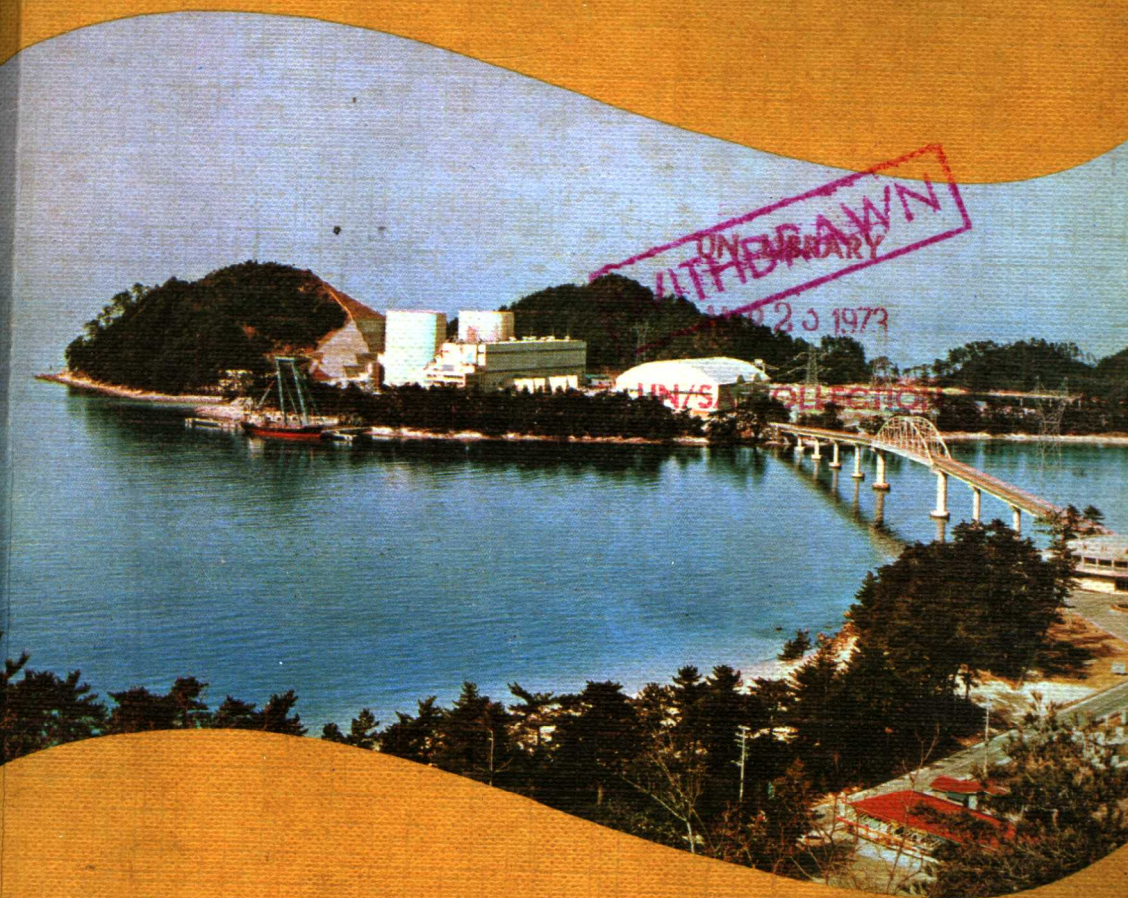


IAEA  
STI/PUB/313  
copy ✓

# RADIOACTIVE CONTAMINATION OF THE MARINE ENVIRONMENT

Proceedings  
of a  
Symposium  
Seattle  
10-14 July 1972



INTERNATIONAL ATOMIC ENERGY AGENCY, VIENNA, 1973

PROCEEDINGS SERIES

# RADIOACTIVE CONTAMINATION OF THE MARINE ENVIRONMENT

PROCEEDINGS OF A SYMPOSIUM  
ON THE INTERACTION OF RADIOACTIVE CONTAMINANTS  
WITH THE CONSTITUENTS OF THE MARINE ENVIRONMENT  
HELD BY THE  
INTERNATIONAL ATOMIC ENERGY AGENCY  
IN SEATTLE, UNITED STATES OF AMERICA, 10-14 JULY 1972

INTERNATIONAL ATOMIC ENERGY AGENCY  
VIENNA, 1973

## FOREWORD

The nuclear energy industry has grown during the past several years and a continuing growth is predicted over the next few decades during which time nuclear power is expected to become the main source of energy for fulfilling the needs of many of the more developed nations. Although considerable effort is being made to minimize the release of the increasing amounts of radioactive wastes into the marine environment, it is evident that the potential for radioactive contamination will continue to grow. In addition, nuclear weapons testing in recent years has added to the contamination of the marine environment through fallout which has taken place on a global scale. Although fallout levels are lower than in previous years, the recent resumption of such tests clearly indicates the need for continued surveillance of fallout radionuclides in all constituents of the marine environment so as to be more able to evaluate the potential hazards to man and to the biological components of the marine ecosystem.

A previous IAEA symposium on the Disposal of Radioactive Wastes into Seas, Oceans and Surface Waters, held in Vienna in 1966, covered much of what was then known concerning the disposal of radioactive wastes into aquatic ecosystems. One conclusion drawn from that symposium as well as subsequent IAEA panels on marine radioactivity studies was that a better understanding of the consequences of artificial radionuclide contamination could be gained through knowledge of the interaction of radionuclides and their stable isotopes, particularly as pertains to the different physico-chemical forms and their behaviour in relation to organic substances, sediments, and marine biota. Accordingly, the Agency convened a Symposium on the Interaction of Radioactive Contaminants with Constituents in the Marine Environment in Seattle, Washington, USA, on 10 - 14 July 1972. The meeting covered four main topics: physical and chemical forms of radioactive contaminants in the marine environment; interaction of radionuclides with marine biota; evaluation of hazards to the health and safety of man; and study of radiologically labelled environments. The 48 papers comprising these Proceedings give results of recent research on many aspects of the topics mentioned and should serve as a guide not only for those interested in marine radioactivity studies but also in the whole subject of oceanography.

The Agency would like to express its appreciation to the United States authorities who did so much to make the symposium a success.

## EDITORIAL NOTE

*The papers and discussions incorporated in the proceedings published by the International Atomic Energy Agency are edited by the Agency's editorial staff to the extent considered necessary for the reader's assistance. The views expressed and the general style adopted remain, however, the responsibility of the named authors or participants.*

*For the sake of speed of publication the present Proceedings have been printed by composition typing and photo-offset lithography. Within the limitations imposed by this method, every effort has been made to maintain a high editorial standard; in particular, the units and symbols employed are to the fullest practicable extent those standardized or recommended by the competent international scientific bodies.*

*The affiliations of authors are those given at the time of nomination.*

*The use in these Proceedings of particular designations of countries or territories does not imply any judgement by the Agency as to the legal status of such countries or territories, of their authorities and institutions or of the delimitation of their boundaries.*

*The mention of specific companies or of their products or brand-names does not imply any endorsement or recommendation on the part of the International Atomic Energy Agency.*

## CONTENTS

### PHYSICAL AND CHEMICAL FORMS OF RADIOACTIVE CONTAMINANTS IN THE MARINE ENVIRONMENT (Sessions I, II and III, Part 1)

Intercalibration of methods for measuring fission products in seawater samples (IAEA-SM-158/1) .....	3
R. Fukai, S. Ballestra, C.N. Murray	
Discussion .....	26
Incomplete exchange reaction between radioactive ionic zinc and stable natural zinc in seawater (IAEA-SM-158/2) .....	29
A. Piro, M. Bernhard, M. Branica, M. Verzi	
Discussion .....	45
The physico-chemical behaviour of radioactive cerium in seawater (IAEA-SM-158/3) .....	47
S. Hirano, T. Koyanagi, M. Saiki	
Discussion .....	54
Specific activity of radionuclides sorbed by marine sediments in relation to the stable element composition (IAEA-SM-158/4) ...	57
E.K. Duursma	
Discussion .....	71
Sorption-desorption reactions of mercury with suspended matter in the Columbia River (IAEA-SM-158/5) .....	73
M.H. Bothner, R. Carpenter	
Discussion .....	86
Distribution patterns for some particulate and dissolved trace metals within an active glacial fjord (IAEA-SM-158/6) .....	89
D.C. Burrell	
Adsorption-desorption equilibria of some radionuclides in sediment-fresh-water and sediment-seawater systems (IAEA-SM-158/7) .....	105
C.N. Murray, L. Murray	
Discussion .....	122
Effects of ocean water on the soluble-suspended distribution of Columbia River radionuclides (IAEA-SM-158/8) .....	125
D.W. Evans, N.H. Cutshall	
Discussion .....	139
Transport and depletion of radionuclides in the Columbia River (IAEA-SM-158/9) .....	141
D.E. Robertson, W.B. Silker, J.C. Langford, M.R. Petersen, R.W. Perkins	
Discussion .....	155
The flux of Mn, Fe and Zn in an estuarine ecosystem (IAEA-SM-158/10) .....	159
D.A. Wolfe, F.A. Cross, C.D. Jennings	
Discussion .....	175

Behaviour and distribution of radioactive substances in coastal and estuarine waters (IAEA-SM-158/11) .....	177
Y. Nishiwaki, Y. Honda, Y. Kimura, H. Morishima, T. Koga, Y. Miyaguchi, H. Kawai	
Discussion .....	192
Transport of radionuclides in lake and river systems flowing through areas characterized by precambrian bedrock and peat-bogs (IAEA-SM-158/12) .....	195
Anneli Salo, A. Voipio	
Physico-chemical characteristics of five ruthenium salts during fresh-water to marine transition (IAEA-SM-158/52) .....	219
H. Peperstraete, J. Vos, S. Van Puymbroeck, O. Vanderborcht	
Discussion .....	222

# INTERACTION OF RADIONUCLIDES WITH MARINE BIOTA (Session III, Part 2, and Sessions IV, V and VI)

Aspects biologiques et physico-chimiques de la contamination radioactive d'espèces et de sédiments marins (IAEA-SM-158/19) .	225
J. Ancellin, M. Avarguès, P. Bovard, P. Guéguéniat, A. Vilquin	
Discussion .....	242
Radioecology of benthic fishes off Oregon (IAEA-SM-158/14) .....	245
W.G. Percy, H.A. Vanderploeg	
Discussion .....	260
Retention of fall-out constituents in upper layers of the Pacific Ocean as estimated from studies of a tuna population (IAEA-SM-158/15) .....	263
V.F. Hodge, T.R. Folsom, D.R. Young	
Discussion .....	275
Decline of <sup>65</sup> Zn in marine mussels following the shutdown of Hanford reactors (IAEA-SM-158/16) .....	277
A.H. Seymour, V.A. Nelson	
Discussion .....	285
Zinc-65 specific activities from Oregon and Washington continental shelf sediments and benthic invertebrate fauna (IAEA-SM-158/17) .....	287
A.G. Carey, Jr., N.H. Cutshall	
Discussion .....	304
Radioecology of certain molluscs in Indian coastal waters (IAEA-SM-158/13) .....	307
B. Patel, P.G. Valanju, C.D. Mulay, M.C. Balani, S. Patel	
Discussion .....	329
Fallout <sup>54</sup> Mn accumulated by bay scallops <u>Argopecten irradians</u> (Lamarck) near Beaufort, North Carolina (IAEA-SM-158/20) ....	331
Claire L. Schelske	
Discussion .....	345



Incorporación de radioestroncio por organismos marinos (IAEA-SM-158/21) .....	347
D. Cancio, J.A. Llauro, N.R. Ciallella, D.J. Beninson	
Discussion .....	357
Chemical behaviour of $^{106}\text{Ru}$ in seawater and uptake by marine organisms (IAEA-SM-158/22) .....	359
M. Ishikawa, M. Sumiya, M. Saiki	
Discussion .....	367
The state of cobalt in seawater and its uptake by marine organisms and sediments (IAEA-SM-158/23) .....	369
F.G. Lowman, R.Y. Ting	
Discussion .....	383
Uptake and loss of $^{65}\text{Zn}$ and $^{60}\text{Co}$ by the mussel <u>Mytilus edulis</u> L. (IAEA-SM-158/24) .....	385
A.W. Van Weers	
Discussion .....	400
The kinetics of and a preliminary model for the uptake of radio-zinc by <u>Phaeodactylum tricornutum</u> in culture (IAEA-SM-158/25) .....	403
A.G. Davies	
Discussion .....	419
The roles of food and water in the accumulation of radionuclides by marine teleost and elasmobranch fish (IAEA-SM-158/26) .....	421
R.J. Pentreath	
Discussion .....	435
Flux of zinc through a macroplanktonic crustacean (IAEA-SM-158/27) .....	437
L.F. Small, S.W. Fowler, S. Kečkeš	
Discussion .....	452
Accumulation and loss of cobalt and caesium by the marine clam, <u>Mya arenaria</u> , under laboratory and field conditions (IAEA-SM-158/28) .....	453
Florence L. Harrison	
Discussion .....	478
Effects on fecundity and fertility of single sub-lethal X-irradiation of <u>Gammarus duebeni</u> females (IAEA-SM-158/29) .....	479
M. Hoppenheit	
Discussion .....	486
Effect of ionizing radiations on haemoglobin of a tubificid worm <u>Tubifex</u> sp. (IAEA-SM-158/30) .....	487
S. Patel, B. Patel	
Discussion .....	497
Levels of radioactivity in the marine environment and the dose commitment to marine organisms (IAEA-SM-158/31) .....	499
D.S. Woodhead	
Discussion .....	524
Effets biologiques et biochimiques des rayonnements gamma sur l'algue marine <u>Acetabularia mediterranea</u> (IAEA-SM-158/32) ....	527
R.J. Kirchmann, S. Bonotto	
Discussion .....	541

Suppression of <i>Chondrococcus columnaris</i> immune response in rainbow trout sub-lethally exposed to tritiated water during embryogenesis (IAEA-SM-158/33) .....	543
J.A. Strand, M.P. Fujihara, W.L. Templeton, E.G. Tangen .....	
Discussion .....	549
Effects of continuous low-level gamma radiation on sessile marine invertebrates (IAEA-SM-158/34) .....	551
R.B. Williams, Marianne B. Murdoch .....	
Discussion .....	562
The differential sensitivity of various species of salt marsh epiphytic algae to ionizing radiation and thermal stress (IAEA-SM-158/35) .....	565
N.M. Saks, J.J. Lee .....	
Discussion .....	570

## EVALUATION OF HAZARDS TO THE HEALTH AND SAFETY OF MAN (Session VII)

Evaluation of public radiation exposure from the controlled marine disposal of radioactive waste (with special reference to the United Kingdom) (IAEA-SM-158/36) .....	575
A. Preston, N.T. Mitchell .....	
Discussion .....	591
Radionuclide transport studies in the Humboldt Bay marine environment (IAEA-SM-158/37) .....	595
R.E. Heft, W.A. Phillips, H.R. Ralston, W.A. Steele .....	
Discussion .....	613
Accumulation of certain trace elements in marine organisms from the sea around the Cape of Good Hope (IAEA-SM-158/39) .....	615
D. Van As, H.O. Fourie, Constance M. Vleggaar .....	
Discussion .....	623
Contributions from the alpha emitter, polonium-210, to the natural radiation environment of the marine organisms (IAEA-SM-158/41) .....	625
T.R. Folsom, T.M. Beasley .....	
Discussion .....	632
Mussels and barnacles as indicators of the variation of <sup>54</sup> Mn, <sup>60</sup> Co and <sup>65</sup> Zn in the marine environment (IAEA-SM-158/42) .....	633
D.R. Young, T.R. Folsom .....	
Discussion .....	649
Concentrations of <sup>65</sup> Zn in marine foodstuffs and Pacific coastal residents (IAEA-SM-158/43) .....	651
T.H. Essig, G.W.R. Endres, J.K. Soldat, J.F. Honstead .....	

## THE STUDY OF RADIOLOGICALLY LABELLED ENVIRONMENTS (Session VIII)

Concentrations and distributions of long-lived fallout radionuclides in open ocean sediments (IAEA-SM-158/45) .....	671
V.E. Noshkin, V.T. Bowen .....	
Discussion .....	686



Oceanic distributions and relationships of $^7\text{Be}$ and fission products (IAEA-SM-158/46) .....	687
W.B. Silker, J.A. Young, M.R. Petersen .....	
Discussion .....	699
Natural $^{210}\text{Pb}$ and $^{210}\text{Po}$ in a marine environment (IAEA-SM-158/47). W.R. Schell, T. Jokela, R. Eagle .....	701
Discussion .....	723
The geochemistry of radiocarbon in the Gulf of Mexico (IAEA-SM-158/48) .....	725
T.D. Mathews, A.D. Fredericks, W.M. Sackett .....	
Distributions of radionuclides in reef corals: opportunity for data retrieval and study of effects (IAEA-SM-158/49) .....	735
D.W. Knutson, R.W. Buddemeier .....	
Discussion .....	745
Anomalous $^{228}\text{Th}/^{232}\text{Th}$ and $^{230}\text{Th}/^{232}\text{Th}$ activity ratios in backwater sediments along the west coast of India (IAEA-SM-158/50) .....	747
L.U. Joshi, A.K. Ganguly .....	
A revaluation of the marine geochemistry of uranium (IAEA-SM-158/51) .....	757
W.M. Sackett, T. Mo, R.F. Spalding, M.E. Exner .....	
Discussion .....	769
Chairmen of Sessions and Secretariat of the Symposium .....	771
List of Participants .....	773
Author Index .....	783
Index of Preprint Symbols .....	785

**PHYSICAL AND CHEMICAL FORMS OF RADIOACTIVE  
CONTAMINANTS IN THE MARINE ENVIRONMENT**

**(Sessions I and II, and Session III, Part 1)**

### Chairmen

**Session I**

**W. R. SCHELL (United States of America)**

**Session II**

**M. BERNHARD (Italy)**

**Session III**

**B. PATEL (India)**

# INTERCALIBRATION OF METHODS FOR MEASURING FISSION PRODUCTS IN SEAWATER SAMPLES

R. FUKAI, S. BALLESTRA, C. N. MURRAY

International Laboratory of Marine Radioactivity, IAEA,  
Principality of Monaco

## Abstract

INTERCALIBRATION OF METHODS FOR MEASURING FISSION PRODUCTS IN SEAWATER SAMPLES.

To examine the present-day comparability of fission product measurements on seawater samples with the aim of achieving better comparability in the future, an intercalibration exercise was organized by the Monaco Laboratory in 1970-71; two kinds of homogeneous seawater samples contaminated with various radionuclides under natural conditions at monitoring levels were distributed to laboratories around the world - 46 laboratories reported the results of measurements on fission products in these samples. In this paper a survey made on the reported results is presented together with the results of homogeneity tests of the samples. The "preferred values" for strontium-90, ruthenium-106, caesium-134 and caesium-137 are estimated for these samples by statistical treatments of the obtained results. The scatter of the results is less pronounced for strontium-90 and caesium-137 than for zirconium-niobium-95, ruthenium-106, caesium-134 and cerium-144. For ruthenium-106 in the higher level sample, the results are especially noteworthy, being spread over almost two orders of magnitude. This seems to relate to the incapability of some methods to measure different chemical forms of this radionuclide occurring in seawater. Specific observations made on the results for each radionuclide as well as general remarks on the reported results are also given.

## 1. INTRODUCTION

In recent years considerable progress has been made in improving techniques for measuring radioactivity in marine organisms and their environment. This has been due in particular to the increasing requirements for monitoring the surroundings of nuclear installations and also to the expansion of research coverage in marine radioactivity. Recent developments of analysis methods for several radionuclides have been reviewed by a group of experts at an IAEA panel, which presented a series of reference methods for measuring radionuclides of strontium, caesium, cerium, cobalt and zinc as well as their stable counterparts occurring in the marine environments [1]. Although these methods have been widely applied to marine radioactivity studies, it was also noted that the results obtained for specific elements by different laboratories were not always comparable owing to the use of different experimental techniques. In some instances, this has even led to conflicting conclusions being drawn (e. g. Ref. [2]). As the results of radionuclide measurements are the basis of any radioecological studies, it is especially important to ensure the comparability of results obtained by different laboratories from various countries in environmental studies of international interest: the sea.

To achieve the comparability of results of measurements by different laboratories several approaches can be made. One is to adopt a unified method for measurements of a specific element and to recommend its use in all laboratories concerned. The effectiveness of this approach has

been demonstrated by the well-known example of chlorinity determination in the oceanographic research; the argentometric titration method established by Knudsen in 1902 [3] had been used everywhere until replaced by conductometric measurements in the 1960s. This standardization of the method had a tremendous impact on the developments of physical oceanography as a whole.

In marine radioactivity studies as in many other research fields, however, it is generally not advisable to recommend one method as the only standard procedure since the speed of development of modern technology is so rapid that widespread acceptance of a single method is unlikely before new and perhaps better techniques appear. In this case the necessary assurance of the comparability of measurement results can only be provided by group intercalibration analyses of aliquots of homogeneous samples or by analyses of standard reference material. In the latter, certified values of compositions concerned must be given and these values should be determined by several independent methods of analysis.

Based on these considerations, an intercalibration exercise of methods for measuring fission product radionuclides<sup>1</sup> in seawater samples was organized by the Monaco Laboratory in 1970-71. The main object of this exercise was to examine present-day comparability of fission product measurements on seawater samples to achieve improved comparability in the future. This paper is a survey of the results reported by laboratories participating in the intercalibration exercise. The results of homogeneity tests of seawater samples distributed are also discussed in detail.

It should be emphasized that the contents of this paper are a result of the joint efforts of a number of participating national institutions as well as the IAEA laboratories, and represent a good example of voluntary international collaboration towards achieving a common scientific goal.

## 2. COLLECTION AND PREPARATION OF SEAWATER SAMPLES

Since there are still considerable uncertainties about the chemical forms in which radionuclides occur in seawater in situ, the preparation of spiked seawater samples with known amounts of radionuclides for intercalibration was purposely avoided; any practical analytical method should be capable of measuring not only radionuclides in known chemical forms in synthesized samples, but also in samples taken in a monitoring program.

The field collections of two kinds of seawater which were expected to be contaminated in nature with various radionuclides at monitoring levels, were made by the British Fisheries Radiobiological Laboratory, Lowestoft, with IAEA financial support. For each collection 1000 litres of seawater were taken on board and stored in a plastic tank, filtered through membrane filters of 0.45  $\mu\text{m}$  pore size, homogenized thoroughly, acidified to pH 1.5 ~ 2 with hydrochloric acid and sub-sampled into 200 5-litre polyethylene containers. Since no special precaution was taken against contamination with trace metals, these seawater samples

---

<sup>1</sup> Although strictly speaking caesium-134 is not a fission product, it was treated similarly to the fission products presented in this paper.

should not be considered as representative of natural levels of stable trace elements. The 5-litre bottles were transported by rail from England to Monaco. The seawater collected in November 1969 and January 1970 was code-numbered as SW-I-1 and SW-I-2, respectively. Each 5-litre bottle was arbitrarily numbered at Monaco.

### 3. HOMOGENEITY OF THE SAMPLES

To examine the homogeneity of the samples several 5-litre containers were picked at random from the batches and the seawater in each container was independently analysed for several radionuclides at the Monaco Laboratory (Monaco) and Woods Hole Oceanographic Institution (WHOI). The results of these analyses are given in Tables I and II, respectively for SW-I-1 and SW-I-2.

In Table III the results of analyses of Mediterranean water spiked with known amounts of radionuclides, such as strontium-90, ruthenium-106, caesium-134 and caesium-137, are also presented. These analyses were performed at Monaco in order to estimate the variations in the analytical results which are inherent to the methods used. The methods adopted were those described by Bowen [4] for strontium-90, by Yamagata and Iwashima [5] for ruthenium-106, and by Fukai et al. [6] for caesium-134 and caesium-137. On the basis of these analytical data standard deviations for single determination of each radionuclide were computed, as given also in Table III; these values are between  $\pm 3$  and 4% of the averaged values of the spiked samples for strontium-90 and caesium-137, slightly greater for ruthenium-106 in different chemical forms, and much greater for caesium-134. Since caesium-134 and caesium-137 had been added into the same water sample in a similar chemical form and were analysed simultaneously by chemical separation and  $\gamma$ -spectrometry, the greater standard deviation for caesium-134 analysis should be caused only by the procedure of data processing. The greater variations of the data for ruthenium-106 are probably due to uncertainty involved in the chemical recovery of this isotope in the adopted procedure. These values of standard deviation offer certain measures of aid for the evaluation of the homogeneity data.

For the evaluation of the homogeneity of the water samples information on the stability of radionuclides in solution is also useful. The studies carried out by the British Fisheries Radiobiological Laboratory (Preston and Dutton [7]; unpublished data) using seawater sample SW-I-2, showed that the stability of the fission products concerned, with the exception of cerium-144, was good even after more than 200 days storage. In the case of cerium-144 a considerable fraction was attached to the wall of the polyethylene containers, even when the pH-value of the water samples was kept between 1.5 and 2. On the basis of this information it is quite likely that, if the content of one bottle is inhomogeneous in relation to that in other bottles, the inhomogeneity identified by the analysis of one radionuclide of strontium-90, ruthenium-106, caesium-134 or caesium-137, should reflect, to a similar degree, the inhomogeneity of the other three radionuclides. This implies that inhomogeneity of the contents of the bottles should be detected by examining systematic deviations from averaged values of sets of data on the above-mentioned radionuclides.

TABLE I. RESULTS OF THE HOMOGENEITY TESTS ON SW-I-1 CARRIED OUT BY MONACO LABORATORY (MONACO) AND WOODS HOLE OCEANOGRAPHIC INSTITUTION (WHOI)

Laboratory	Bottle No.	Quantities found (pCi/kg)			
		<sup>90</sup> Sr	<sup>106</sup> Ru	<sup>134</sup> Cs	<sup>137</sup> Cs
MONACO	1	5.0	-	2.5	12.5
	2	4.8	-	2.3	12.7
	3	5.3	-	2.7	12.4
	4	5.2	-	2.4	12.8
	5	5.1	-	2.5	13.2
	6	5.3	-	2.5	12.9
	7	5.4	-	2.5	12.9
	8	5.3	2.9	2.2	13.4
	9	4.8	3.5	2.9	13.2
	10	5.4	2.8	-	-
	Average	5.2	3.0	2.5	12.9
	σ (single det.)	± 0.2 (3.8%)	± 0.4 (13%)	± 0.2 (8.0%)	± 0.3 (2.3%)
	Chauvenet's range	± 0.4 (7.7%)	± 0.6 (20%)	± 0.4 (16%)	± 0.6 (4.6%)
WHOI	21	4.64	-	0.88	14.1
	22	5.35	-	1.26	13.7
	23	4.59	-	1.59	13.6
	24	4.82	-	1.42	13.6
	Average	4.85	-	1.29	13.8
	σ (single det.)	± 0.35 (7.2%)	-	± 0.30 (23%)	± 0.2 (1.4%)
	Chauvenet's range	± 0.54 (11%)	-	± 0.57 (44%)	± 0.3 (2.2%)

With the foregoing discussions in mind the data in Tables I and II were evaluated. For SW-I-1 (Table I) the standard deviations for a single determination estimated on strontium-90 and caesium-137 data are  $\pm 3.8\%$  and  $\pm 2.3\%$ , respectively, of the averaged values by Monaco, and  $\pm 7.2\%$  and  $\pm 1.4\%$ , respectively, by WHOI; standard deviations for the results on ruthenium-106 and caesium-134 are much greater than those for strontium-90 and caesium-137, as may be predicted from the data in Table III. After being tested by Chauvenet's criterion [8, 9], no results



TABLE II. RESULTS OF THE HOMOGENEITY TESTS ON SW-I-2 CARRIED OUT BY MONACO LABORATORY (MONACO) AND WOODS HOLE OCEANOGRAPHIC INSTITUTION (WHOI)

Laboratory	Bottle No.	Quantities found (pCi/kg)			
		<sup>90</sup> Sr	<sup>106</sup> Ru	<sup>134</sup> Cs	<sup>137</sup> Cs
MONACO	5	54.8	-	-	-
	6	54.0	-	-	-
	7	53.6	34.0	23.1	184
	8	52.6	30.3	26.1	179 <sup>a</sup>
	9	52.4	-	22.8	183
	10	53.8	-	26.8	187
	97	52.7	28.2	24.6	188
	101	53.9	36.0	24.8	190
	102	53.6	32.2	33.4	186
	103	54.8	34.3	30.2	185
	Average	53.6	31.7	29.4	185
	$\sigma$ (single det.)	$\pm 0.8$ (1.5%)	$\pm 2.8$ (8.8%)	$\pm 4.8$ (16%)	$\pm 3$ (1.6%)
	Chauvenet's range	$\pm 1.6$ (3.0%)	$\pm 4.8$ (15%)	$\pm 8.9$ (30%)	$\pm 6$ (3.2%)
WHOI	21	51.8	-	25.1	200
	22	52.2	-	23.7	198
	23	50.9	-	23.4	194
	24	52.2	-	22.5	197
	25	50.0	-	15.8	170*
	26	59.9*	-	28.2	196
	27	52.7	-	30.1	182
	28	53.6	-	20.7	195
	Average	52.9	-	23.7	192
	$\sigma$ (single det.)	$\pm 3.0$ (5.7%)	-	$\pm 4.4$ (19%)	$\pm 10$ (5.2%)
	Chauvenet's range	$\pm 5.6$ (11%)	-	$\pm 8.2$ (35%)	$\pm 19$ (9.9%)

<sup>a</sup> The values which should be excluded according to Chauvenet's criterion.

TABLE III. RESULTS OF ANALYSES ON MEDITERRANEAN WATER SPIKED WITH RADIONUCLIDES (PERFORMED BY MONACO LABORATORY)

Radionuclide	<sup>90</sup> Sr	<sup>106</sup> Ru		<sup>134</sup> Cs	<sup>137</sup> Cs
		CL-form <sup>a</sup>	NN-form <sup>b</sup>		
Source of supply	IAEA	Amersham (UK)	Amersham (UK)	CEA (France)	CEA (France)
Quantity spiked (pCi/l)	46.7	103	103	99	109
Quantity found (pCi/l)	46.7	97	101	95	109
	48.2	103	101	113	112
	47.7	108	98	104	104
	44.3	110	110	105	113
	46.0	104	107	101	111
Average (pCi/l)	46.6	104	103	104	110
σ (single det.)	±1.4 (3.0%)	±5 (4.8%)	±5 (4.9%)	±7 (6.7%)	±4 (3.6%)
Chauvenet's range (pCi/l)	±2.3 (4.9%)	±8 (7.7%)	±8 (7.8%)	±12 (12%)	±7 (6.4%)

<sup>a</sup> Chloride complex forms.

<sup>b</sup> Nitrate-nitrosyl complex forms.

from Table I should be excluded. Considering that the radionuclides in solution other than cerium-144 are similarly stable to each other and that the best reproducibility of series of analytical results obtained for one radionuclide among various radionuclides analysed should thus be a measure of the sample homogeneity, it can be said that in terms of per cent standard deviation of the content of the radionuclide concerned (excluding cerium-144) the homogeneity should be better than ±3% for SW-I-1. This value is based on the caesium-137 data.

For SW-I-2 (Table II) standard deviations estimated for strontium-90 and caesium-137 data are respectively ±1.5% and ±1.6% of the averaged values by Monaco, and ±5.7% and ±5.2% by WHOI; those for ruthenium-106 and caesium-134 are much greater, as is the case of SW-I-1. In the case of SW-I-2, however, the results marked by an asterisk (\*) should be discarded according to Chauvenet's criterion. This means that those samples where the results are marked by (\*) should be suspected for occurrence of the sample inhomogeneity. The inspection of the sets of data for the various radionuclides in these specific samples excludes the possibility of occurrence of sample inhomogeneity, except for the