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An Impact Assessment for the French Nuclear Weapon Test Sites in French Polynesia

by

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Abstract

A numerical dispersion model was used to elaborate an impact assessment for the French nuclear weapon testing site in French Polynesia. The three dimensional equation of advection/diffusion was solved with the mean of the Monte Carlo Technique. The mean transport field, isotropic horizontal and vertical turbulent exchange and radioactive decay were taken into consideration, but no biochemical processes were included. Over a period of ten years the dispersion of the as conservative assumed radionuclide cesium 137 was monitored considering two different scenarios of its introduction into the marine environment. The results of both scenarios are quite different in the farfield. However, in both cases the local environment of French Polynesia is the most effected.

Introduction

Recently, in the framework of the United Nation Environmental Program the only study about the environmental radioactivity in the South Pacific was published (SPC/SPEC/ESAP/UNEP, 1984). Hardly any statements concerning the contamination of the hydrosphere and the transport of contaminated water masses were made. A few conclusions, mainly a repetition of already published results, were based on the incomplete GEOSECS (Geochemical Ocean Section Studies) South Pacific data base, the result of the first large scale examination of the distribution pattern of natural occuring and artificially produced radionucildes. Although the South Pacific Ocean is the largest and least examined part of the world ocean, a non-irrelevant fraction of the large volume samples, obtained during the GEOSECS survey, remained unanalysed 'for reasons of lack of funding or scientific interest' (Livingston et al., 1985).

Since the agreement on the ban of atmospheric nuclear weapons testing, the Partial Test Ban Treaty, by the United States of America, the Union of Soviet Socialist Republic's and the United Kingdom in 1963, nuclear weapon tests of the French government at the Moruroa Atoll in French Polynesia represent the largest producer of artificial radionuclides in the South Pacific region. The French atmospheric nuclear weapon testing program begun in 1966, followed by an underground testing program since 1974. Concerned governments, scientists and environmentalists considered the deduction of atmospheric and underground

nuclear weapon explosions always as a potential future threat for the environment of the South Pacific Ocean (Tomczak, 1984; Hochstein, 1984; GREENPEACE, 1985; PCRC, 1989, Revkin, 1989), although official scientific missions (Tazieff, 1982; Atkinson et al., 1983; Cousteau, 1988), invited by the French government, confirmed the harmlessness of the testing program. In general agreement all official scientific missions concluded that the effects of the French nuclear weapon testing program on the environment and its inhabitants were insignificant so far, although their scientific program always imposed restrictions and limitations of the scientific research by the French authorities. Samples of corals, soil and water were limited to designated places. Proofing of the atoll's integrity was restricted to the upper 150 m of the atoll, although the underground nuclear weapon tests were carried out in depths of 800-1200 m, and fractures in the upper part of the atoll were already observed.

Since 1974 a total of 112 underground tests were carried out mainly at the Moruroa Atoll, one of the largest atolls of the Tuamotu Archipelago in French Polynesia, located at 21o 50' S and 139o W (Fig. 1). Although lately several tests were shifted for reasons of safty to the Fangataufa Atoll, some fourty kilometre away from Moruroa Atoll, the testing program at Moruroa Atoll has not been terminated. There, the latest test was carried out at June 2nd marking the beginning of the 1990 series (PCRC, 1990). The testing program will continue to conduct 6 to 8 tests per year during the next decade. The missing link in all represented reports of the visiting scientific teams is the answer of questions concerning the furture testing program. How will further testing effect the marine environment of the South Pacific? Which countries will be effected by accidents resulting in large scale venting of radioactivity into the hydrosphere?

A numercial dispersion model was used to examine and evaluate the results of possible large scale venting of radionuclides from Moruroa Atoll. Recently, comparable studies were carried out for the European Shelf Sea to study the transport of radionuclides from the reprocessing plants at Sellafield, Dounreay, both in the United Kingdom, and Cape de La Hague in France and the effects of possible accidents (Prandle, 1984; Mller-Navarra & Mittelstaed, 1988; Pohlmann et al., 1988). In present study the distribution of the released and as conservative assumed radionuclide cesium 137 was explained solving numerically the three dimensional equation of transport using the mean of the Monte Carlo Technique. Mean transport velocities obtained from a global ocean-atmosphere model (Manabe & Stouffer, 1988), turbulent exchange and radioactive decay were taken into account, but no biochemical interactions were considered. In the impact assessment two scenarios were assumed to observe the possible large scale dispersion of radioactivtiy from Moruroa Atoll. In the first one a single release of the total radioactivity occured which is currently stored in the interior of the atoll. The scenario was considered as the 'worst case'. The transport and mixing of the radioactive contaminated water mass or 'radioactive cloud' was monitored within the area covered by the model (Fig. 1) over a period of 10 years. During the second scenoria a more likely and more realistic case was studied: the venting of radioactive contaminated water from a constant source. This case was considered as the 'realistic case' based on observed damage to the atoll's geological structure in its upper part and a recorded cesium 137 anomaly (Cousteau, 1988). The resulting cesium 137 activity concentration from the simulations provides a basis for the estimation of possible harmful effects caused by further nuclear weapon testing and will highlight the most effected regions of the South Pacific environment.

Method

The numerical dispersion model

The three dimensional equation of advection/diffusion (1) was employed to study transport and mixing of the 'radioactive cloud', i.e. the contaminated water mass:

$$Ct + u.Cx + v.Cy + w.Cz = Kh.(Cxx + Cyy) + Kv.Czz + Q - l.C. \quad (1)$$

C represents the activity concentration; u,v and w are the horizontal and vertical components of the velocity vector, Kh and Kv are parameterizing horizontal and vertical turbulent exchange which were assumed as isotropic having values of 103 m2.s-1 and 10-4 m2.s-1 (Garrett, 1979). Q represents the tracer source, and l is the decay constant of the monitored tracer. The equation describes the time variability of the activity concentration C of a conservative radionuclide at a position x,y and z. This equation was numerically solved using the Monte Carlo Technique which can be briefly described as a Langrangian particle-tracking technique used to model the dispersion of pollutants in the marine environment. In opposite to finite differences the Monte Carlo Technique is computationally more efficient for cases of higher dimension and does not violate the law of mass conservation due to the effect of numerical diffusion (Hunter, 1987; Maier-Reimer, 1973).

The velocity input data

The advection field used in the impact assessment was realised by taking into consideration mean velocity data obtained from a coupled ocean-atmosphere model (Manabe & Stouffer, 1988). Within the model area the results of Manabe & Stouffer's second experiment are in quite a good agreement with the already known general circulation pattern of the South Pacific which can be considered as in a steady-state. The gyre-structure is well presented. Western boundary current, the Antarctic Circumpolar Current and the equatorial current system are the regions with the highest horizontal surface velocities. These decrease approaching the centre of the gyre to values of 0.01-0.03 m.s-1. Interannual and seasonal effects like El Nio/Southern Oscillation or convective sinking of water masses in the centre of the South Pacific gyre as a result of increasing evaporation during the summer are not represented in the velocity data.

Reliability of the model

The modelling technique and the model's reliabiltiy were confirmed in several applications. Comparable to Sarmiento (1983), who studied the bomb tritium entry into the Atlantic Ocean, the model used for the impact assessment explained, sufficiently for the proposed impact assessment, the bomb tritium pattern in the South Pacific (Ribbe & Tomczak, 1990). In opposite to Sarmiento (1983), who used finite differences, the Monte Carlo Technique was chosen. In several applications, it was proofed that it is the more appropriate method to explain the dispersion of pollutants (Maier-Reimer, 1973; Hunter, 1987; Mller-Navarra & Mittelstaedt, 1988; Pohlmann et al., 1988).

The radiological input data of the impact assessment

Atkinson et al. (1983) assumed that the final inventory of the underground tests carried out at Moruroa Atoll will be in the range of 100 Mt of fission explosions which compares with values of past atmospheric testing of 72 Mt by the United States of America and 111 Mt by the Union of Soviet Socialist

Republic's. Since the release of the Atkinson report in 1983 several changes were made to the testing program by the French government. They included the move of the test site to Fangataufa Atoll and a decrease of the size in the maximum nuclear weapon yield. Therefore, in this study the likely value of the total inventory estimated by Atkinson et al. (1983) was reduced to 60 Mt. Costello's (1983) estimation about the accumulated cesium 137 activity concentration, ten years after the last nuclear weapon test was carried out, resulted for this impact assessment in a final value of 3.2.1017 Bq. It was assumed that the inventory will be released in the surface layer. The value of 3.2.1017 Bq appears as a reasonable in comparison to other sources of the artificial radionuclide cesium 137 (Tab. 1). The value lies in the range of the produced cesium 137 activity concentration of 1.3.1018 Bq by past atmospheric nuclear weapon testing, the input of 1.5.1017 Bq cesium 137 from the northern into the southern hemisphere, the unique cesium 137 release of 3.8.1016 Bq during the nuclear power plant accident at Chernobyl and the cumulative inventory of cesium 137 at the European Shelf Sea of 3.3.1016 Bq.

Results

Worst case

The released 'radioactive cloud' was monitored over a period of 10 years (Fig. 2a-2f). To get a first order estimate of transport and mixing, the maximum activity concentration will be followed during its path through the South Pacific. This maximum represents the 'centre of mass' for the cloud. Its displacement is a result of the transport field, whereas mixing or turbulent diffusion results in an break-up of the cloud's edges. The horizontal velocities in the region of the source, quite close to the centre of the South Pacific gyre, are very low. The range is 0.01-0.03 m.s-1, and the currents are directed to the south-west, i.e. mainly into the centre of the South Pacific gyre. During the first five months, the maximum is hardly influenced by the advective field. Assuming a value of 0.02 m.s-1, the 'cloud' is drifting with velocities of nearly one kilometre per day, resulting in approximately 150 kilometre during these first five months. Twenty months after the event (Fig. 2a), the maximum activity concentration can be observed near approximately 24o S and 143o W. The 'cloud'was displaced by the mean transport field in the south-west direction. The break-up of the cloud's edges due to turbulent diffusion is clearly shown. The elliptical shape of the cloud is a result of the different mean velocities in the latitudal bands of the model region. The lower the mean transport velocity, the higher the influence of the turbulent diffusion. The longer the centre of the 'cloud' remains in region of low velocities, the faster an break-up of the spot at the edges can occur. The radioactive contaminated water is mixed in the higher or lower latitudes and transported rapidly to the west in the northern part of the South Pacific and to the east in the southern part, faster than the centre of mass. During the following months (Fig. 2b-2f) the maximum can be followed crossing the western South Pacific. After a period of 10 years it is located near 175o E, i.e. approximately 1400 kilometre north of New Zealand. The 'cloud' is more elongated to the north than to the south as a result of the asymmetric velocity field. Considering the 'cloud's' displacement of nearly 5000 kilometre since the event ten years ago, a mean transport velocity of 0.02 m.s-1 can be derived which closely represents the input velocity data.

Realistic case

During the following assessment, ten per cent of the previously determined total cesium 137 inventory of 3.2.1017 Bq was discharged from Moruroa Atoll over a

period of 10 years. This assumption results in an annual discharge of 3.2.1016 Bq or in an input of 1.0.108 Bq.s-1 which is a factor 7 higher than that calculated by Cousteau (1987). In Fig. 3 the activity concentration in the surface layer is shown after a period of 10 years. Contrary to the 'worst case' study, the maximum activity concentration can always be found in the vicinity of the source. The maximum was not displaced, because the highest activity concentration for a dissolved tracer should always be found at the source, assuming a continuous release. The greater the distance from the source, the greater the dilution of the contaminated water mass. An additional decrease due to radioactive decay occurs. The transport field is responsible for the torsion of the radioactive 'cloud' into an elliptical shape.

Discussion

The evaluation of the modeled cesium 137 activity concentration requires some background information about the present activity concentration in the marine environment resulting from past anthropogenic activities (Tab. 2). The highest cesium 137 activity concentration in the marine environment was recorded in the northern Baltic Sea for a few months after the nuclear power plant accident near Chernobyl. For a comparison with Tab. 2 the maximum of the simulated cesium 137 activity concentration is represented on a semi-logarithmic scale in Fig. 4. During the first months of the 'worst case' study the activity concentration lies well above the average activity concentration of naturally produced radionuclides. Over the following six years, the activity concentration is very high and comparable to that measured in the northern part of the Baltic Sea after the nuclear power plant accident at Chernobyl and decreases during further years reaching a final value of 87 Bq.m-3. This value lies well above the activity concentration of 3.34 Bq.m-3 observed in the West Pacific (Tab. 2), but is still in the range of that determined from continental shelf waters. In the whole central South Pacific (Fig. 2f) the activity concentration is above 10 Bq.m-3,therefore higher than the background activity concentration from past releases. However, quite interesting in this 'worst case' study is the relative long residence time of the highly contaminated water mass in the vicinity of French Polynesia.

Due to the continuously introduced amount of radioactivity during the 'realistic case' study, the activity concentration is generally low. Only the local region or nearfield of Moruroa Atoll is effected by a relative high activity concentration of approximately 60-70 Bq.m-3. The activity concentration near Tahiti, some 1200 km away from the source, is below 10 Bq.m-3. A separation between the background activity concentration and the contribution from Moruroa Atoll is hardly possible.
A quite simple model was used to elaborate the proposed impact assessment for the French nuclear weapon test site. Although in the presented study a distinction between 'worst case' and 'realistic case' was made, both scenarios should be considered as realistic, and approriate measures must be taken for their prevention. Usually, the probability of accidents in the nuclear industry was assumed with a possibility of one event in 100.000 years. But large scale uncontrolled releases of artificial radioactivity occured in the past near Windscale/Great Britain in 1957, near Harrisburg/United States of America in 1976 and near Chernobyl/Union of Soviet Socialist Republic's in 1986, approximately 50 years after the first nuclear fission.

Conclusion

The results of both scenarios are quite different. However, in both cases the most effected region is the local environment of French Polynesia. In the first

scenario the loading during the first 3 to 4 years after the accident is more a result of a decreasing but very high activity concentration well above the background activity concentration of 3-4 Bq.m-3, while in the 'realistic case' the loading is characterised by an nearly constant local activity concentration with values between 50 and 150 Bq.m-3. Only in the 'worst case' the western part of the South Pacific and its bordering countries are also effected by an activity concentration with a value higher than 80 Bq.m-3, i.e. well above the background noise. In the future, the obtained activity concentration should be evaluated from a bio-medical point of view. Also in further impact assessments the introduction of biochemical processes into the model should be recommended for the examination of activity concentrations of non-conservative artificial radionuclides like plutonium 239/240 and the interaction in between the biosphere.

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Table 1

Comparison of radionuclide sources and their productivity

Event	Time scale	Productivity (Bq)	Reference
Radon-22	per year:	1.0.1019	UNSCEAR, 1977
Carbon-14	per year:	1.0.1015	UNSCEAR, 1977
Atm. Nuclear Weapon Tests	until 1963, release into southern hemisphere	1.5.1017	Pentreath, 1988
Chernobyl/USSR	release of Cs 137	3.8.1016	SSK, 1986
Sellafield/UK	cumulative inventory at the European Shelf Sea of Cs 137 until 1986:	3.3.1016	Pentreath, 1988

Table 2

Cesium 137 activity concentration in sea surface water. For a comparison the background activity concentration of naturally produced radionuclides is listed.

Region	Activity Concentration (Bq.m-3)	Reference
Natural activity	13000	Gerlach, 1981
North Atlantic (NWF)	3 - 4	Aarkroog, 1986
North Sea (RP)	185 - 370	Dahlgaard, 1984
Baltic Sea (NWF)	33.3	Kautsky, 1971
Baltic Sea (CF)	500 - 3100	Ilus et al., 1987
West Pacific (NWF)	3.34	Livingston et al., 1985
Moruroa Atoll	10.8	Cousteau, 1988

NWF = Nuclear Weapon Fallout
RP = Reprocessing Plants
CF = Chernobyl Fallout