that released by the hypothetical disruptive event.
- Two main release scenarios were modelled: (1) a disruptive event — a slide of carbonate rock, releasing activity from the carbonate zone corresponding to the inventory from one safety trial and one cavity-chimney test; and (2) a time-dependent source arising from migration of material from the underground cavities and the leaching of sediments in the lagoon.

Most of the simulations have assumed release to the surface layers. However, some calculations assumed the source would be located at depth (400 meters), simulating release from the karstic layers.

For these scenarios, maximum elevations in concentrations were estimated in the lagoons and at islands and atolls in the South Pacific. Predicted concentrations at the closest inhabited atoll (Tureia) were compared with background concentrations in the open ocean due to global fallout. Only the plutonium release for a disruptive event would give a higher concentration than the background level and then only for a few years.

For releases at depth, the concentrations at Hao and Tahiti are predicted to be higher than at Tureia. However, when the data for these locations are averaged over the total depth of 450 meters, they are all below the maximum values.

Overall, the modelling of the dispersion of radionuclides from Mururoa and Fangataufa atolls to the open ocean recorded clear results. The work has shown that expected concentrations in nearby inhabited islands would not be high enough to be of any radiological interest. ❐