THE RADIOLOGICAL SITUATION AT THE ATOLLS OF MURUROA AND FANGATAUFA

PROCEEDINGS of an IAEA conference held in Vienna
30 June—3 July 1998

29 - 46
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FOREWORD

In January 1996, France’s programme of expériences nucléaires (nuclear experiments) at the atolls of Mururoa and Fangataufa ceased, and soon after that the French Government requested the International Atomic Energy Agency (IAEA) to carry out a study of the radiological situation at the two atolls.

The Study of the Radiological Situation at the Atolls of Mururoa and Fangataufa lasted almost two years, giving rise to a number of reports which are being issued by the IAEA.

From 30 June to 3 July 1998, the IAEA hosted, in Vienna, an International Conference on the Study, the main purpose being to facilitate discussion of the results of the Study by the scientific community and other interested parties. The Conference was presided over by Eduardo Bobadilla López of Chile.

These proceedings contain the opening addresses of the Conference, a presentation made by a senior representative of France’s Commissariat à l’énergie atomique and closing remarks by the President of the Conference, by E. Gail de Planque, Chairman of the International Advisory Committee, and by Mohamed ElBaradei, Director General of the IAEA. They also contain edited texts reflecting the discussions which took place during the Conference, mainly after the technical presentations covering the various aspects of the Study. These presentations generally paralleled the Main Report on the Study, to which reference is made in the edited texts.
EDITORIAL NOTE

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Throughout the text names of Member States are retained as they were when the text was compiled.

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CONTENTS

OPENING SESSION

Address by Z. Domaratzki
Deputy Director General, Head of the Department of Nuclear Safety, IAEA
(on behalf of the Director General of the IAEA) ................................................................. 1

Address by E. Gail de Planque, United States of America,
Chairman of the International Advisory Committee ......................................................... 3

Address by H. Curien, France,
Head of French Delegation .................................................................................................... 5

Address by E. Bobadilla López, Chile,
President of the Conference .................................................................................................. 7

SEMINAR: BACKGROUND

Presentation by A. Barthoux (France) on The French test programme at Mururoa
and Fangataufa ................................................................................................................................. 11

Discussion on
- The French test programme at Mururoa and Fangataufa (A. Barthoux, France)
- Framework of the Study (E. Gail de Planque, United States of America)
- Retrospective assessment of the French atmospheric tests and their contribution to exposures (B. Bennett, UNSCEAR) ........................................................................................................ 15

TECHNICAL SESSIONS A: CURRENT SITUATION

Discussion on Session 2: Residual radioactive materials in the terrestrial environment
2.1. Terrestrial sampling and survey campaign (F. Schönhöfer, Austria) ................................. 17
2.2. Residual contamination in the Colette area of Mururoa (P.R. Danesi, IAEA) .................. 17

Discussion on Session 3: Residual radioactive material in the aquatic environment
3.1. Aquatic sampling and surveillance campaign (D.S. Woodhead, United Kingdom) ............ 18

TECHNICAL SESSIONS B: FUTURE SITUATION

Discussion on Session 5: Assessment of the underground repository (L.-E. De Geer,
Sweden) ..................................................................................................................................... 21

Discussion on Session 6: Assessment of the geosphere radionuclide transport
6.1. Hydrogeology of the atolls (G. de Marsily, France) ......................................................... 22
6.2. Atoll geology (C. Fairhurst, United States of America) .................................................. 23
6.3. Stability of the atolls (C. Fairhurst, United States of America) ....................................... 25
6.4. Radionuclide release in the cavity-chimneys (J. Hadermann, Switzerland) ..................... 25
6.5. Radionuclide release into the carbonates (J. Hadermann, Switzerland) ....................... 26
6.6. Sampling of underground waters (E. Warnecke, IAEA) .................................................... 27
6.7. Radionuclide release into the lagoon/ocean (D.M. Levins, Australia) ............................... 29

Discussion on Session 8: Assessment of radionuclide dispersion in the marine environment
8.1. Oceanographic modelling and mixing in the lagoons (E. Mittelstaedt, Germany) ............ 30
8.2. Regional scale modelling (I. Osvath, IAEA) ....................................................................... 31
8.3. Far field modelling (E. Mittelstaedt, Germany) ................................................................. 33
TECHNICAL SESSIONS C: OTHER ISSUES

Discussion on Session 9: Long term monitoring (J.-F. Sornein, France) ........................................35
Discussion on Session 10: Effects on species other than man (D.S. Woodhead, United Kingdom) .........................................................36
Discussion on Session 11: Ciguatera (H. Garnett, Australia) .........................................................37

TECHNICAL SESSIONS D: ASSESSMENTS

Discussion on Session 12: Assessment of the present and long term radiological situation (A. McEwan, New Zealand) .........................................................39
Discussion on Session 13: Criteria for remediation (A.J. González, IAEA) ........................................40

CLOSING SESSIONS

Session 15: Panel discussion .................................................................43
Summary of the Conference and closing remarks
Conclusions and closing remarks by E. Bobadilla López, Chile, President of the Conference .........................................................47
Closing remarks by E. Gail de Planque, United States of America, Chairman of the International Advisory Committee .........................................................60
Closing remarks by Mohamed ElBaradei, Director General of the International Atomic Energy Agency .........................................................62
Closing remarks by E. Bobadilla López, Chile, President of the Conference .........................................................65
List of Participants .................................................................67
OPENING SESSION

Address by Z. Domaratzki
Deputy Director General
Head of the Department of Nuclear Safety, IAEA

(on behalf of the Director General of the IAEA)

In the name of the Director General of the Agency, Dr. ElBaradei, it is a great pleasure for me to welcome you to our headquarters in Vienna to attend the International Conference on the Radiological Situation at the Atolls of Mururoa and Fangataufa. Dr. ElBaradei had intended to open the Conference himself but sudden events called for his presence in the Middle East. He appeals for your understanding and advised me that, unless unforeseen events occur, he will join us at the Closing Session of the Conference.

I would like to take this opportunity to wish you a very pleasant stay in Vienna and productive discussions at the Conference. We view this as an important conference, important enough to devote significant funds from our Regular Budget to convene it. It is the Agency’s intention to facilitate the scientific community’s close scrutiny of the findings, conclusions and recommendation of the vast Study on the radiological situation at those atolls in the South Pacific, a study which has been supervised by an International Advisory Committee of senior experts under the chairmanship of Ms. Gail de Planque, who is sitting here on my left.

For obvious geographical reasons and due to the political sensitivity of the issue, the findings, conclusions and recommendation of the Study have already been presented to the people and authorities of the South Pacific region. A team headed by Ms. de Planque made presentations in Suva to the authorities of the South Pacific Forum, in Nandi to representatives of countries of the Forum, and in Faaa, Papeete, to the people and authorities of French Polynesia; all these presentations took place a few weeks ago. I am pleased that Dr. Graham Shorten representing the South Pacific Forum is also at this Conference. The Agency’s Board of Governors also took note of the Study at its meeting earlier this month and passed it to the forthcoming Agency General Conference in September.

This Study represents a major effort by many experts from some twenty States and six intergovernmental organizations, together with the Agency. Twenty laboratories around the world, including the Agency laboratories at Seibersdorf and Monaco, participated in the analysis of data. The Agency is grateful for the generous contributions in kind made to the Study by experts, laboratories, organizations and States. I wish, on behalf of the Agency, to express our gratitude to all the experts who contributed so much to the success of the Study. In particular, I wish to thank the chairperson, Ms. Gail de Planque. The task of a chairperson is a challenging one and demands a tremendous amount of time, dedication and energy. Thank you, Ms. de Planque!

I also wish to express the Agency’s appreciation to the Government of France for its openness in sharing information and for its substantial financial and other support in the conduct of the Study. Without the enormous logistic support received from the Governments of France, the execution of such a complex endeavour would have been impossible. I wish to ask the representative of the French Government at this Conference, former Minister of Research and Technology, Mr. Hubert Curien, to convey to the French Government the Agency’s deep gratitude for all the assistance provided.
The Mururoa Study is the third study organized by the Agency, at the request of a Member State, to provide objective international radiological assessments of radioactive wastes and residues from nuclear weapons testing. The States that have to date requested radiological assessments of former nuclear weapon test sites are: Kazakhstan, where the Agency conducted a preliminary evaluation at Semipalatinsk; the Republic of the Marshall Islands, where the Agency assessed the situation and recommended protective measures that would be required for the potential rehabilitation of Bikini Atoll; and France, which requested the Study now presented for your consideration. The purpose of all these studies has been to assess present and future radiological conditions and possible hazards and, if the affected areas are to be inhabited or otherwise put to human use, to make recommendations on any remedial actions needed. I urge you to convey to your governments that they are welcome to make use of the Agency's expertise in this regard.

In this context, I wish to recall that in 1995 the Agency's General Conference called on the States concerned "to fulfil their responsibilities to ensure that sites where nuclear tests have been conducted are monitored scrupulously and to take appropriate steps to avoid adverse impacts on health, safety and the environment as a consequence of such nuclear testing".

Finally, I wish to express the Agency's appreciation to the President of the Chilean National Atomic Energy Commission, Mr. Eduardo Bobadilla López, for accepting the challenge of chairing this Conference.
Address by E. Gail de Planque

United States of America

Chairman of the International Advisory Committee

I am delighted to be here this morning and welcome all of you to Vienna on behalf of the International Advisory Committee (IAC), and indeed on behalf of the entire Study group. We are pleased and eager to present our Study to the scientific community and very happy to have the opportunity to receive your comments and questions and to discuss our results with you. You will probably know that the Study has taken about two years to complete. We came close to engaging about 100 people in the efforts of this Study, and we have produced about 10 cm of reports.

I feel very privileged to have worked with so many dedicated experts from around the world and from the IAEA. The IAC and the Study group are indebted to the former Director General, Hans Blix, and to the current Director General, Mohamed ElBaradei, for their encouragement, their support and their commitment of the resources necessary for carrying out the Study. We are indebted to the IAEA staff for their untiring efforts, and to them we offer our heartfelt thanks. We are also grateful to the Government of France for their total co-operation in this effort. They provided us with a tremendous amount of material, in including everything we requested and deemed necessary for the conduct of the Study. Their help and logistical support during our campaign of measurements and sampling at Mururoa and Fangataufa was superb, and we thank them for that — without their co-operation the Study would not have been possible.

At this point, I would like to give you a general introduction to the Study and discuss how we are going to proceed through the rest of the week.

As I am sure all of you know by now, the Government of France conducted 193 tests at Mururoa and Fangataufa, which are about equidistant from the west coast of the United States and Latin America and the east coast of Australia. The atolls are located on the eastern edge of French Polynesia, about 1000 kilometres from Tahiti. There were essentially two types of tests carried out at Mururoa and Fangataufa: 178 nuclear tests in which devices were exploded with the release of fission energy, and 15 safety trials — these involved nuclear devices that are subjected to simulated accident conditions and nuclear weapon cores that are destroyed by conventional explosives with no or very little release of fission energy. Most of the tests were conducted at Mururoa, the larger of the two atolls, and the rest, mostly the larger tests, were conducted at Fangataufa. The tests were conducted in the atmosphere as well as underground. There were 41 tests conducted in the atmosphere, 37 at Mururoa and 4 at Fangataufa. Most of these tests were conducted by hanging the device from a balloon at a considerable elevation above the ground. We will hear about this in great detail as the Conference progresses.

There were 137 underground tests — 127 at Mururoa and 10 at Fangataufa. The majority of these tests were conducted with devices lowered into holes drilled into the rock beneath either the rim or the lagoon of the atolls. There were 15 safety trials in all — 5 conducted in the atmosphere and 10 underground.

That is the general background of why we were asked to perform the Study. I would like to discuss the aims and objectives of the Study so that we are clear from the beginning about what we did in the Study and what we did not do.
First of all, the aims of the Study were to assess the situation at the two atolls and in the involved areas from the point of view of radiological safety, to ascertain whether there are any radiological hazards to people, and to make recommendations on the form, scale and duration of any remedial action, monitoring, or any other follow-up action that might be required. The specific objectives of the Study were to assess the residual radiological conditions at the atolls after the end of the nuclear tests and to cover both the present radiological situation and the potential long-term radiological situation. It is important to understand the objectives of the Study because the Study was not designed to look at past exposures due to fallout during testing — this was done by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR). However, because we knew that that would be of interest to you, we have included the assessment of past exposures in our report and there will be a presentation almost immediately after this on that subject. It is also important to understand that the Study was not designed to look at worker doses; it is our understanding that the French will be publishing a report on this subject some time soon.

The IAC had 14 members from various countries around the world and 4 ex officio representatives of the European Commission, the South Pacific Forum, UNSCEAR and the World Health Organization. Apart from the IAC and the IAEA staff, there were 55 experts from 21 countries involved during the Study. As indicated earlier, the Study, which was not just a paper study, involved a campaign of measurements and sampling at the atolls of Muruoa and Fangataufa; we looked at materials both in the terrestrial and in the aquatic environment. Altogether, there were 18 laboratories in 12 countries involved in this campaign, which was led by the IAEA laboratories at Seibersdorf and Monaco.

This has been a very general introduction. I will later describe in more detail the framework of the Study, but before that Dr. Barthoux of the Commissariat à l'énergie atomique will describe the French test programme and Dr. Bennett of UNSCEAR will give us an assessment of the exposures from the atmospheric tests. During the rest of the Conference, we will take you in logical progression through the Study and its results, finishing on Friday with our ultimate findings, conclusions and recommendation.
The French Minister of Foreign Affairs, Mr. Hubert Vedrine, requested me to lead the French delegation at the international conference which is opening today in order to review the results of the international study of the radiological situation at the atolls of Mururoa and Fangataufa, where France’s nuclear tests were carried out between 1966 and 1996. I was very happy to accede to his request.

As a scientist, I am greatly impressed by the calibre of the conference participants, which augurs well for our proceedings. As a former minister, I am happy to see how a policy of exceptional transparency with regard to military activities is culminating in independent confirmation of the care and seriousness with which my country has always conducted its military nuclear activities.

In June 1995, when announcing its decision to resume nuclear testing, France undertook to invite an international team of independent experts to verify the innocuousness of the tests. That team would not be the first of its kind: teams of French scientists (led by Cousteau and by Tazieff) and foreign scientists (led by Atkinson) had already visited the atolls several times in order to study the radiological situation there.

On this occasion, the French Government requested the then Director General of the Agency, Hans Blix, to set up an international committee of independent experts. It is this committee, chaired by Dr. Gail de Planque, which has carried out the study of the radiological situation at the atolls of Mururoa and Fangataufa, with the help of the Agency’s Secretariat and of several laboratories in different parts of the world.

Immediately after the end of our nuclear tests, in January 1996, the study team was given very extensive access to the available data, and over a period of 18 months the team then carried out measuring and sampling operations at the test sites.

The competent institutions in France co-operated to the full, and I think one can speak here of complete transparency.

As a rule, questions regarding nuclear energy give rise to impassioned debate, into which objectivity and rationality can be injected only through true transparency. That is why I have dwelled on the approach of successive French Governments in this regard: in my view, it points the way that should be followed.

The international committee of experts and the Agency’s Secretariat have done a vast amount of scientific work of exceptional quality. The study involved a complete assessment of the current situation and the predicting of how that situation will evolve over time, all on the basis of an in-depth examination of the rock mechanics and geology of the atolls — the subject of special scrutiny by Professor Fairhurst, whose findings were drawn upon by the Agency’s Secretariat and the committee of experts.

The well over a thousand pages of the report indicate the extent and the seriousness of this scientific inquiry, which lasted nearly two years. I shall not dwell on the exceptional scientific calibre of the experts who carried out this inquiry: it is unquestionable, and it ensured that the job was done rigorously and that the conclusions are reliable.
The conclusions of this very comprehensive study of the radiological situation at the atolls of Mururoa and Fangataufa confirm that the French nuclear tests were conducted with the utmost regard for the safety of people and for the environment.

The experts and the Agency’s Secretariat drew extensively on the documentation built up during the years since the start of our nuclear tests by scientists working in the French establishments concerned, who, in the interests of protecting people and the environment, never stopped measuring radionuclide concentrations and carrying out seismological and geophysical investigations at the atolls.

I would mention in passing that, thanks to the expertise acquired by our scientists in this way, France is now one of the leaders as regards nuclear test detection within the framework of the Comprehensive Nuclear-Test-Ban Treaty, which we signed in 1996 and ratified in April of this year.

Thus, all our efforts were directed towards ensuring that the French nuclear tests caused no harm, and the alarmist reactions to the last test series in particular were unfounded. The study just completed has validated and rounded off French and international findings which, as far as we are concerned, proved the innocuousness of the tests long ago — something which I should like to emphasize here.

This international conference offers an excellent opportunity for sharing, among an impressive number of eminent scientists from many countries, the benefits — in terms of knowledge and expertise — accruing for the extremely thorough job that has been done. The Agency has contributed to studies of the radiological situation at other nuclear test sites, Bikini Atoll in the Republic of the Marshall Islands and Semipalatinsk in Kazakhstan, but it was never involved in a study as thorough and extensive as the one carried out at Mururoa and Fangataufa. This conference is therefore of great scientific interest, and I welcome the Agency’s initiative in organizing it. I believe that the participants will learn a lot from the experts who carried out the study.

Objectivity is the key word, and we have much to gain from a candid discussion among scientists. That was the position adopted in this sensitive matter by France, which abides by it. Also, it is the spirit in which the members of my delegation — all of them scientists — and myself have come to Vienna for this gathering.
Address by E. Bobadilla López
Chile
President of the Conference

It is a great honour for me personally, and for the Government of Chile which I represent at this Conference, to have been invited to preside over this major meeting. As you can all well imagine, the radiological situation at the atolls of Mururoa and Fangataufa since the 193 nuclear experiments carried out there is of primary importance to my Government. I wish to emphasize therefore the recognition of Chile and also my personal expression of gratitude for the opportunity to serve as Conference Chairman.

Not many are aware that, of all Agency Member States, Chile's territories lie nearest to the atolls. My country has sovereignty over a number of islands in the Pacific, such as Easter Island, which are closer to the atolls than are the territories of any other Member State of the Agency except for France. Moreover, Chile, as a Latin American country with its coastline on the Pacific is especially concerned about the impact of nuclear testing on our economies, particularly in the fishing and marine product industries and, moreover, as a signatory State to the Tlatelolco Treaty, has shared the grave concern about the proliferation and the testing of nuclear weapons. For all these reasons, my Government and I personally look forward with avid interest to hearing the results of the Study on the radiological situation at the atolls and the conclusions of this Conference.

Let me express first of all how deeply impressed I was by the series of reports on the Study that I recently had the opportunity to read. These reports have been distributed to you all for your own judgement. I believe that the material presented at this Conference is one of the most comprehensive radiological studies of the environment carried out at an international level. Let me submit in this regard that our first task at this Conference is to express our recognition and appreciation to the International Advisory Committee, represented on this occasion by its Chairman, Ms. Gail de Planque who is sitting here on my left, as well as to the many experts who have generously invested their time, effort, and expertise to complete the Study.

I greatly appreciate the presence of the representative of the South Pacific Forum at the Conference: Dr. Graham Shorten, Engineering Geologist with the South Pacific Applied Geoscience Commission (SOPAC). Dr. Shorten is here to participate fully in the scientific scrutiny of the report. He will subsequently report on the outcome of the Conference to Forum member countries for their consideration at their meeting in Pohnpei in August this year.

Looking at how much has been done, it is clear to me that all this work could not have been undertaken without the tremendous amount of logistic support provided. The successful completion of the Study could not have been achieved without the full commitment and co-operation of France. For this, we would like to express our appreciation to the Government of France, which is represented here by the former Minister of Research and Technology, Mr. Hubert Curien.

The Study of Mururoa and Fangataufa forms part of a series of studies that the Agency has been performing in the area of radiological rehabilitation of former nuclear weapon sites. A similar but preliminary Study has been carried out in the area of Semipalatinsk in Kazakhstan and — as I understand — the Study report is currently being printed by the Agency. Another Study has been undertaken on the atoll at Bikini in the Republic of the Marshall Islands and has already been issued by the Agency. This was in a way simpler than
the one to be discussed this week because only atmospheric explosions took place in Bikini. These Agency initiatives are certainly praiseworthy and I kindly request Mr. Domaratzki to transmit our commendation to the Director General, Mr. ElBaradei. These activities are in line with one of the major statutory responsibilities of the Agency, namely that the Agency shall not only establish standards of radiation safety but also — a crucial point — shall provide for the applications of its safety standards at the request of any State. The three governments involved, namely Kazakhstan, the Republic of the Marshall Islands and France have simply followed this statutory framework and have asked the Agency to discharge one of its most important functions. As Governor of my country to the Agency, I feel it my duty to record that what these Member States have done is to duly fulfil a request by the 1995 General Conference which — you may recall — called on the States concerned, I quote: “to fulfil their responsibilities to ensure that sites where nuclear tests have been conducted are monitored scrupulously and to take appropriate steps to avoid adverse impacts on health, safety and the environment as a consequence of such nuclear testing” unquote. From this podium I would like to call on all other States which have either performed nuclear weapon testing or experienced testing in their territories to follow the Agency's General Conference request.

It is my understanding that the ultimate purpose of this Conference is to deeply scrutinize in a purely scientific manner the comprehensive work performed by the scientists headed by Ms. Gail de Planque. With this understanding, allow me to propose herewith the procedure to be followed during the Conference. After the opening session, I will call on senior participants of the Study to explain the main points of the work they have carried out. After their presentations I invite a lively discussion of the technical issues. All statements, opinions, and counterarguments will be recorded by the engineer, summarized by the record officer, and reflected in the proceedings of the Conference. After each session I will examine the records of the presentations and discussions and, with the assistance of Ms. de Planque and the Secretariat, I will endeavour to make a summary. On the last day of the Conference I will present you with my summary of the individual sessions and, based on these, an overall summary of the Conference.

Let me repeat that a record of the discussions, which are a major raison d’être for this Conference, will be included in the Conference proceedings. For this purpose, and in order to accurately reflect your questions, answers or comments, I kindly ask all participants to fill out the discussion participation forms that will be provided to you. It is also extremely important that the speakers strictly adhere to the time allocated to them. Not only will this enable time for discussion but will allow proper interpretation of the proceedings. Let me remind you that there are strict rules in the United Nations’ system for the hours of work of the interpreters and it is my duty to follow these rules during the Conference.

As indicated in my opening statement, this is very important for my country which I represent at the level of its highest authority in nuclear matters. In addition, the conclusions of the Study and the Conference are very important for me personally, because I cannot (and must not) forget that I am a medical doctor who has dedicated part of his professional life to the radiological health of people. It is within this capacity that I feel I am able to assist you in your deliberations.

I am also convinced that this will be an initial step on a long road that the Agency should follow in order to help its Member States deal with the legacies of the cold war. And while in this case as you will see the results indicate that there are no situations of radiological significance, this is not an endorsement for either the development or testing of nuclear
weapons. It is my personal hope that for the sake of humankind, the era of nuclear threat is forever a thing of the past.

I look forward to a successful conference that will aid us all to foster information exchange on the radiological situation at the atolls. With these words, I formally declare the International Conference on the Radiological Situation at the Atolls of Mururoa and Fangataufa open.
The French test programme at Mururoa and Fangataufa

A. Barthoux
France

The purpose of my presentation is to describe the logic which governed the development of this programme and the safety concerns which existed throughout the programme and were reflected in the technical choices made.

The selection of Mururoa and Fangataufa as nuclear test sites followed the attainment of independence by Algeria, where France had to evacuate its underground experimentation site at Hoggar before 1967. At the time when the selection was made, in 1962 (just two years after the first French tests), France did not yet possess all the knowledge necessary for producing thermonuclear weapons. It therefore needed to continue testing. The early experience of the countries which were already nuclear Powers indicated that the first thermonuclear weapon tests would involve very high yields (several megatonnes), with a great margin of uncertainty in predicting the yields.

At the time, it did not seem feasible to ensure the confinement of thermonuclear tests carried out underground and thereby avoid substantial radioactive contamination near the test site and at intermediate distances from it. For this reason it was decided to revert temporarily to atmospheric testing, using a detonation system that would ensure maximum safety.

The technical choice was for suspending the nuclear device below a balloon at a certain altitude above a stretch of water, in order to avoid any interaction between the fireball and an underlying ground surface with consequential entrainment of a substantial mass of heavy material into the base of the cloud. As a result, there would be no intense radioactive fallout near the test site or at intermediate distances.

Besides these precautions, thanks to the geographical location of Mururoa and Fangataufa in the extreme eastern part of French Polynesia there was down-wind an uninhabited zone extending for several thousand kilometres, as the prevailing winds at high altitudes blow during the summer from west to east.

An elaborate special meteorological network with land-based, airborne and seaborne stations enabled us to make reliable weather forecasts. Authorization to detonate was given only if the fallout trajectory was expected to be confined within a predetermined area, for which we issued an international warning to all ships and aircraft.

The fallout prediction rules were observed from the very beginning.

However, the development of balloons of large volume (6000–10 000 m³) took longer than expected, as the fabrication techniques had been forgotten, so that during the first test series only one device was detonated while suspended from a balloon; the three other tests were conducted with the device mounted on a barge at anchor in the Mururoa lagoon.

Balloons were available for the next series of tests, all of which were to be carried out with devices suspended from balloons. Unfortunately, severe weather during the preparations
for the tests seriously damaged several balloons, so that the last test of the series had to be carried out with a barge-mounted device.

All of the nuclear tests from 1968 to 1974 were carried out at altitudes which ensured that there was no interaction between the fireball and the lagoon water. All in all, 41 nuclear tests were carried out in the atmosphere — four with barge-mounted devices, 34 with devices suspended from balloons and three with devices released from aircraft at altitudes such that there was no interaction with the ocean.

Over and above that, there were five safety trials carried out above ground in the northern part of Mururoa Atoll in order to make sure that there would be no significant release of nuclear energy from nuclear weapons subjected to severe external forces — particularly explosive forces — as a result of military action or of accidents.

These safety trials, which involved a total chemical energy release of some tens of kilograms, caused fallout of fissile materials near Mururoa Atoll; no fissile materials were dispersed over distances such that people might have been at risk. The safety procedures governing the choice of a favourable weather situation were applied in the same manner as with the nuclear tests.

After atmospheric testing had been terminated, the areas where radioactive materials from the safety trials had been dissipated were cleaned up so that access to those areas could be granted without restriction on radiological grounds. The collected waste — of low and intermediate activity — was buried, after immobilization in cement, below the atolls in two shafts more than 1100 m deep.

In 1972 the progress made in nuclear device design allowed us once again to consider the possibility of testing. The decision was taken to look closely into two prospective sites: an island with high ground, EIAO in the Marquesa archipelago, where tunnels could be drilled, and the atolls of Mururoa and Fangataufa, where the tests would obviously have to be carried out in shafts sunk into water-saturated ground.

Access to EIAO island appeared to be difficult, and geological and hydrological studies indicated that the desired levels of safety could not be ensured on that island. The subsoil at Mururoa and Fangataufa, on the other hand, proved to be completely suitable despite the initially unfavourable impression deriving from the narrow limestone band that appears at the surface.

The two atolls are coral diadems crowning very high submarine mountains made up of hard, compact rocks cemented by clay formations. The basalt is at a reasonably accessible depth (300–400 m), and the surrounding ocean offered considerable potential for dilution should a slight fraction of the radioactivity from the tests escape.

So it was decided to carry out a first test in order to validate the feasibility of underground testing in shafts at the atolls. We needed to be sure that we had mastered all the techniques necessary for operations in this very special environment (for example, techniques for the drilling of large-diameter shafts and for post-test lava sampling), that we could achieve a high measurement quality and that we could meet the safety requirements — in particular, that we could ensure confinement of the radioactive materials in the subsoil.
Given the nature of the rocks, and particularly the low mechanical resistance of the carbonates, it was decided at the outset to line the shafts with tubing so as to avoid cave-ins. This proved to be a difficult job, which became still more difficult with increasing shaft depth.

As regards safety, it was decided at the outset that complete containment should be ensured by going to depths such that

- the tests would be taking place in the basalt, and
- the top of the chimney would not reach the ground surface and there would be no subsistence crater \( h > 170 W^{1/6} \), where \( h \) is the depth in metres and \( W \) is the yield.

The first underground test, carried out at Fangataufa in June 1975, showed that all requirements had been met. So it was decided to abandon atmospheric testing permanently and to continue the test programme using shafts sunk into the atoll rims.

The techniques developed for the first test were of a prototype nature, especially as far as drilling was concerned. They evolved very rapidly in the ensuing years, however, and from 1980 onwards we were able to dispense with shaft lining, which made drilling at great depths much easier. At that point, we decided that the chimney resulting from each test should be completely contained within the basalt, with a safety margin of at least 100 m below the base of the carbonates; 96 tests were carried out in accordance with this decision (between 1976 and 1980, 12 out of 41 tests resulted in chimneys which reached the base of the carbonates; after that, the chimneys were all within the basalt).

The abandonment of atmospheric testing applied also to safety trials, which were thenceforth carried out in shafts — initially in the carbonates and then in the basalt. Three of them resulted in slight releases of nuclear yield.

Some tests carried out below the Mururoa atoll rim produced fairly powerful stresses in the carbonates, causing — inter alia — subsidence, submarine rock-slides, and fracturing. It was therefore decided in 1977 to modify our techniques so as to reduce the stresses undergone by the weakened test areas. The only solution — we ultimately concluded — was to move away from those areas and carry out future tests below the Mururoa lagoon. Our drilling and handling techniques had to be modified so that they could be used by people working on barges anchored or platforms erected in the lagoon. It took some time to build and try out the necessary new equipment, and the first test below the Mururoa lagoon did not take place until April 1981.

These precautions proved extremely helpful, but they were not sufficient to completely protect the northern part of Mururoa Atoll from stresses. It was therefore decided in 1985 to move further away from that area and, for the more powerful tests, to start using Fangataufa Atoll again. Barges of a new type were built for this atoll, and the first test in a shaft under the Fangataufa lagoon took place in November 1988.

Throughout the period of underground testing, we collected — for analysis — samples of radioactive material from the cavities. After each detonation, a small-diameter shaft was drilled for the extraction of cores from the vitrified zone. The most representative samples were sent to France for measurement purposes, while the rest of the material — generally of low radioactivity — was reintroduced into the cavity.
Throughout the period of atmospheric and underground testing, from 1966 to 1996, the environment was monitored constantly by us in order to be sure about the radiological conditions at the test site and to comply with the regulations for radiological protection of the personnel working at the site and of the neighbouring populations.
Discussion

J.T. Doom (World Council of Churches): Did fallout from the atmospheric tests reach inhabited islands?

A. Barthoux (France): Yes, owing to local variations in the meteorological conditions there was after five tests some slight fallout over inhabited islands near Mururoa and Fangataufa. However, the exposure levels were very low — of the order of, or less than, 5 mSv.

B. Bennett (UNSCEAR): Global or regional exposures occurred after all atmospheric tests, and local exposures (within 1000 km of the test sites) occurred after some as a result of particular meteorological conditions. The exposures were relatively high in the case of downwind inhabitants following tests at Bikini Atoll and Semipalatinsk.

In the case of the five French nuclear tests reported as having given rise to local exposures, residents of the Gambier Islands, Tureia Atoll and Tahiti were affected — Gambier Island residents after two tests, Tureia Atoll residents after two tests and Tahiti residents after one test.

The highest estimated whole-body doses (5.5 mSv, at the Gambier Islands) were incurred after the test of 2 July 1966, a relatively low-yield barge test. The estimated whole-body doses from the other four tests were 1.3 mSv or less — of the same order of magnitude as the average annual dose from the natural background and hence not of radiological significance.

R. Fry (IAEA): I would add that the subject is dealt with in French Liaison Office document No. 13. The information in question is summarized in Annex I to the Main Report on the Study.

J.T. Doom (World Council of Churches): The International Advisory Committee received a great deal of data from the French authorities for the Study. Did it also seek information from Tahitians who worked on Mururoa and Fangataufa at the time of the nuclear tests?

A.J. González (IAEA): Some members of the team which visited the South Pacific region in May 1998 in order to present the results of the Study to representatives of the governments of member States of the South Pacific Forum and representatives of French
Polynesia met informally with workers’ representatives at the University of the South Pacific in Faaa. They explained that one cannot in retrospect determine occupational doses received in the past and that, according to international practice and the requirements of the International Labour Organisation, employers are responsible for monitoring occupational doses. I understand that the French authorities will soon be issuing a report on this matter.

**G. Shorten (South Pacific Forum):** The radiation doses due to nuclear tests are often expressed as multiples of natural background radiation doses. That being so, I should like to know whether the types of ionizing radiation which have emanated from nuclear tests affect the human body differently from those which are in the natural background.

**B. Bennett (UNSCERAR):** The radionuclides responsible for the ionizing radiation associated with nuclear tests are caesium-135, strontium-90 and other radioactive fission products; those responsible for the natural radiation background are potassium-40 and radionuclides in the uranium and thorium series. However, the energy spectra of the gamma radiation from the two sets of radionuclides overlap and are similar. Moreover, the cells of the body respond in the same way to the energy deposition whether the radiation emanates from nuclear tests or is of natural origin. Thus, I think it is reasonable to compare radiation doses due to nuclear tests with natural background radiation doses.
Session 1. Overview of the assessment of the current radiological situation

Overview of the assessment of the current radiological situation
A. McEwan (New Zealand)
(see Section 4 of the Main Report)

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Session 2. Residual radioactive materials in the terrestrial environment

2.1. Terrestrial sampling and survey campaign
F. Schönhofe (Austria)
(see Section 4.3.1 of the Main Report)

Discussion

G. Fraser (European Commission): In his presentation, Dr. Schönhofe referred to the European Union limit of 600 Bq/kg for total caesium-134 plus caesium-137 in foodstuffs. I would merely point out that this limit (or 370 Bq/kg in the case of milk, various milk products and baby foods), imposed soon after the Chernobyl accident for foodstuffs imported from third countries, is still in force for certain types of foodstuffs. However, it is not part of the permanent legislation of the European Union and, in the absence of further action, will become invalid no later than the year 2000.

D.M. Levins (Australia): Fangataufa Atoll and Tureia Atoll are of roughly the same size but, whereas people live permanently on Tureia, there is no record of Fangataufa ever having been inhabited. What are the reasons for that difference between the two atolls.

F. Schönhofe (Austria): Fangataufa is often inundated and sometimes almost completely submerged. Moreover, Tureia can support coconut palm plantations, whereas the number of coconut palms growing on Fangataufa is very small.

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2.2. Residual contamination in the Colette area of Mururoa
P.R. Danesi (IAEA)
(see Section 4.3.1.6 of the Main Report)

Discussion

D.K. Smith (United States of America): With regard to the hot particles on Colette motu, did you look into the possibility of an association between the occurrence of plutonium-239 and the effective surface area of the particles? Smaller particles may have greater effective surface areas.
P.R. Danesi (IAEA): No, we did not. However, we did investigate — with a 1 kg sample of debris (sand) — how the activity concentration was distributed over the different particle size fractions. The highest activity concentration (about 700 kBq/kg) was measured for the fraction between 125 μm and 250 μm.

G. Shorten (South Pacific Forum): Has the surface of Colette motu been modified since the safety trials were carried out?

P.R. Danesi (IAEA): Yes, it has been modified by the several clean-up operations conducted by the French. Moreover, the distribution of sand and other debris changes as a result of inundation, high waves, strong winds and erosion.

G. Shorten (South Pacific Forum): Is there any evidence that, because of its higher density, particulate plutonium is being concentrated in deposits on the motu?

P.R. Danesi (IAEA): We did not find such evidence. I believe that the movement and concentration of particulate plutonium are fairly random.

G. Shorten (South Pacific Forum): Is the particulate plutonium being removed from the atoll system or just being moved about?

P.R. Danesi (IAEA): In order to answer that question, one would have to carry out surveys like the one carried out by us at — say — intervals of one year.

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Session 3. Residual radioactive material in the aquatic environment

3.1. Aquatic sampling and surveillance campaign
D.S. Woodhead (United Kingdom)
(see Section 4.3.2 of the Main Report)

Discussion

E. Wirth (Germany): In your presentation, you referred to two sets of comparisons between the French results relating to the contamination of fish and your results. Could you give more details?

D.S. Woodhead (United Kingdom): First, there was an analytical inter-comparison, carried out on samples of fish collected in 1994. The samples were homogenized, and sub-samples were sent to a number of laboratories, including the SMSRB (Service mixte de surveillance radiologique et biologique de l'homme et de l'environnement) in France. The results confirmed the analytical capabilities of the laboratories and the quality of the data.

Second, there was a comparison between the radionuclide concentrations measured in fish sampled in 1996 during the Study environmental and surveillance campaign and the
monitoring data published by the SMSRB for fish sampled in 1994 and 1995. Here, given the nature of the spot samples separated in time, one would not expect exact agreement.

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3.2. Radionuclide release into the ocean
P.P. Povinec (IAEA)
(see Section 4.3.2.4 of the Main Report)
Session 4. Overview of the assessment of the future situation

Overview of the assessment of the future situation
D.M. Levins (Australia)
(see Sections 5–8 of the Main Report)

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Session 5. Assessment of the underground inventory

Assessment of the underground inventory
L.-E. De Geer (Sweden)
(see Section 5 of the Main Report)

Discussion

S. Carroll (Greenpeace International): You referred to 12 instances where the chimneys penetrated beyond the volcanics into the carbonate layer. Was the number of instances verified, or did the Study simply accept the number — 12 — given by the French authorities?

L.E. De Geer (Sweden): The number was not verified. That would have involved a lot of drilling, which would have produced new leakage paths.

S. Carroll (Greenpeace International): Where chimneys penetrated beyond the volcanics, did the associated fracture zones also penetrate beyond them?

L.E. De Geer (Sweden): Yes, they did. With a nuclear explosion in rock, the chimney extends up to the top of the outer circumference of the fracture zone.

S. Carroll (Greenpeace International): What about the extended fracture zones?

L.E. De Geer (Sweden): If by that you mean the “crack zones”, which surround the fracture zones caused by nuclear explosions in rock, they too penetrated beyond the volcanics at Mururoa and Fangataufa, but there is little evidence of radial cracks in the crack zones.

D.M. Levins (Australia): How did you estimate the partitioning of plutonium between the lava and the rubble?

L.E. De Geer (Sweden): Our estimates were based on information relating to various other nuclear test sites and on the known volatility of plutonium. At the same time, we tried to be conservative; we took 98% as the figure for plutonium in the lava although experience indicates that the figure should be much closer to 100%.
E. Wirth (Germany): How important is the volatility of plutonium from the point of view of the future behaviour of the plutonium in the lava?

L.E. De Geer (Sweden): The volatility of plutonium was important mainly during the post-explosion cooling-down phase, when partitioning took place; elements with low volatility (high refractivity) tended to concentrate in the lava. It tells one nothing about the future behaviour of the plutonium once it is in the lava.

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Session 6: Assessment of the geosphere radionuclide transport

6.1. Hydrogeology of the atolls
G. de Marsily (France)
(see Section 6.3 of the Main Report)

Discussion

S. Carroll (Greenpeace International): I noted that the transport velocities are not yield-dependent, but may be about an order of magnitude higher where the chimneys reach into the carbonate layers. I also noted that direct sampling data were available for the inclined drill-holes relating to only two tests (Aristée, 1984, 2 kt; Céto, 1986, 5 kt). Was there direct verification of the flow models with any other drill-holes, and would direct examination of larger-yield tests help in verifying the models?

G. de Marsily (France): In order to verify its flow models, Working Group 4 essentially used the tritium measurements carried out by the IAEA. The tritium released from the volcanics is a very good indicator of the vertical velocities above the chimneys. The results were found to be most significant, for verifying these high velocities, in the case of the Lycos test (a large-yield test performed in 1989 at Fangataufa, with poor volcanic cover). After this test, it was found that the estimated Darcy velocity above the chimney (20 m/year) created a tritium release that was in reasonable agreement with the measurements.

With the CRTV tests, which occurred much earlier at Mururoa, the results were not very sensitive to the Darcy velocity since, with both higher and lower velocities, most of the resulting tritium was transferred to the carbonates.

Further measurements of tritium release in the carbonates is an appropriate way of further validating the models.

G. Shorten (South Pacific Forum): You showed groundwater entering the test chamber and ultimately exiting upwards out of the chamber, diluting the concentrations in the chamber with time. When the question whether groundwater would interchange between the unaffected rock and the fractured rock in the explosion cavity was being considered, was any account taken of CSIRO research where nuclear waste is buried in specially engineered
tunnels that are backfilled with permeable rock and water, which essentially creates an independent circulation cell segregated from the bulk of the rock?

G. de Marsily (France): I assume that the tunnels involved in the CSIRO research are horizontal. The chambers created by nuclear explosions, on the other hand, are more or less vertical chimneys, and the convective cells are probably much stronger than with horizontal tunnels as convection is a function of height relative to a given temperature difference. However, the temperature in the chimneys will decline much faster than that in the tunnels as heat is not generated after the initial explosions.

Since the rubble filling the chimneys is also very permeable, the cells constitute a set of “semi-independent” convective circulation patterns ensuring intense mixing within the chimneys — as in the waste-filled tunnels. Superimposed on these “internal” cells, however, are large circulation patterns that make water entering the chimneys at the base leave them at the top. The intensity of this larger circulation pattern relative to the internal convective cells depends on the permeability contrast between the volcanics and the rubble, and also on the damage that the volcanics suffered during the explosion. Both circulation patterns were taken into account by Working Group 4.

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6.2. Atoll geology

C. Fairhurst (United States of America)
(see Sections 2.3 and 6.2 of the Main Report)

Discussion

G. Shorten (South Pacific Forum): In view of the high horizontal stresses that have been found in unsuspected places in the south-west Pacific region (for example, at the Bougainville copper mine in Australia), I think it is perhaps too early to assume that there is no high horizontal stress below the two atolls. If there is high horizontal stress, what is the possibility of hydraulic fracturing in the surrounding ground and what is the likely effect of fracture propagation by high-pressure fluids into the rocks around the test chambers?

C. Fairhurst (United States of America): Although there may be localized variations within the atolls, the horizontal stress must be essentially equal to the hydrostatic pressure of the ocean. Similarly, the vertical stress must be essentially equal to the overburden — the lithostatic pressure. High horizontal stress — which is not considered likely (see, in this connection, Fig. 11 in Vol. 4 of the Technical Report) — would tend to produce horizontal fractures. Although the probability of such fractures extending over large distances is considered negligibly low, the result would be some additional distribution of radionuclides within the zone of the tests. It seems, therefore, that such a scenario would not significantly modify the pathways of radionuclide release which were taken into account by Working Group 4.
G. Fraser (European Commission): You spoke of atoll cross-section depictions being reduced to schematics owing to a scarcity of data. What implications does the scarcity of data have for the final conclusions?

C. Fairhurst (United States of America): I do not wish to overstate the “schematic” nature of the diagrams. The indicated locations of the various rock formations are essentially correct for the cross-sections which I showed. Of course, the views involve two-dimensional (planar) interpolations from one-dimensional (linear) observations of drill-cores from holes (usually vertical) drilled into the atolls. Also, nuclear tests were conducted at 147 different locations across the two atolls, so that, even with several cross-sections, some interpolation is always needed.

Scientists of the Commissariat à l'énergie atomique have fairly precise data on the geology at each test location, based on the cuttings produced during drilling of the 1.5 m-diameter emplacement holes. This is presumably how data on the thickness of the volcanic cover over the chimneys were derived — data provided to the Study.

The approach taken in assessing geological variability and uncertainty at the atolls — a normal approach when dealing with geochemical problems — was to analyse the physics or a particular phenomenon (the development of an explosion cavity, slope instability, etc.) in terms of dimensionless groups of the parameters involved. This helped us to understand the relative influence of the uncertainties associated with specific parameters and assumed values.

Since many engineering studies have been conducted worldwide on carbonates and volcanics, reasonable data exist on the large-scale properties of masses of those rock types and on their variability. One can use those data — taking average properties and variations from them — in a first assessment of the likely behaviour of atolls, and reasonable bounds can usually be established. This approach was taken in the Mururoa and Fangataufa stability and hydrology investigations and has, I believe, led to a very good understanding of the actual situation at the atolls and provided a sound basis for assessing future changes.

In summary, the data scarcity does not detract from the validity of the final conclusions.

R. Rajar (Slovenia): There is a lot of sediment on the outer slopes of Mururoa Atoll. Do you consider it possible that at least some of that sediment was washed out from the lagoon? The modelling of sediment transport from the lagoon done within the framework of Working Group 5 showed that sediment can be washed out from the lagoon over the rim — especially the southern rim.

C. Fairhurst (United States of America): It appears from the Working Group 5 report that some sediment deposition may occur by means of the mechanism which you suggest. However, in the many thousands of years during which the sediment has accumulated (at depths down to 2000 m and beyond), that mechanism on its own would probably have resulted in a more or less uniform distribution of sediment around the outside of the atoll. The markedly thicker deposits in some orientations suggest that other deposition mechanisms — probably related to the local geology of the slope zone — have also contributed to the accumulation of sediment.
6.3. Stability of the atolls
C. Fairhurst (United States of America)
(see Sections 2.3 and 6.2 of the Main Report)

Discussion

G. Shorten (South Pacific Forum): As a major slide on the north-east rim of Mururoa is considered to be a likely — or credible — disruptive event, why have more data (on the lines of some of the data just presented by you) not been provided in the Main Report or in Vol. 4 of the Technical Report regarding rates of subsidence, inclinometer readings, high-resolution bathymetry and side-scan imagery? Could you provide the South Pacific Forum in the near future with the relevant data which you presented?

C. Fairhurst (United States of America): I shall do that. The questions of the atolls' stability and hydrology were examined in detail by the International Geochemical Commission (IGC) set up for that purpose, and I shall let the South Pacific Forum have a copy of the IGC's report "Stability and Hydrology Issues Related to Underground Nuclear Testing in French Polynesia".

D.M. Levins (Australia): In response to Dr. Shorten's first question, I would mention that the Main Report refers to publicly available documents containing data of the kind which Dr. Shorten has in mind, including Vol. 4 of the Technical Report, a number of French reports and the IGC report just referred to by Dr. Fairhurst.

I would also mention that the French have been monitoring for possible creep in the northern part of Mururoa and will, I imagine, continue to do so.

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6.4. Radionuclide release in the cavity-chimneys
J. Hadermann (Switzerland)
(see Section 6.4 of the Main Report)

Discussion

G.J. Buckau (Germany): Are there results confirming the Kd values given by you for plutonium?

J. Hadermann (Switzerland): Yes, there are. That issue will be addressed in the presentation of Dr. Warnecke on "Sampling of underground waters" (6.6).

P.P. Povinec (IAEA): Comparing your estimates for technetium-99 concentrations in water leaving the cavity-chimneys with our experimental data, we see a disagreement. Is it possible that you overestimated the concentrations of technetium-99 in the cavity-chimneys water?

J. Hadermann (Switzerland): Yes, the aim of the release calculations was to overestimate the concentrations. A very low sorption/distribution ratio was used for that reason — and also because the redox conditions in the cavity-chimneys were not known. A
higher — and perhaps more realistic — Kd value would reduce the calculated concentrations. In addition, the partitioning of technetium in lava and rubble has an influence on the concentrations in the cavity-chimneys.

**L.E. De Geer (Sweden)**: I should like to make two comments.

Firstly, the variability as regards caesium and strontium may well be due to the complex processes that took place during solidification; depending on the time taken by the lava to solidify, different fractions are found in the rubble.

Secondly, the reason why plutonium concentrations scale inversely with yield is that the absolute amount of plutonium is the same (3.7 kg) in each test whereas the volume scales with yield. In the case of fission products, both the absolute amount and the volume scales with yield, so the ratio does not.

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**6.5. Radionuclide release into the carbonates**

**J. Hadermann (Switzerland)**

*(see Section 6.5 of the Main Report)*

**Discussion**

**D.M. Levins (Australia)**: Evidence presented by Dr. Povinec (3.2 — “Radionuclide release into the ocean”) suggests that there might be some release of strontium-90 from underground into the Mururoa lagoon. Do you think it is likely?

**P.P. Povinec (IAEA)**: Of the radionuclides for which we have experimental data, tritium and strontium-90 are the only ones that could be associated with an underground source contributing to the radioactivity of the lagoon.

**J. Hadermann (Switzerland)**: The overall picture suggests that there is no appreciable release of strontium-90 into the lagoon from underground sources. The quoted measurement value might be attributable to the three safety trials carried out in the carbonates that went critical, but I doubt it — although the depths at which these trials were carried out are unknown.

**S. Carroll (Greenpeace International)**: The difference between the predicted levels of strontium-90 and the measured levels suggests that further monitoring should be carried out in order to determine whether the model needs to be refined (in order to obtain a more accurate prediction of the strontium-90 releases from underground) or the strontium-90 observations are spurious.

**J. Hadermann (Switzerland)**: Comparison of the modelling results and the measurements shows that the models fulfil the purpose of overestimating the releases to the carbonates. As I indicated earlier, from the model calculations there appears to be no underground source of strontium-90, except perhaps as a result of the three safety trials carried out in the carbonates that went critical.
At present, it is not clear to me whether the models need refinement, whether there is a source of strontium-90 in the sediment or whether the measurements are unrepresentative. As the impact is negligible, however, I do not think that further monitoring is necessary.

**S. Carroll (Greenpeace International):** Do strontium and calcium have similar chemical properties? If so, is it possible that strontium is being concentrated in the lagoon by some biological process in preference to other radionuclides?

**J. Hadermann (Switzerland):** Strontium and calcium do have chemical similarities, but I do not know whether strontium is being concentrated by a biological process.

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### 6.6. Sampling of underground waters

**E. Warnecke (IAEA)**

*(see Sections 6.6.1 to 6.6.4 of the Main Report)*

**Discussion**

**G.J. Buckau (Germany):** Are the plutonium and americium concentrations in the waters of the cavity-chimneys produced by the Aristée and Céto tests (carried out in 1984 and 1986 respectively) the result of equilibrium with the solid source or of kinetically controlled dissolution of the solid source?

**E. Warnecke (IAEA):** The waters in both cavity-chimneys were sampled for more than ten years, and the plutonium and americium concentrations were reported by the French experts to be very low or not detectable; this was confirmed by the Study. That being so, it is impossible to judge between “equilibrium” and “kinetics”.

However, the real point of the question is presumably whether the plutonium and americium concentrations in the cavity-chimney waters are found to be very low because the dissolution reaction is so slow that “equilibrium” — or, better, “steady state”— has not yet been reached.

Judging by the calculations of the plutonium and americium inventories in the rubble and in the lava (see Vol. 3 of the Technical Report) and the releases of these radionuclides into the cavity-chimney waters, the main contribution to the releases is from the rubble; this may be described as a kind of “desorption” reaction.

Sorption/desorption reactions involving plutonium and americium may be slow, in which case “steady state” is reached only after a few years. The two tests were carried out over ten years ago, however, and, even with a kinetically slow reaction, steady state should have been reached by now (for tritium, strontium-90 and caesium-137, the measured concentrations in the cavity-chimney waters indicate that the cavity-chimneys are well mixed systems and that a steady state was reached within about a year).

**D.M. Levins (Australia):** Figure 92 in the Main Report suggests that for strontium-90 and caesium-137 it takes about three years for equilibrium or steady state to be reached.
H. Hadermann (Switzerland): I should like to make a comment regarding the discrepancy between the measured and the calculated plutonium concentration.

The measured plutonium concentration depends on two factors — the sorption coefficients (for which a very low value was deliberately chosen) and the partitioning between lava and rubble (we assumed a high rubble contribution). However, the experimental results seem to indicate that much more plutonium is confined in the lava.

E. Warnecke (IAEA): I agree with that comment. In terms of the sorption coefficients, the calculations are based on the inventories of plutonium and americium and their partitioning between lava and rubble as given in Vol. 3 of the Technical Report.

If the plutonium fraction in the rubble were assumed to be 99.9% instead of 98% the calculated Kd values for the plutonium and americium would be lower by a factor of 20, which is still higher by several orders of magnitude than the values used in the model calculations.

H. Garnett (Australia): In this connection, we need to remember that the partitioning estimate for model calculations is 95% of the plutonium in the lava and 5% in the rubble. Given the plutonium on particulate material in the cavity-chimney waters, not all the plutonium is in the lava, but the figure of 5% for the plutonium in the rubble would seem to be high.

D.K. Smith (United States of America): I would add a comment regarding the presence of plutonium-239/240 and europium radionuclides in the retentates associated with the cavity-chimneys. Because these species are associated with the solids, trying to explain their presence in terms of equilibrium chemistry may not be entirely appropriate.

S. Carroll (Greenpeace International): Was any investigation carried out to determine whether the partitioning of plutonium between lava and rubble after the Aristée and Céto tests was the same as what might be encountered after tests with higher yields?

E. Warnecke (IAEA): I think Dr. De Geer would be better placed to answer that question.

L.E. De Geer (Sweden): No, only the Aristée and Céto drillback holes were available for sampling by Study participants.

It should be noted, however, that there are no physical reasons for assuming a correlation between partitioning factors and explosion yields — for example, boiling points obviously do not scale with yields. This conclusion is based also on extensive experience with other nuclear test sites.

A. McEwan (New Zealand): Is it possible that the solid residue on which plutonium was detected arose from — or was introduced by — the sampling operations?

E. Warnecke (IAEA): The solid residue was definitely not introduced by the sampling operations; the only activities carried out with regard to the cavity-chimneys were the pumping of water and — after the pumping — the pressure test with compressed air. The most likely origin of the solid residue was corrosion of the borehole casings; observations during the sampling operations support this hypothesis.
When the cavity-chimney waters were sampled, most of the solids were pumped off at
the beginning of the pumping operation; this suggests that the solids were inside the borehole
casings. As to the monitoring wells in the carbonates, the polytubes had a protective lining. In
the absence of major amounts of iron in the carbonates, this protective lining must have been
the source of the iron-rich solids.

H. Garnett (Australia): Is the elemental composition of the iron- and silicon-rich
particulates from the cavity-chimney waters different from that of the volcanic rock?

E. Warnecke (IAEA): Yes, the silicon content of the volcanic rock is some four times
higher than the iron content, whereas the iron content of the particulates is 2–5 times higher
than the silicon content (see G. Guille et al. 1996, page 91, and Vol. 4 of the Technical
Report).

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6.7. Radionuclide release into the lagoon/ocean
D.M. Levins (Australia)
(see Sections 6.6.5, 6.6.6 and 8.4 of the Main Report)

Discussion

P.P. Povinec (IAEA): A comparison of experimentally derived and theoretically
predicted release rates for tritium, strontium-90, caesium-137 and plutonium-239/240 shows
very good agreement. I tried also to compare predicted rates of release to the open ocean with
some possible experimental signals. Although we did not have high-resolution depth profiles
for tritium and strontium-90 available, the existing data are in rough agreement with
modelling results. Would you care to comment?

D.M. Levins (Australia): I have noted the depth profile measurements of tritium and
strontium-90 as shown in Figs 40 and 41 in Vol. 2 of the Technical Report. The data indicate a
possible source term at depth, but I do not consider them to be conclusive.

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Session 7. Disruptive events

Disruptive events
D.M. Levins (Australia)
(see Section 7 of the Main Report)

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Session 8. Assessment of radionuclide dispersion in the marine environment

8.1. Oceanographic modelling and mixing in the lagoons

E. Mittelstaedt (Germany)
(see Section 8.3 of the Main Report)

Discussion

G. Fraser (European Commission): You presented a diagram of residence times in the Mururoa lagoon which showed maximum values in the most easterly segment of the lagoon. However, a diagram of tritium concentrations resulting from releases over the floor of the lagoon showed maximum values in the most northerly segment. Is the difference due to vertical circulation components?

E. Mittelstaedt (Germany): The modelled relationship between residence time and activity was confirmed by measurements in 1996 by the IAEA Marine Environment Laboratory.

The discrepancy between the shown tritium concentration and the residence time pattern is due to the trapping of tritium at the north-west corner of the lagoon as a result of circulation. Whether the vertical component of the circulation is responsible is hard to say at the moment since the presented figures relate to depth-integrated situations.

G. Shorten (South Pacific Forum): In trying to be conservative when estimating the amount of material carried to the ocean from the Mururoa lagoon by steady-state events and storms, you adopted a figure — 2 mm/year — which seems excessively high to me. This figure (implying no deposition) leads to discrepancies relative to other atolls in the Pacific (whose lagoons are filling up) and to internal contradictions: there cannot be burial of plutonium without net deposition; and, if most of the material is removed from the beaches during storms, then there is implied concentration of the plutonium particles in areas where they are not likely to be removed by such processes.

Could these inconsistencies (see Section 8.4.2 of the Main Report) and the related ones (see Section 7.3.2) be eliminated in order to have a credible and consistent set of models throughout the Main Report?

E. Mittelstaedt (Germany): Perhaps Dr. Rajar would care to respond.

R. Rajar (Slovenia): The figure of 2 mm/year is a “worst case” figure for the removal of sediment from the lagoon by cyclones — an average for the entire lagoon. Several rough assumptions had to be made when calculating the flow of water and sediment over the southern and south-eastern rim, but various checks showed that the results were not unrealistic. Some further details regarding sediment formation (estimated also to proceed at a rate of 2 mm/year), removal and burial are given on page 64 of Vol. 5 of the interim edition of the Technical Report.

I would add that some rough calculations of the settling velocities of the outwashed particles and of the turbulence energy in the ocean have shown that almost all of the sediment will settle very near the atoll and not be transported further into the Pacific Ocean.
**P.P. Povinec (IAEA):** There is evidence that the plutonium inventory in the surface sediment is decreasing with an effective half-life of about ten years.

Two processes are mainly responsible for the sediment dynamics in the Mururoa and Fangataufa lagoons: the deposition of fresh sediment and the removal of sediment by the tide and by storms. A deposition rate of 2 mm/year has been measured, but the value averaged over the lagoons is higher — perhaps by a factor of two (otherwise there would not be any sediment in the lagoons).

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**8.2. Regional scale modelling**  
I. Osvath (IAEA)  
*(see Section 8.5.3 of the Main Report)*

**Discussion**

**J. Hadermann (Switzerland):** Do fish, plankton and the like contribute to the transfer from one compartment to another?

**I. Osvath (IAEA):** Yes, but the contributions are negligible when one is talking about radionuclide concentrations in model compartments. It is only when one is talking about radiological exposure pathways that migrating biota may be of interest — for example, in connection with the IAEA’s International Arctic Seas Assessment Project and similar assessments relating to radioactive waste dumping sites.

**C. Fairhurst (United States of America):** Can one assume that, over a period of hundreds or thousands of years, sediment transfer from within the lagoons as a result of storm-induced wave action would occur more or less uniformly at all parts of the atoll rims — or would there be a consistent, preferred orientation?

**I. Osvath (IAEA):** Perhaps Dr. Rajar should answer that question.

**R. Rajar (Slovenia):** In the Tuamotu region, the pathway of tropical cyclones observed during the past century has been from the north-west. Although the wind direction is changing as a cyclone is passing over a given location, French observational data indicate that, at least during the period of the strongest winds, the main wind direction is also north-westerly.

Strong south-easterly winds can occur during the winter, but our modelling has shown that more sediment will be washed out over the south and south-east sections of the atoll rims.

As to the long term, this situation might change if the climatic conditions change.

**A. McEwan (New Zealand):** I assume that the particle size distribution of sediment in a storm situation is different from that of the sediment lost normally through the pass and that this would mean more rapid sedimentation in the ocean and less transport of plutonium to locations far from the atolls. Did you take that into account?
I. Osvath (IAEA): No, but in Vol. 5 of the Technical Report it is shown that not taking it into account leads to overestimated values for the radionuclide concentrations in water predicted by the compartment models (especially for the plutonium concentrations at locations in the regional field). In other words, not taking it into account was in line with our general conservative approach.

P.R. Danesi (IAEA): You showed that the plutonium concentration at Tureia Atoll could be about ten times higher following a very disruptive event than it is now. In what form did you assume that the plutonium would be released into the sea water?

I. Osvath (IAEA): The source term given to Working Group 5 specified that all the plutonium should be considered to be in soluble form. This is unrealistic, of course, but consistent with the policy of making conservative assumptions.

D.M. Levins (Australia): We assumed that in the event of a plutonium release due to a carbonate rock slide all the plutonium would be in solution. That is a highly pessimistic scenario, but if we had assumed — say — 10% of the plutonium to be in solution we would have had to defend our assumption. Clearly, if even our very conservative assumption leads to an insignificant dose rate (which it does), we can have full confidence in our conclusion.

D.S. Woodhead (United Kingdom): That very conservative assumption becomes even more conservative if one recalls that in the Colette sandbank there is particulate plutonium derived from the safety trials that has been there for many years.

P.R. Danesi (IAEA): I accept that, when using such models, it is reasonable to consider events of very low probability — but not impossible events. The assumption that following a rock slide (a possible event) all the released plutonium becomes dissolved in sea water runs counter to the well-known fact that the solubility of plutonium is very low.

E. Wirth (Germany): In this context I should like to make a general remark about the Study as a whole.

Not everyone is familiar with questions of environmental contamination, so I think one should put the values calculated and measured during the Study into perspective. Thus, when giving a calculated value of 1 Bq/m³ for the tritium activity in sea water around Tahiti one might mention that the natural tritium activity in rainwater and surface waters is about 20 times higher; similarly, one might mention that the measured caesium-137 activity in the lagoons is significantly lower than that in the North Sea. As to the tritium concentration in the lagoons, I imagine that it is lower than that in the River Danube, which flows past the venue of this Conference.

I. Osvath (IAEA): I agree with you.

E. Gail de Planque (Chairman of the International Advisory Committee, United States of America): I also agree that such values should be put into perspective. That will be done in later sessions, when the Study findings as regards doses received by people from the residual radioactive material will be compared with natural background radiation doses and recommendations for follow-up activities will be made on the basis of the International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources.
A.J. González (IAEA): I believe that Dr. Wirth has put his finger on a problem which is very important, and not just in the context of this Study.

In some environmental contamination studies, people are talking about activities of 1 μBq/m³ — one radioactive disintegration every million seconds within a volume of one cubic metre. It is like talking about the "flow" in a pipe at the end of which the tap has been adjusted to give off one drop of water a year.

The problem is one of communication.

E. Gail de Planque (Chairman of the International Advisory Committee, United States of America): It is indeed a problem of communication. Selective reporting in the media has often indicated that there is a lot of radioactivity in the environment without indicating what that means in terms of doses to people. Early in the Study, we had doubts about the usefulness of doing transport calculations. However, we realized that we would be open to criticism if we did not do them, even though some of the numbers are ultimately meaningless.

I hope the participants in the Conference will bear that in mind when asked about the results of the Study.

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8.3. Far field modelling
E. Mittelstaedt (Germany)
(see Section 8.5.4 of the Main Report)

Discussion

D.M. Levins (Australia): It is important to put the predicted concentrations into perspective. For instance, in normal release situations the maximum predicted concentrations of tritium are typically 8 Bq/m³, compared with the background concentration in the open ocean of about 100 Bq/m³. Similarly, for strontium-90 the maximum predicted concentration is 8 mBq/m³ compared with a background concentration in the open ocean of 1–2 Bq/m³; for caesium-137, the corresponding figures are 1.5 mBq/m³ and 2–3 Bq/m³. In no case could the predicted concentration be differentiated statistically from the background.
Session 9. Long term monitoring

Long term monitoring
J.-F. Sornein (France)
(see Section 4.1.3 of the Main Report)

Discussion

K. Aoki (Japan): Do you intend to use television for examining boreholes in which there is no casing?

J.-F. Sornein (France): No, we do not; there are no longer any open boreholes.

K. Aoki (Japan): Do you intend to carry out pore pressure measurements?

J.-F. Sornein (France): No, we do not; it would be difficult to carry out such measurements with sufficient accuracy.

L.E. De Geer (Sweden): Why did you choose the Aristée and Céto boreholes for follow-up measurements?

J.-F. Sornein (France): Because the Aristée and Céto tests were the last to be carried out in the areas in question, so that there was no risk of the casings and other fittings being damaged by subsequent tests in the vicinity. Moreover, the two tests were carried out under the atoll rim — not under the lagoon.

We have been monitoring the Aristée and Céto cavity-chimneys for over ten years. During the early years, we observed homogenization of the tritium in the cavity-chimneys. Now, we intend to continue — in the medium term — checking for plutonium in the cavity-chimney water.

J. Hadermann (Switzerland): The impact of tides on tracer migration in the karstic zone is little understood. Since you intend to measure nuclide concentrations in the karstic zone, do you intend also to develop models for studying their impact?

J.-F. Sornein (France): In our modelling, the mixing effect due to tides was taken into account through a high dispersion coefficient. Future measurements in the monitoring wells will tell whether our model is predictive at the necessary level of detail. We do not intend to do any more modelling as it does not appear to be necessary.

P.P. Povinec (IAEA): Have you any plans for stationary underwater monitoring in the Mururoa lagoon?

J.-F. Sornein (France): No, we do not. It would be necessary to measure reliably caesium-137 concentrations lower than 1 Bq/m$^3$ in an environment where the natural radioactivity level due to potassium-40 is 12 000 Bq/m$^3$.

F. Schönhofer (Austria): What are the plans regarding future access to the two atolls?
J.-F. Sornein (France): The two atolls are military sites, and requests for access will have to be submitted to the competent authorities.

A.P. Owono (Cameroon): Why do you transport samples to France for measurement purposes?

J.-F. Sornein (France): The laboratory on Mururoa was dismantled as the costs of continuing to run it would have been prohibitive. Since there is no urgency about performing the measurements, we decided to perform them at our laboratory in France.

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Session 10. Effects on species other than man

Effects on species other than man
D.S. Woodhead (United Kingdom)
(see Section 10 of the Main Report)

Discussion

A. McEwan (New Zealand): The effect of a high dose to a very small volume of tissue would presumably be similar to that of a burn of pin-prick dimensions, where normal repair processes would replace the damaged cells.

D.S. Woodhead (United Kingdom): That is so. We did not consider the effect on total reproductive capacity of the loss of a small volume of gonad tissue.

P.R. Danesi (IAEA): I have a question indirectly related to the subject of your presentation. What is the likelihood of a person experiencing internal irradiation as a result of eating a fish which has ingested a hot particle?

D.S. Woodhead (United Kingdom): The likelihood is very small. There is not much that is worth eating around the Colette sandbank. Moreover, people may eat sprats and shrimps and the like whole, but fish are usually filleted before being eaten.

A. McEwan (New Zealand): I would add that the hot particle — being of very low solubility — would transit the person’s gut and that the gut transfer factor for plutonium in digestible material is of the order of $10^{-5}$. The likelihood of internal irradiation is indeed very small.

E. Wirth (Germany): When we talk of protecting humans against the effects of ionizing radiation, we are thinking of the protection of individuals; when we talk of protecting non-human species against such effects, we are thinking of the protection of entire populations.

As only a small fraction of any population will be affected by the presence of hot particles, which are confined to a small area, there will be no risk to entire populations; in fact, there would be no risk even if the plutonium contamination were much greater.

D.S. Woodhead (United Kingdom): I agree with you.

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Session 11. Ciguatera

Ciguatera
H. Garnett (Australia)
(see Annex II to the Main Report)

Discussion

C. Fairhurst (United States of America): Is there any known treatment for ciguatera?

H. Garnett (Australia): No. However, the structure of ciguatoxin is now known, so a treatment may be developed in due course.

L.E. De Geer (Sweden): Can one tell from the appearance of a fish whether it is contaminated with ciguatoxin?

H. Garnett (Australia): No. The fish may look perfectly healthy.

A. McEwan (New Zealand): There have been reports from widely dispersed areas of the Pacific region of women giving birth to “jelly babies” (grossly deformed foetuses), and nuclear testing has been cited as the cause. However, neither the true cause nor the incidence is known. As ciguatoxin can cross the human placenta, could there be a link between ciguatera and the “jelly baby” syndrome?

H. Garnett (Australia): I have not heard of any such link.

E. Bobadilla López (President of the Conference, Chile): Is there any method for determining the presence of the toxin in the meat of fish?

H. Garnett (Australia): There is a complex biochemical method of analysis for determining it, but that method is not suitable for application by people living on atolls and small islands, where sophisticated facilities are not available.

E. Bobadilla López (President of the Conference, Chile): What sort of structure does the toxin have?

H. Garnett (Australia): The toxin is a complex heterocyclic molecule.

E. Bobadilla López (President of the Conference, Chile): Does the toxin induce the production of antibodies?

H. Garnett (Australia): Antibodies have been produced in challenged animals, but the toxin can have several forms and from the antibodies one cannot infer which form one is dealing with.
Session 12. Assessment of the present and long term radiological situation

Assessment of the present and long term radiological situation
A. McEwan (New Zealand)
(see Section 9 of the Main Report)

Discussion

E. Wirth (Germany): I was surprised to learn that the natural dose level at Mururoa is higher than the world average owing to very high doses from polonium-210 and lead in fish. How high are these doses?

A. McEwan (New Zealand): The values shown by me are from an international study in which concentrations in fish were determined, but a comparison was also made with values around atolls in the Republic of the Marshall Islands.

P.P. Povinec (IAEA): Actually, we found that the differences in dose were due mainly to the consumption of shellfish, in which the polonium-210 concentration is much higher than in fish. What assumptions did you make about shellfish consumption by hypothetical residents at Mururoa?

A. McEwan (New Zealand): We assumed that the hypothetical residents would eat a mixture of crustaceans, molluscs and fish like that eaten by the Tureia population.

P.P. Povinec (IAEA): If you assumed that they would eat only shellfish, the maximum natural dose would be higher by no more than a factor of ten.

G. Shorten (South Pacific Forum): On the issue of glaciation, it is stated in Section 7.2.3 of the Main Report that “The next ice age is unlikely to occur for at least 50 000 years.” However, a fall of 5–10 m in the sea level, which could occur well before 50 000 years have passed, would make Mururoa a much more attractive place to live on. Would you care to comment?

A. McEwan (New Zealand): Even if the sea level fell by 5–10 m, the lagoon would not dry out; the sea level would have to fall by 30–40 m for that to occur.

G. Shorten (South Pacific Forum): A fall in the sea level of 5–10 m would uncover a large part of the lagoon floor, so that there would be some exposure to the plutonium source.

J. Hadermann (Switzerland): In my view, such exposure is not a matter for concern. People would not be drinking sea water from what was left of the lagoon.

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Session 13. Criteria for remediation

Criteria for remediation
A.J. González (IAEA)
(see Section 11 of the Main Report)

Discussion

S. Carroll (Greenpeace International): I have comments covering a number of areas.

To begin with, I do not dispute the estimates of radiation exposure presented by the Study.

On the other hand, I have a problem with the fact that in your presentation you said that with annual dose levels of 100 mSv intervention is "usually required". If I were a regulatory official in a country where such levels existed, I would say "I must deal with the situation".

Next, I would recall the accepted international philosophy — with which many people admittedly disagree — that one should assume in radiation protection that there is no threshold below which no damage to health occurs as a result of radiation exposure. In that connection, I believe that in the Study documentation it should be made clear that, in situations like those at Bikini Atoll and Semipalatinsk, an intervention is essential — not optional.

With regard to Mururoa Atoll, I believe that, if the levels of radiation exposure were higher, it would be technically possible to take remedial action to deal with the surface contamination and with the contaminants in the lagoon. What I think would be technically impossible is dealing with the contamination in the cavities.

A.J. González (IAEA): I am extremely pleased that you do not dispute the estimates of radiation exposure presented by the Study.

As regards the need for intervention, I agree with you that one should intervene in situations where annual dose levels of 100 mSv exist. However, there may be resistance to mandatory intervention in such situations. For example, in the development of the Basic Safety Standards, representatives of countries where high annual dose levels due to the natural radiation background are fairly prevalent expressed concern about the idea of mandatory intervention at a level of 100 mSv. For that reason the expression "almost always required", rather than "mandatorily required", has been used.

As regards the threshold question, I also agree with you. Not only am I not one of the opponents of the philosophy you referred to — I am one of its strong defenders. However, I would point out that the opponents include bodies like the French Academy of Sciences. I would also point out that, although the international standards are based on what we call the "linear no-threshold" assumption, they apply only to radiation doses which are additional to the natural background dose. This is an important qualification. Whether there is — as I personally believe — linearity right down to zero cannot be verified by experimental proof, and we will not be able to verify it — at least not in the near future.
As regards remedial action at Mururoa Atoll, one could always intervene if intervention is justified, but the underground contamination there seems not to warrant major expenditure on remediation. However, I am not so sure whether this would be the case at other nuclear test sites.

**D. Puig (Uruguay):** Do you think that, as a result of the Study, it will be necessary to modify some of the international recommendations concerning radiation protection?

**A.J. González (IAEA):** Those recommendations do not address the question of exposures to high levels of background radiation. I believe that if people generally come to agree with the representative of Greenpeace International that there must be intervention in situations where there are annual dose levels of 100 mSv due to the natural background, we shall have to modify the recommendations.

**F. Schönhofe (Austria):** When talking about the situation underground at Mururoa Atoll, one should remember that the people removing the radioactive material would receive high radiation doses and that the material would have to be stored somewhere. Would you care to comment?

**A.J. González (IAEA):** I agree with you; when one has a safe repository, the radioactive material is best left there. However, one might have a continuum between high surface contamination and the safe repository, and one should not close the door on intervention in that continuum.
Session 14. Findings, conclusions and recommendation of the Study

Findings, conclusions and recommendation of the Study

E. Gail de Planque
United States of America
Chairman of the International Advisory Committee

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Session 15. Discussion

(Discussion panel: E. Gail de Planque, United States of America, Chairman of the International Advisory Committee; D.M. Levins, Australia; and A. McEwan, New Zealand)

E. Gail de Planque (United States of America): I should like to ask a question. Seeing the results of the Study, how do you think one should go about planning and conducting similar studies in the future?

P.R. Danesi (IAEA): I am not the best person to respond to that question, but I should like to say a few words about the possibility of similar studies being conducted in the future.

The results of the Study are more reassuring than most of us thought they would be when we embarked upon it. I hope that this fact will be a stimulus as regards the launching of radiological studies of other former nuclear test sites.

The launching of such studies will depend on decisions taken by States at the political level. As far as the Agency’s Secretariat is concerned, I am sure that it would be ready to participate if the necessary resources were made available.

S. Carroll (Greenpeace International): I think the Study could serve as a model for similar studies of former nuclear test sites. There are some sites — like the Semipalatinsk one — where we have a fairly good general idea of what to expect, but there are some about which we know nothing, or next to nothing, and I would urge the States within whose territories these sites are located to open them up to international scrutiny the way France finally decided to do.

I should like to make two critical comments here which should not be taken as criticisms of the manner in which the Study was conducted.

Firstly, it would have been useful if the reports available at this Conference (the Main Report, the six Technical Reports and the Summary Report) had all been made available sufficiently ahead of the Conference for us to examine them properly. In my view, they should ideally have been issued before the results of the Study were presented, in May, to
representatives of the governments of member States of the South Pacific Forum and representatives of French Polynesia.

Secondly, I think it should have been made clearer in the documentation what the Study did not look into and which data were not validated by the Study.

That having been said, I congratulate the Study participants on a marvellous effort and thank France for making so much information available — as Greenpeace had been urging it to do for more than 20 years.

D.M. Levins (Australia): Dr. Danesi just said that the results of the Study were more reassuring than expected by most. In that connection I would mention that I was recently asked by a newspaper representative whether, in my view, those results indicated good luck or good planning on the part of the French. In response, I said basically that in my view the French made a few mistakes — particularly in connection with the safety trials — but resolved the resulting problems and learned the necessary lessons. One can only hope that those who have carried out nuclear tests at other sites learned from whatever mistakes they made.

M. Tschurlovits (Austria): It has been stated that the conclusions of the Study are very robust. Nevertheless, I should be interested in knowing the uncertainties associated with the various conclusions.

A.C. McEwan (New Zealand): The conclusions arise out of the doses which have been calculated. In the case of the calculated doses to a current hypothetical population, we consider the values to be correct to within a factor of two. In the case of future doses, the uncertainties are much greater. For example, the values obtained by assuming that all the plutonium would go into solution in the event of a rockslide could be too high by a factor of 100 or more.

D.M. Levins (Australia): I would point out that, even with the conservative assumptions made in order to be sure of obtaining maximum calculated dose rates, the dose rates which we calculated are several orders of magnitude below the level of significance.

E. Gail de Planque (United States of America): There were uncertainties due to the dose calculations and uncertainties due to the modelling. We did not sum them, but even together they are not radiologically significant and therefore would not affect our conclusions.

G. Shorten (South Pacific Forum): I should like to commend the International Advisory Committee and the other people involved in the Study for two years of intense work done in a very professional and open manner. At the same time, I hope that, before being issued in their final versions, the various reports will be adjusted so that people like me can tell those to whom we are responsible that the Study covered everything of significance.

If someone had told me, at the start of the programme of French nuclear tests at Mururoa and Fangataufa, that after completion of the programme it would be safe to “eat the sands” of the atolls, I would not have believed that person. Now the Study has shown that the site is clean, but an act of faith will be required of the South Pacific Forum and those whom it serves. I hope that I shall receive help in getting the message across.
E. Gail de Planque (United States of America): I am sorry that there are not more representatives of the South Pacific Forum present at this Conference.

On the other hand, I am not sorry that we did not have the final versions of the various reports available when we visited the South Pacific region in May to present the results of the Study to representatives of the governments of member States of the South Pacific Forum and representatives of French Polynesia — or that we have not had the final versions available at this Conference. The reason why I am not sorry is that the discussions this week have convinced me that certain clarificatory adjustments could usefully be made before the final versions go to press.

E. Bobadilla López (Chile, President of the Conference): I would be interested in knowing the opinion of panel members regarding the use of knowledge gained through the Study in the design of high-level radioactive waste repositories.

D.M. Levins (Australia): The amounts of fission products underground at Mururoa are very low — equivalent to the amounts produced during seven weeks of operation of a 1000 MW(e) power reactor. Nevertheless, the atoll is an excellent "laboratory" for studying the fate of radionuclides in the environment — albeit an unusual environment. I am therefore glad that the French are going to continue monitoring at the atoll.

The nuclides of greatest interest in the high-level waste context will be not so much radioactive forms of caesium and strontium, against which repositories can be provided with engineered barriers that will survive a long time, as very long-lived radionuclides like technetium-99 and neptunium-237.

E. Gail de Planque (United States of America): In that connection I would recall that the International Advisory Committee concluded that no further environmental monitoring at Mururoa and Fangataufa is needed for purposes of radiological protection, but, at the same time, recommended that the emphasis in any future monitoring be placed on the migration behaviour of long-lived and relatively mobile radionuclides and radiocolloids because of its particular scientific interest.

G. Shorten (South Pacific Forum): I believe the people of the South Pacific region will be pleased about France's plans for continued monitoring at Mururoa and Fangataufa.

S. Carroll (Greenpeace International): I accept that the radiation doses at the atolls are low and I believe that continued monitoring there is essential, but hope no one is thinking of using either atoll as a radioactive waste dump.

E. Gail de Planque (United States of America): We members of the International Advisory Committee would certainly not endorse the idea of using the atolls for that purpose. We had in mind the use of knowledge gained through the Study about — for example — radionuclide transport through various geological media and various types of water body — in the design of repositories to be built elsewhere.

C. Fairhurst (United States of America): The radionuclides now present underground at the atolls have been immobilized by the nuclear explosions which gave rise to them in a manner different from the manner in which radionuclides are — or would be — immobilized...
in a repository, so the analogy between underground nuclear test sites and high-level radioactive waste repositories should be treated with care.

**D.K. Smith (United States of America):** I think the Study has produced a unique set of scientific data which will be useful in studying both radionuclide migration underground at other nuclear test sites and proposals for the construction of high-level radioactive waste repositories.
SUMMARY OF THE CONFERENCE AND CLOSING REMARKS

Conclusions and closing remarks by E. Bobadilla López
Chile
President of the Conference

Director General of the International Atomic Energy Agency; participants in this International Conference on the Radiological Situation at the Atolls of Mururoa and Fangataufa; members of the International Advisory Committee and of the Task Groups and Working Groups which carried out the impressive Study discussed during this week; representatives of the French Government; officers of the Agency; observers from governmental and non-governmental organizations; representatives of the media; ladies and gentlemen.

As we come to the end of this Conference, it is my duty and my pleasure to convey to you my impressions and conclusions regarding the deliberations of the Conference and the subject matter which the Agency convened us all to consider — namely, the current and future radiological impact of the residual radioactive materials remaining from the nuclear weapon testing carried out in the South Pacific over the past three decades.

You have received for your scrutiny the Main Report of the Study on the Radiological Situation at the Atolls of Mururoa and Fangataufa, which was organized by the Agency at the request of the French Government. You have also received six bulky technical volumes supporting this report, plus a summary report designed to guide you through the Study — all in all, some 1300 pages of technical material. In the light of all this material, I wish to reconfirm the impression that I conveyed to you at the opening of the Conference: we have had the opportunity to review one of the most comprehensive radiological studies of radioactive residues in the environment ever carried out at the international level. After going through a massive amount of detailed technical information this week, we should again acknowledge:

- firstly, the work of the many experts who generously invested so much time, effort and expertise in the Study,
- secondly, the openness of the French Government in requesting a thorough radiological assessment in territories under its control, and
- thirdly, the efforts of the International Atomic Energy Agency in organizing and managing such an impressive endeavour.

Before going on to summarize the work of the Conference, I wish to present my general conclusions and reflections.

It is evident to me from the Study (and the discussions during the week confirm this) that — fortunately — the radiological impact from the residual radioactive materials remaining from the period of nuclear testing at Mururoa and Fangataufa is absolutely negligible. This scientific finding is the positive news from the Conference for the people of the South Pacific, who include the people of my own country. For me, as a medical doctor who has devoted his professional life to people's health, it is indeed good news.

However, let me emphasize something that has been said repeatedly during the week. This good news should not be interpreted as condoning the practice of nuclear weapon
testing, either in the South Pacific or in any other part of the world. In my opinion, nuclear weapon testing is not only a grave offence against the environmental habitat, but also — and more importantly — incompatible with ethical principles. Therefore, it should be condemned with all the force at our disposal. Let me state from this podium that the world has experienced more than two thousand nuclear weapon tests TOO MANY! I call on all States to stop this practice once and for all.

At the same time, I submit that this Conference was very glad to learn:

- first, that the Agency’s General Conference has already called on all States concerned “to fulfil their responsibilities to ensure that sites where nuclear tests have been conducted are monitored scrupulously and to take appropriate steps to avoid adverse impacts on health, safety and the environment as a consequence of such nuclear testing”, and

- second, that two States besides France have already requested international assessments of the residual radioactive material from nuclear weapon testing carried out in their territories and that, in addition to the Study at Mururoa and Fangataufa, a study has already been conducted — and the results published — on the prospects for resettlement of the Bikini Atoll in the Republic of the Marshall Islands and a preliminary study has been conducted at Semipalatinsk in Kazakhstan — with the results soon to be issued by the Agency.

The news from these two studies is far from being as good as the news from the Mururoa and Fangataufa Study, but bad news can be converted into good news if proper action is taken. I hope that the remedial measures necessary for resettlement of the Bikini Atoll will be taken and that a comprehensive study will be carried out at Semipalatinsk with a view to ensuring that appropriate remedial measures are taken there.

In this context, I reiterate the call I made at the opening of the Conference to all other States which have conducted nuclear weapon tests or in whose territories nuclear weapons have been tested to request the competent United Nations body — the International Atomic Energy Agency — to carry out scrupulous assessments, in collaboration with other specialized organizations, of the current radiological situation at all former test sites and to provide for the application of international standards for the protection of people from the potential effects of ionizing radiation.

After these general conclusions and reflections, let me now turn to the details of the Conference.

We first of all benefited from a background seminar which set the scene for the Conference:

- The French nuclear test programme at Mururoa and Fangataufa was described in detail by the Directeur Adjoint de la Direction des Applications Militaires du Commissariat à l’Energie Atomique, Monsieur Barthoux, representing the French Government. We learned that France’s nuclear test programme began in 1960, with a series of atmospheric tests. The first four tests, of low yield, were conducted in Algeria, at a site in the Sahara desert. In 1962, a decision was taken to establish a test site in the South Pacific, at Mururoa Atoll, 460 km to the south of an air base at Hao and 1200 km to the south-west of a main logistical base on Tahiti. Mururoa had the advantage of being
uninhabited and remote from populated areas. Atmospheric tests at the South Pacific test site occurred from 1966 to 1974; 37 tests were conducted at Mururoa and four tests at nearby Fangataufa Atoll. Following the cessation of atmospheric testing, an underground test programme began; it lasted from 1975 until January 1996. Of the 137 underground tests, 127 were conducted at Mururoa and ten at Fangataufa. In addition to nuclear tests, a series of safety trials was carried out at Mururoa. In these, nuclear devices were subjected to simulated accident conditions with destruction by conventional explosives. In summary, 193 tests (including safety trials) with a total yield of 13 megatons were conducted during the French nuclear test programme, which ceased on 27 January 1996. *The Conference was pleased to learn that the test site facilities are being dismantled and that the site will be closed.*

The framework of the Study was described by the Chairman of the International Advisory Committee, Dr. Gail de Planque. Dr. de Planque reminded us that the Study had been prospective in nature and that it had not been within the terms of reference of the Study to assess retrospectively doses received by inhabitants of the region as a result of the atmospheric nuclear tests at the time when those tests were carried out (doses due in part to the fallout of radioactive material that included short-lived radionuclides). She recalled, however, that an assessment of exposures of all countries as a result of atmospheric testing had been carried out by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), with the findings reported to the General Assembly of the United Nations and to the world scientific community; it had therefore not been necessary to include an evaluation of past atmospheric tests in the Study. Nevertheless, for completeness and in order that the present and future radiological situation at the test site may be better understood, details regarding the radiation doses attributable to atmospheric testing at the atolls have been reported.2

The background seminar was therefore completed by a presentation of the Director of the UNSCEAR Secretariat, Dr. Burton Bennett, who provided to the Conference a comprehensive summary of the UNSCEAR findings.3 The Conference was pleased to learn that the atmospheric tests conducted by France made a relatively low contribution to the total yield of the tests conducted by all countries; the number of atmospheric tests conducted by France was less than 10% of the total number of atmospheric tests conducted by all countries and the total yield of the French tests was only just over 2% of that of all tests. Many measurements have been made throughout the world of the dispersion and deposition of radionuclides produced in atmospheric tests, and an accurate assessment can be made of the deposition and doses from individual tests or from test series. The latitude band receiving the greatest deposition from the French atmospheric tests was the 20-30° band in the southern hemisphere. Even there, the deposition from the tests conducted by other countries was five times higher than that from the French tests. During the period of maximum cumulative deposition, from 1962 to 1972, the average dose rate to persons residing at latitude 20-30° south was extremely low — a few tens of microsieverts per annum, of which 20% can be attributed to French atmospheric testing. The maximum dose rate has since decreased by an order of magnitude. The present dose rates are two to three orders of magnitude less than the annual background rate due to natural radiation sources.

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1See the Main Report on the Radiological Situation at the Atolls of Mururoa and Fangataufa (Report by an International Advisory Committee, in the International Atomic Energy Agency’s Radiological Assessment Reports Series), Section 1.2.1.
In spite of the fact that these initial presentations were intended only to set the scene for the subsequent technical sessions, there was some discussion. For instance, an observer from a non-governmental organization asked whether fallout from the atmospheric tests had reached inhabited islands and whether information had been sought from people who had been working on Mururoa and Fangataufa at the time of the tests and who are now living on Tahiti. The ensuing discussion made it clear that after the atmospheric tests there was fallout of residual materials not only over inhabited islands in the South Pacific but throughout the southern hemisphere; the data are in Annex I to the Main Report (Tables I-I, I-II and I-III). Because of the remoteness of the test site, however, local exposures occurred after only five of the atmospheric tests. Residents of the Gambier Islands may have received doses of about 5 mSv following the first atmospheric test, of 2 July 1966, when winds and rainfall caused local deposition. Doses of 1 mSv or less were estimated for the four other tests. These doses are of the same order as annual doses from natural radiation and are thus not of radiological significance. As to information on workers and occupational doses, the ensuing discussion made it clear that a representative of the Project Management Office had candid talks with workers' representatives at a briefing meeting for people of French Polynesia that took place recently at the University of the South Pacific, Faaa. It was stated that it is not possible to determine in retrospect doses received in the past. According to international practice, and the requirements of the International Labour Organization, it is the responsibility of employers to monitor occupational doses. The Conference understands that the French authorities will soon be issuing a report on this matter.

And thus we moved into the technical sessions.

The first technical session provided us with an overview of the current radiological situation, including the residual radioactive materials present in the accessible terrestrial and aquatic environments of the atolls. Descriptions were given of the terrestrial and aquatic surveillance campaign, of the residual radioactive materials on Colette motu, Mururoa Atoll, and of the radionuclide releases into the ocean. It is clear, I believe, that the terrestrial and aquatic environments of the atolls that are accessible to people contain residual radioactive materials attributable to the testing, but at generally low concentrations. It is also clear that, in addition to the several kilogrammes of plutonium that remain in sediments of the lagoon of each atoll, particles containing plutonium resulting from atmospheric safety trials remain in the area of the trial sites — the motus of Colette, Ariel and Vesta, Mururoa Atoll. Clearly, the concentration of tritium in each lagoon is higher than in the open ocean, and elevated levels of caesium-137 exist over small areas on the Kilo Empereur rim of Fangataufa Atoll.

Let me say here that I was very impressed — as was, I believe, the Conference as a whole — by the big effort involved in the environmental sampling campaign. As a result of prior quality control tests, the relevant French laboratories and the network of laboratories co-ordinated by the Agency laboratories in Seibersdorf and Monaco proved to have a similarly good analytical competence. The Conference was relieved to hear that the results of the environmental sampling campaign showed generally good agreement with values provided by the French authorities. The campaign involved, it was emphasized, a large number of people and laboratories around the world and the collecting of hundreds of samples — vegetation, coconuts, sand, top soil, corals, cores of coral bedrock, aerosols, water from sediment cores, water from the lagoons and the ocean, lagoon sediment, flora and fauna.

Although the terrestrial sampling and monitoring campaign focused on Mururoa and Fangataufa, the Conference noted that, as there had also been some deposition of radionuclides on nearby islands at the time of the atmospheric nuclear testing, it was decided to carry out some measurements of activity levels at Tureia Atoll. On Tureia, the environmental contamination — partly due to global fallout — was low. In the discussion it was pointed out that the reason why Mururoa and Fangataufa had always been uninhabited, in contrast to Tureia, was frequent inundations.

The Conference noted that each sample had been divided into three, for analysis by the large network of laboratories, for analysis by French laboratories and — very important — for archiving (from where material can be retrieved for subsequent analyses).

The discussion about the small particles containing plutonium and americium which were found in the area comprising the Mururoa motus of Colette, Ariel and Vesta was also very encouraging. The contamination stemmed from safety trials in the area. Even after extensive cleaning by the French authorities, the general level of fixed contamination was estimated by the Study to be perhaps three times the level of the French cleanup criterion. In response to questions it was pointed out that the motus were frequently covered by the sea and much redistribution of sand and coral particles therefore took place. Thus, there are small discrepancies between the French values and the Study values for the plutonium levels on the motus. The discrepancies are probably due to the different survey techniques used. The French technique, which was the only feasible technique for large areas, tended to underestimate the total residual plutonium activity. The small discrepancies do not affect the robustness of the assessment.

As far as the residual radioactive material in the aquatic environment is concerned, I believe that the Conference is satisfied with the comparisons with the French data from earlier years: although the Study data show generally lower levels of tritium and some variability for strontium, there is very good agreement for caesium and generally good agreement for plutonium. The open ocean concentrations also showed good correlation for caesium and plutonium. The difference in sampling times between the French measurements and the Study measurements were noted in the discussion. A wide range of samples was collected, including water from sediment pores, the lagoons and the ocean, sediments, corals and biota. Altogether some thirteen thousand litres of water and one tonne of solid samples were collected, processed in situ, and sent to Monaco for distribution to the analytical laboratory network. In order to optimize the sampling, underwater gamma spectrometry was used in surveying the sea bed.

The Conference noted that, by combining the good historical record of activity concentrations obtained from the French data with the recent data points obtained by the Study, it was possible to investigate the time trends in the concentrations of certain key radionuclides in lagoon water. As I already indicated, the concentration of tritium as measured by the French had been reasonably constant for some years, but the concentration measured by the Study was lower. The constancy of the concentrations was doubtless due to a source of tritium in the carbonate rock; the concentration decrease, as measured by the Study, could have been due to the closing of shafts and the cessation of drilling. This explanation was supported by the correlation between the measured lagoon concentrations and the data on the distribution in carbonate rocks for both lagoons provided by the French authorities. For

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7Op. cit., Section 4.3.2.
strontium the concentrations have been stable for some time, which also indicates a possible release to the lagoons from the carbonates. The Conference noted that the main source of caesium is the sediments in the lagoons, so the lagoon concentration is steadily decreasing, with an effective half-life of about ten years, and the concentration of plutonium in the soluble phase is also decreasing, with an effective half-life of about eight years. The inventories of radionuclides — notably plutonium — in the sediments were also calculated, as were the release rates which form the input to the oceanographic modelling.

Now let me turn to the second group of sessions — those relating to the future situation. These sessions were the most complicated — at least for me as a medical doctor — since they covered a wide range of scientific disciplines, showing the overall complexity of the Study.

We were provided first with an overview of the assessment of the future radiological situation. The overall objective of this part of the Study was to estimate the rate at which residual radioactive materials at present underground at Mururoa and Fangataufa Atolls might migrate into the atoll lagoons or directly into the surrounding ocean. The results would be used to estimate the hypothetical doses that local population groups and people anywhere in the South Pacific region might receive in the future. The initial stage was an assessment of the yield of each underground nuclear test in order to determine the radionuclide inventory and how it was partitioned — the inventory source term. The second stage was to assess the rate at which these radionuclides might be released from the cavity-chimneys and migrate through the surrounding rock. This effective source term was the input in modelling the dispersion of the released material and in calculating the future concentration of the radiologically significant radionuclides. The final stage was to estimate the dose rates for critical groups of people. The Conference noted with satisfaction that, as far as possible, the Study had been based on independent data measured as part of the Study and used in independent models.

The Conference noted with interest the detailed assessment of the underground inventory of residual radioactive materials.\textsuperscript{9} The activity of residual radionuclides remaining after an underground nuclear test depends essentially on the explosive yield of the nuclear device. In the French information, the yields were given only in three broad ranges and grouped into seven areas for Mururoa and two for Fangataufa. Altogether, the residual radioactive materials underground fell into seven categories — materials from normal tests, materials from some tests that apparently had inadequate cover and material from some tests in which the cavity-chimney had reached the top of the volcanic rock (CRTV tests); materials from three categories of safety trials, differing according to the rock in which they took place (volcanics or carbonates) and to whether there was a fission yield; and waste plutonium disposed of into two deep repository shafts.\textsuperscript{9}

The Conference noted that the yields had been estimated \textit{independently}, on the basis of seismic monitoring information, mainly from New Zealand sources, and that they agreed well with the total yields reported by the French Liaison Office.\textsuperscript{10} Some assumptions, based on the open literature, had to be made regarding weapon design in order to estimate the contribution from nuclear fission and fusion as the first step in determining the underground inventory of radionuclides.\textsuperscript{11} The initial large number of radionuclides was reduced to 36 on the basis of selection criteria. This number was greater than the numbers in French studies. In response to a question, it was confirmed that the only information on the number of tests in which the top

\textsuperscript{8}Op. cit., Section 5.
\textsuperscript{9}Op. cit., Table XXIX and Fig. 52.
\textsuperscript{10}Op. cit., Section 5.5 and Table XXV.
\textsuperscript{11}Op. cit., Sections 5.6 and 5.8.
of the chimney reached the top of the volcanics and penetrated into the carbonates was information provided by the French authorities. Direct verification by drilling was neither feasible nor advisable as it would open new leakage paths. It was pointed out that the assumption of only a few percent of plutonium in the rubble was very conservative, as was subsequently confirmed by underground sampling. Basic properties of other elements, especially volatility, were used in order to estimate the partitioning between lava and rubble.\textsuperscript{12}

Once the Conference was satisfied about the amount of radioactive material that remained underground, it went on to discuss the assessment of the migration of radioactive material through the geosphere.

This started with what for me was a very interesting tutorial on atoll geology.\textsuperscript{13} The evolution of an atoll from a volcanic island was described. Over the period since their creation, the atolls have moved with the lithospheric plate some distance from the hot spots that created them. I believe that the Conference was convinced that there is no potential for renewed volcanism and that the seismicity in the region is now low. The volcanics and carbonate rocks forming the atolls are extensively fractured on various scales, so they behave from a modelling viewpoint as essentially isotropic. Slope failures occur naturally in the upper carbonate layer of such atolls.\textsuperscript{14} The question was asked whether the sediments came from the lagoons; the bulk of them are attributed to erosion of the slopes.

A separate but related issue discussed by the Conference concerned the effect of underground nuclear tests on atoll stability. Even though an explosion caused a cavity and later a cavity-chimney with a fractured surrounding volume, the bulk strength of the rocks is essentially unchanged. Even two major tests carried out in close proximity resulted in only a small settlement at the surface. The Conference noted with interest that there remained a potential for slides, especially in the north-east area of Mururoa. Discussion at this point focused on the slide potential and future French monitoring, which was generally considered adequate.

An interesting description of the hydrogeological situation at the atolls followed.\textsuperscript{15} The Conference learned that the main influence on the groundwater flow in an atoll in an undisturbed condition is buoyancy forces due to the geothermal flux heating the system from below. Cooler and denser ocean waters penetrate at depth from the atoll flanks and move upwards towards the lagoon. There is a freshwater lens from rainfall, but at Mururoa it is only a few metres thick and brackish. The groundwater velocities in the volcanic rocks are generally very low, whereas in the carbonates with karstic inclusions they are much higher. Independent calculations were made of permeabilities; the resultant temperature profiles and flow patterns were in good agreement with observations. Nuclear testing has changed the hydrogeological system in two ways:

- by creating zones of increased permeability around each test location, and
- by generating energy in situ, which results in a significant increase in temperature in the cavity-chimney (typically to 25–50 degrees celsius above ambient levels).

\textsuperscript{12}Op. cit., Section 5.10.
\textsuperscript{13}Op. cit., Section 2.3.
\textsuperscript{14}Op. cit., Section 6.2.
\textsuperscript{15}Op. cit., Section 6.3.
This temperature excess is not dependent on yield, and it will decline to negligible levels after a few hundred years. The main results from many calculations were the Darcy velocities between the top of the cavity-chimneys and the carbonates. It was suggested that, in a future ice age accompanied by a substantial drop — in excess of 100 metres — in sea level, the freshwater lens would become much larger and could intersect some of the safety trial locations.

The importance of verifying the overall model and the parameter values against the tritium data was emphasized in the discussion. The model was also robust against uncertainties in the relative horizontal and vertical permeabilities.

The Conference noted that the release of radionuclides into the water within the cavity-chimneys would be from two sources, the rubble — with concentrations in the chimney water determined by sorption equilibrium — and the lava, from which the radionuclides would be released very slowly.\(^{16}\) Initially, the transport models were temperature-driven; later, for test chimneys and for safety trials, normal water flow was assumed, with dissolution at the solubility limit. Where possible, data from the Study or from the literature were used, and conservative parameters were generally chosen, but more realistic parameters were used where direct verification was possible — by measuring radionuclide concentrations in the cavity-chimneys from two tests. In discussion, it becomes clear that the Study's modelling would overestimate releases, especially for plutonium — as a result of the assumption that only 95% was in the lava.

The Conference now turned to the radionuclides released into the carbonate zone.\(^{17}\) A dual porosity model, using the water velocities determined by the hydrogeological studies described in the previous session, was employed to estimate the rate of migration of material dissolved in the waters of the cavity-chimneys through the volcanics to the carbonate layers. The results of the modelling were presented to the Conference. Thirty-two radionuclides had been selected for consideration: tritium and the three nuclides of major radiological significance — namely, strontium-90, caesium-137 and plutonium; six non-sorbing nuclides; 14 short-lived sorbing nuclides; and eight long-lived sorbing nuclides. The results of the modelling were presented for each nuclide as a set of break-through curves showing the rate of release (in becquerels per annum) as a function of time over the next 10 000 years. The discussion centred around the apparent increase in the concentration of strontium-90 in the Mururoa lagoon observed in the aquatic sampling campaign — an increase inconsistent with the modelling, which predicted virtually no release of strontium-90 from the volcanics into the carbonates. It was suggested that too much reliance should not be placed on single measurements of single radionuclides. However, a possible source of the apparent increase in the strontium-90 concentration was the three safety trials that went critical, which were carried out in the carbonates.

The results of independent measurements carried out by the Study of the concentration of various radionuclides in the underground water of the atolls were reported to the Conference.\(^{18}\) As well as samples from wells drilled into the carbonates, water was taken from the cavity-chimneys of two underground tests. The results were used in checking the calculations of the solution source term made by the Study. The samples taken from the test cavity-chimneys confirmed the extremely low levels of plutonium and other actinide elements in the cavity water, indicating the high degree of retention of these elements in the lava.

\(^{17}\)Op. cit., Section 6.5.
Discussion focused on the very low levels of plutonium and americium found in the water of the two cavity-chimneys and the concentration of these nuclides assessed in the modelling done by the Study. The Study had clearly, and deliberately, assumed conservative values for the fraction of plutonium absorbed on rock surfaces and for the fraction of plutonium trapped in the lava. The evidence was that much more of the plutonium was trapped in the lava than the 95% assumed in the migration calculations. This observation of a very high fraction of plutonium trapped in the lava was expected to hold for all tests, independently of their yield.

A simple model to describe the release to the environment of radionuclides that have migrated to the carbonates was discussed. They collect in the carbonate layer, from which a fraction will be released to the lagoons and a fraction direct to the ocean through the sides of the atolls. The results of this modelling were presented in terms of the change with time in the concentrations of the key radionuclides mentioned before, in the water of the lagoons, and in terms of the rate of release of these radionuclides direct to the ocean, also as a function of time. It was pointed out that, using conservative values for certain parameters, this model predicted that the rate of release of strontium-90 to the lagoons could increase over the next decade or so, which was consistent with the observations made during the Study sampling campaign. In my view, the Conference was not inclined to give much weight to the predicted increase in the rate of strontium-90 release to the lagoons as it was based on the very conservative — low — value assumed for the Kd of strontium in the carbonates.

The Conference discussed a number of hypothetical disruptive events that could possibly lead to an enhanced rate of release to the environment of radionuclides at present underground, or to enhanced levels of exposure. It was noted that glaciation (assumed to occur in 50,000 years’ time, with a 100 metre drop in sea level) could result in exposures due to residual plutonium in lagoon sediments and to the drinking of water from the freshwater lens that would form within the carbonates and which could possibly intersect one or more of the safety trial cavities. A scenario involving an assumed slide of carbonate rock at the northern rim of Mururoa Atoll, where it might intersect the cavity-chimney of a CRTV test and the cavity of a safety trial that did not go critical, was analysed in detail. To provide a “worst case scenario”, it had been assumed that all the plutonium in the safety trial cavity would go immediately into solution and would be available for transport to neighbouring islands — a very conservative assumption that was criticized by some participants as being unrealistic. The consequences of the slide were later discussed in the sessions on oceanographic modelling and on the assessment of the radiological situation.

A review of the oceanographic modelling was discussed. Models were used to simulate, assuming no changes in oceanographic conditions, the concentrations of the key radionuclides at sites in the South Pacific Ocean over the next 10,000 years — in the lagoons, within a thousand kilometres or so from the atolls, and in the far field extending to the coasts of South America and Australia. The near field modelling of flow in the lagoons was described. It led to residence time and turnover time values for both lagoons. A related model was used in estimating the rate of removal of plutonium-containing sediments from Mururoa lagoon under normal conditions and during a major (one year in ten) tropical cyclone.

During the discussion, it was questioned whether the bottom sediment removal rate predicted by the sediment removal modelling was consistent with assumptions about sediment accumulation rates made elsewhere in the Study. Two points were made during the discussion.

The concentration values for the key radionuclides found in the ocean are for the most part extremely low, and very much lower than existing concentrations due to global fallout. Subsequently, it was pointed out that it would be difficult for laymen to appreciate the significance of concentrations of microbecquerels per cubic metre and the like. One microbecquerel per cubic metre is the equivalent of one disintegration every million seconds in one cubic metre of water. This enters the range where statistical fluctuations in count rate become very significant.

There was also some discussion on “worst case scenarios”. It was argued, for example, that the assumption in the rock slide scenario that all the plutonium goes instantly into solution was scientifically not credible. It was suggested that conservatism in the assumptions leading to this source term had been taken so far that the concentrations calculated for Tureia as a consequence of the rock slide were not plausible.

The three compartment models used in simulating concentrations within a thousand kilometres or so of the atolls (the intermediate region) resulting from instantaneous and time-dependent releases were described. An advantage of compartment models is that they can cover long time periods without excessive use of computer time; however, because of the spatial and temporal averaging that is inherent in compartment modelling, the resolution is often not high. Wherever possible, independent — verified and conservative — oceanographic data were used. The use of three models allowed intercomparison of results where the models overlapped. In general there was agreement within an order of magnitude in predicted concentrations.

The results of far field modelling were illustrated in a number of figures showing concentrations throughout the South Pacific of key radionuclides — particularly tritium and plutonium — resulting from instantaneous and time-dependent releases into the surface layer of the ocean and at depth, below the thermocline. Because of the very large amount of computing time required in order to run the model, migration was followed for only a few decades. A feature of the model is the prediction that surface releases will initially move in an easterly direction, with some migration towards the west due to dispersion. Releases at depth will move towards the west, with less initial dilution than for surface releases. All increases in concentration rapidly become very small — orders of magnitude below existing background concentrations due to global fallout. In the discussion, it was noted that the far field simulations result in extremely small radionuclide concentration elevations a thousand kilometres or so from the atolls. It was again emphasized that concentrations of microbecquerels per cubic metre are “virtual concentrations”; concentration elevations of this size are orders of magnitude less than existing background concentrations in the open ocean due to global fallout and would be unmeasurable. Let me emphasize what these background concentrations are: for tritium about 100–200 Bq/m$^3$; for strontium-90 and caesium-137 about 2 Bq/m$^3$; and for plutonium about 3 mBq/m$^3$.

In the last group of technical sessions, the Conference addressed other issues related to its main topic. First, the proposals of the French Government for long-term monitoring at the atolls were discussed. The Conference noted that radiological and geomechanical

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22 Op. cit., Section 8.5.3.
monitoring has been carried out at the atolls for more than 30 years. On the basis of the Study, it was concluded that no further environmental monitoring is needed at the atolls for the purposes of radiological protection. The radiological programme will be similar to that carried out over the past decade or so, but at a somewhat reduced level. A sampling campaign at the atolls will take place once a year. It was noted that a scientific programme of monitoring of the radionuclide concentrations in the carbonate formations and in the nuclear test cavity-chimneys will continue. The Study recommends that emphasis be placed on monitoring the migration behaviour of long-lived and relatively mobile radionuclides and radiocolloids because of their particular scientific interest. There will be geomechanical monitoring of the stability of the northern part of Mururoa and of the flanks of both atolls — monitoring by a permanent system, with automatic satellite transmission of results, and on-site inspections every 3-10 years. The Conference noted that the scientific programme, supplemented by some monitoring of radionuclide levels in the biosphere, may also be useful in assuring the public about the continuing radiological safety of the atolls. It is expected that the monitoring results will be published on an annual basis.

Then, the Conference took note of the assessed effects on species other than man. The Study had assessed the dose rates to native biota resulting from the residual radioactive material at the atolls and, in the great majority of cases, had found them to be similar to or lower than dose rates due to natural radiation sources. It was assumed that radiation doses are distributed over the whole body of the animal with no differentiation between organs, but account was taken of different water, tissue and sediment pathways, and of low- and high-LET radiation separately. Benthic crustacea in the lagoons receive the highest exposures from ambient concentrations of radioactive material. Potentially high dose rates could be experienced by individual members of some species owing to plutonium contained in “hot particles” in the Colette sandbank. It was suggested that the question of damage to gonad tissue in small animals might be studied for scientific purposes. The possibility of many hot particles being concentrated in larger fish and eaten by man was considered to represent no real risk because of the combination of low probability of intake by fish, low human consumption of the gut contents of fish, and a very low human gut uptake factor. Overall, the Study concluded that the expected radiation dose rates and modes of exposure are such that no effects on biota population groups could arise, although occasionally individual members of a species might be harmed, but not to the extent of endangering the whole species or creating imbalance between species.

Finally, an issue which is rather esoteric as far as this Conference is concerned but which interests me professionally very much, was discussed: CIGUATERA. Ciguatera is a type of food poisoning which people contract by eating fish contaminated with a toxin generated by a marine micro-organism often found in association with disturbed coral reefs. There have been some reports in news media that outbreaks of ciguatera may be linked to exposure to radiation from the residual radioactive contamination at the atolls. The symptoms of ciguatera poisoning were recognized long before the start of the nuclear test programme (over a century ago, in fact), and a range of anthropogenic and natural disturbances may contribute to abrupt ciguatera outbreaks. At present, there is no known medical treatment. A question was asked about whether Ciguatera could be transmitted through the placenta, resulting in the birth of deformed children. No evidence exists to resolve this issue. However, there is certainly no evidence in the scientific literature of radiation exposure being a causal factor for outbreaks of ciguatera.

And thus, the Conference moved on to the technical sessions on assessments. The Conference learned of the final assessment of the present and long-term radiological situation. Mururoa Atoll has been inhabited 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 Study the existence of a hypothetical population resident on Mururoa was assumed in order to determine potential radiation doses. Also, the estimation of doses to more distant communities was necessary in order to establish the significance of any releases of radioactive materials to the ocean. Account was taken of radionuclides migrating from underground and remaining from the atmospheric tests and of radionuclides that might be released as a result of disruptive events, such as a landslide, or of changes in climatic conditions. The dose assessments undertaken for the purposes of the Study were described after a brief introduction to the methods used for dose calculations. The conclusion of the assessment is that the calculated annual doses due to the dispersion of radionuclides from the French nuclear testing programme at Mururoa and Fangataufa Atolls are all very small when compared with annual doses from natural background sources; the corresponding health impact is similarly insignificant. Overall, the radiation risks to current and future generations from the French nuclear testing programme at Mururoa and Fangataufa are so small that they can be considered to be negligible.

In response to questions raised about the hypothetical radiation doses from seafood consumption, it was stated that the transfer parameters used were based largely on the results of an international study (the MARDOS Study) and that the dietary information was taken from published literature on consumption patterns at Tureia. Assumptions made with regard to the impact of future climate changes were questioned, particularly those concerning the effects that might be caused by glaciation. For example, relatively minor lowering of the sea level (by perhaps 10-15 metres) could presumably occur during inter-glacial periods well before 50 000 years. The consequences of such alternative scenarios did not appear to have been taken into account in the Study. In response, it was stated that the assumptions made as to when glaciación will occur in the future would have little effect on the resulting assessed radiation doses. Lowering of the sea level by 10–15 metres would expose only small areas of the lagoon bottom near the present coral rim.

Given the results of all the technical sessions, I submit that it is obvious to all of us that there is no need for radiation protection remediation at Mururoa and Fangataufa. However, the criteria for remediation were discussed by the Conference. In my view, this is good because, as we noted before, the Agency has been involved in a number of radiological assessments where the need for remediation was in fact demonstrated. The Conference noted that there is currently no explicit international guidance on generic action levels for chronic exposure due to radioactive residues from previous activities and events, such as nuclear weapon testing. The guidance established in the International Basic Safety Standards for other situations has been used in providing indications of the levels that might be appropriate. In addition, typical levels of doses caused by chronic exposure to the unavoidable natural background radiation have been used as a reference for comparison. On the basis of these considerations, it appears that intervention in chronic exposure situations is unlikely to be warranted in order to achieve a reduction in annual effective dose to levels of less than about 10 mSv. A dose in the region of 10 mSv therefore appears to be a reasonable generic guideline for intervention.

I believe that the Conference was glad to learn about the many developments that are taking place in this area of basic radiation protection criteria, both within the International Commission on Radiological Protection and within the International Atomic Energy Agency. I conclude that we should encourage these two organizations to continue to steer towards simple criteria for dealing with radioactive residues from the past. Such criteria will have to be used in many places around the world where there is a legacy of radioactive residues from the past, particularly from military activities.

So we arrived at the findings, conclusions and recommendation of the Study, which have just been so brilliantly presented by the Chairman of the International Advisory Committee, Dr. de Planque. I would request the Agency’s Secretariat to ensure that the findings, conclusions and recommendation and the discussion which took place a few minutes ago are brought to the attention of the Agency’s General Conference.
Closing remarks by E. Gail de Planque
United States of America
Chairman of the International Advisory Committee

I would like to take a moment at this point to thank all the Study participants for a job well done. I hope that the Study has added to the fundamental knowledge base of science and technology. I also hope that it will help our societies to face technical challenges such as the designing and constructing of safe facilities for the disposal of radioactive waste.

From the scientific point of view, the Study was for me a wonderful opportunity to learn a lot about many areas of which I knew very little. I hope that all the Study participants learned as much as I did. At the personal level, I find that such exercises provide an opportunity to acquire many new friends for life. I think I acquired new friends for life, and I hope the other Study participants did also.

As to the Conference, I would like to thank you all; you made this a very successful four days. The questions asked and comments made were very perceptive, and the discussions were very useful.

I wish to single out two Conference participants for special thanks: Mr. Shorten from the South Pacific Forum and Mr. Carroll from Greenpeace International. We had hoped to have more representatives of the South Pacific Forum here, but that was not possible. The interests of the people of the South Pacific region were very much in our minds during the Study, and in May a small group of us visited the region in order to present the Study results there. I hope Mr. Shorten will convey the conclusions of this Conference to the people of the South Pacific region. I am very pleased that Mr. Carroll was able to be with us. I thank him for the complimentary statements that he made, but even more for sharing his thoughts with us. I believe that essentially we all have the same basic goal, the protection of our planet and its inhabitants, and that improved communications among the various groups around the world will help us all in achieving that goal.

Turning to the IAEA, I should first like to thank Director General ElBaradei for his encouragement and support and for making the necessary IAEA resources available for the Study. The IAEA staff involved in the Study — and there were many of them — contributed enormously; the Study would not have been successful without their efforts. Unfortunately, time prevents me from naming them all, but there are three whom I should like to single out: Abel González, the Project Manager; Bob Fry, the Technical Project Manager; and Renate Boldizsar, the Administrative Assistant.

I have always had the greatest respect for Abel González's scientific expertise and managerial talents, but on this occasion Abel absolutely outdid himself, eliciting an extraordinary effort in an unbelievable amount of time. It was a delight to work with him.

Bob Fry came to Vienna from Australia innocently thinking that he was going to spend six months here in connection with the Study; he has been here for the past year and a half. He has laboured untiringly behind the scenes, often under-appreciated, putting together a comprehensive scientific patchwork quilt and making possible the production of all the Study documents. Bob deserves the gratitude of us all.
Renate Boldizsar has been absolutely amazing, bringing people together from all parts of the world and keeping them happy. I am sure she has many fascinating stories to tell. Thank you, Renate!

I thank the French Government for requesting the Study; it has set a fine example for others. I also thank our French colleagues for their openness and co-operation throughout the Study; it was a marvellous experience. In particular, I would mention Mr. Sornein and Col. Corion, who were extremely patient and shared their expertise with us as we struggled to understand the technical aspects of a programme with which they were very familiar.

I thank Dr. Bobadilla López, who has done an excellent job in chairing the Conference, and I hope that I can count him among the new friends acquired through the Study.

In summary, it has been a pleasure and a privilege to work with all of you. I found the Study and the Conference a rewarding and enriching experience, both professionally and personally. I hope that our paths cross again many times. When Abel González feels that an issue has been resolved, that there is nothing more to be done, he often concludes with “Punto, finito!” So I say: “Punto, finito!” and thank you all.
I have just returned from visiting the Middle East where, among other matters, I addressed a Conference on Emerging Nuclear Energy Systems. My message there is equally relevant here:

Since its very beginnings, atomic energy has carried hopes and apprehensions. The hopes — for a safe, environmentally friendly, cost efficient and virtually unlimited source of energy used for exclusively peaceful purposes for the benefit of humanity — are even more relevant today to help mitigate global climate change and to meet the growing energy demand that is essential for developing countries.

The apprehensions — that atomic energy may be used unsafely or for destructive purposes — have been underscored by a number of events, notably the Chernobyl accident and Iraq’s clandestine weapons programme, which cast a shadow in the public mind on the peaceful utilization of nuclear energy.

The IAEA was established over 40 years ago precisely to help bring to fruition the hopes for atomic energy and to assist in curbing the apprehensions. Through five inter-related tasks, the Agency has sought to contribute to the beneficial, safe and peaceful uses of atomic energy.

To assist in realizing the hopes, the Agency’s tasks are:

- to act as a catalyst for the scientific community and as a hub for state-of-the-art technology;
- to act as a centre for the transfer of nuclear technologies so as to ensure their accessibility to Member States in general, and to developing countries in particular; and,
- to assist Member States to make informed and appropriate choices concerning the energy mix by conducting comparative assessments of nuclear and other technologies.

To help curb the apprehensions, the Agency’s role is:

- to assure, through its verification system, that pledges to use nuclear energy exclusively for peaceful purposes are fulfilled - that is, the role of “nuclear watchdog”; and
- to strive for the highest level of safety in all areas of the use of nuclear energy.

In the area of verification, through its safeguards system, the Agency seeks to assure that pledges to use nuclear energy exclusively for peaceful purposes are fulfilled. In 1997, over 180 States were subject to IAEA comprehensive safeguards. Safeguards were applied to over 900 facilities involving more than 10,000 days of inspection.

The experiences this decade in Iraq, in the DPRK and in the very different case of South Africa led the international community to show the political will to enable the IAEA to develop a more effective strengthened safeguards system that is designed to provide assurance not only about nuclear activities declared by a State, but also about the absence of undeclared
activities. Very good progress is being made by States in concluding the legal instruments necessary for implementing the new measures.

Most recently, Russia, the United States and the IAEA are examining arrangements for the Agency to verify that fissile materials removed from dismantled nuclear weapons or excess to defence programmes are not returned to weapons use or diverted. This undertaking would be the first specific mission for the IAEA in the international verification of steps towards nuclear disarmament, in relation to the obligations of Article VI of the NPT.

While the responsibility for nuclear safety lies primarily with national Governments, the IAEA plays a fundamental role through three complementary activities: the development of legally binding international agreements and the servicing of their implementation; the establishment of a comprehensive corpus of non-binding safety standards; and the provision of assistance in the application of those standards through activities which include safety services, training, fostering scientific research, technical co-operation and information exchange.

The purpose of this conference has been to present for peer and public review the results of this major and impressive Study directed by an International Advisory Committee of distinguished scientists, convened by the IAEA, to examine the present and future radiological conditions at the two South Pacific atolls following three decades of atmospheric and underground nuclear weapons tests by France.

The Study is one of a series that the Agency has undertaken, at the request of Member States, to assess present and future radiological conditions and possible hazards at former nuclear test sites and, if affected areas are to be populated or otherwise put to human use, to make recommendations on any remedial actions needed.

The role of the Agency in undertaking these studies and, indeed, throughout all our activities, is to be objective and scientifically credible. Hence, we welcome and encourage scientific review of the methodologies, conclusions and recommendations of this Study.

The IAEA General Conference has called on all relevant States “to fulfil their responsibilities to ensure that sites where nuclear tests have been conducted are monitored scrupulously and to take appropriate steps to avoid adverse impacts on health, safety and the environment as a consequence of such nuclear testing.” The Agency remains prepared to respond to further requests in this area. As noted by Dr. Bobadilla, the news from the other two studies in the Bikini Atoll and Semipalatinsk are not the same as the ones that have emerged from this Study. But I concur with him that bad news could be converted into good news if appropriate remedial actions are taken with appropriate resources made available to the Agency.

The conclusions of this particular Study should provide welcome assurance to the people of the South Pacific region. But these conclusions in no way condone nuclear testing. Limiting the environmental impact of testing is not the answer to global and regional apprehensions. The objective of the international community must be to eliminate entirely nuclear weapons and nuclear weapons tests. The cold war has left a legacy which should remain a legacy. A nuclear club with five members too many.

It remains for me to reiterate the Agency's gratitude to the many experts from some twenty States and six intergovernmental organizations who participated in the conduct of the
Study. In particular, I wish to thank you, Mr. President, and the members of the International Advisory Committee and its able chairperson, Dr. Gail de Planque, for the dedication, energy and expertise in guiding this major Study to its conclusion. I would like also to express appreciation for the outstanding work by the many Agency personnel, both in Headquarters and in its laboratories, and to note in particular the meritorious achievements of Drs Abel Gonzalez and Robert Fry.

Finally, I would ask the representative of the Government of France at this Conference, the former Minister of Research and Technology, Mr. Hubert Curien, to convey to the French Government the Agency’s appreciation for its openness in sharing information and for its substantial support in the conduct of the Study — a fine example to be followed.
Closing remarks by E. Bobadilla López
Chile
President of the Conference

Let me now close this Conference with some personal remarks. First, allow me to say that it was an enormous pleasure for me to participate in this Conference with all of you. The presentations and the discussions have introduced me to a number of scientific subjects which were unknown to me and remote from my professional background. During the Conference, I enjoyed the elegance of the presentations and the solidity of the foundations on which the Study conclusions are based. The robustness of the conclusions derives from the strict scientific criteria applied by the International Advisory Committee, from the critical analysis of the data provided by the French authorities and from the consistent adoption of conservative hypotheses throughout the Study. The calibre of the researchers and the institutions involved, which could be taken for granted, was important for the conclusions of the Study.

The results of the Conference may be summarized as follows: "there will be no radiation health effects which could be medically diagnosed in an individual or epidemiologically discerned in a group of people" and "the expected radiation dose rates and modes of exposure are such that no effects on biota population groups could arise".

These simple statements will probably be called into question by the general public and the media. Wide diffusion of the Study reports should therefore be recommended by all of us — by the representatives of 42 countries and eight organizations who took part in the Conference and by the observers from 12 institutions — and, of course, by the Agency.

The Study will gain additional credibility if its results are not used for justifying the development and testing of nuclear weapons. In my view, the development and testing of nuclear weapons should be rejected because, even if the radiation impact on human beings and on biota is negligible, international security and ethics must prevail over all other considerations. Rather, we should use the Study's results in promoting the general advancement of science and in dealing with the greatest problem of nuclear power development — the safe disposal of high-level radioactive waste.

In conclusion, I would like to express my gratitude to Dr. Gail de Planque for the manner in which she chaired the International Advisory Committee and for the role which she played during the Conference. Also, I would like to thank the Agency's Secretariat — especially Dr. Abel González — for courageously inviting me to chair the Conference. In addition, I would like to thank all of you, the Conference participants, who made the Conference so meaningful. Lastly, on your behalf, I thank the interpreters and the Conference Services staff of the Agency.

I declare the International Conference on the Radiological Situation at the Atolls of Mururoa and Fangataufa closed.
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