제 1 차년도
연차보고서

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동해핵폐기물 조사

(러시아 핵폐기물 동해 투기에 따른 방사능 오염 조사)

(Active Watch on the Artificial Radionuclides in the East Sea)

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提出文

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노정래

要 約 文

I. 題 目

동해핵폐기물 조사

(러시아 핵폐기물 동해 투기에 따른 방사능 오염조사)

II. 硏究開發의 目的 및 必要性

연구개발의 최종 연구 목적은 구쏘련 및 러시아의 아국 국익 해역에 투기한 핵폐기물에 의한 해양환경 및 생태계 방사능 오염 영향 평가이며 제 1 차년도 (당해년도) 에는 동해 북부 러시아 투기 해역, 제 2 차년도에는 러시아 투기 해역인 오호츠크, 캄챠카, 태평양 해역, 동경남방의 일본 투기 해역, 아국의 동해 울릉도 부근 저준위 고체 핵폐기물 투기해역을 대상으로 이해당사국인 한국 · 일본 · 러시아와의 3국 공동조사를 실시하고 국제원자력기구 해양환경연구소가 제 3 자의 입장에서 조사에 참여하여 자료의 객관성을 보장받고, 러시아 핵폐기물 해양 투기 행위를 중지하도록 국제적인 정치기반을 조성하는데 또다른 목적이 있다.

III. 硏究開發의 內容 및 範圍

1. 3국 공동조사

러시아 투기 핵폐기물 투기 실해역 조사가 한국 · 일본 · 러시아 3국 공동조사로 1994년 3월 18일부터 1994년 4월 6일까지 동해북부 러시아 투기 해역중 북한 인접 제 10해역을 제외한 러시아 투기 지정 해역 제 1,

해저퇴적물, 해양생물의 주요인공 방사능 핵종 함량 (^{137}Cs, ^{90}Sr, ^{238}Pu, $^{239,\ 240}$Pu)을 조사하였다. 고체 폐기물 투기 해역인 제 9 해역에서는 해수 채취를 수심별로 채취하여 동해북부해역의 해수중 방사성 핵종 총량을 파악하였다.

2. 구쏘련 및 러시아 핵폐기물 해양투기의 실체파악
구쏘련 및 러시아 방사성 폐기물 해양 투기 은폐 사실, 핵폐기물 처리 방법 및 현황, 방사성 폐기물의 특성, 러시아 극동함대 핵폐기물 관련기지 현황, 극동해역 투기현황, 전세계 해역별 주요 인공 방사성 핵종 오염 현황을 개관함.

3. 동해북부 핵폐기물 투기 해역과 동해남부 우리나라 연근 해역의 인공 방사성 핵종 오염현황을 비교하기 위하여 동해 표층수의 ^{137}Cs 과 $^{239,\ 240}$Pu 핵종 농도 분포를 조사하고 그 분포 경향을 규명함.

4. 동해 어류 등 수산자원에 미치는 인공 방사능 오염 평가의 기초자료로서 동물플랑크톤에 함유된 $^{239,\ 240}$Pu 의 분포 특성을 조사함.

5. 해양환경에 존재하는 방사성 핵종은 대부분 대기중 핵무기 실험에 의한 것으로서 대기를 통하여 한반도 지표면에 공급되는 방사성 핵종 ^{137}Cs 과 ^{210}Pb 연구를 통하여 인공방사능 수지 평가 기초 자료를 제공함.

6. 러시아 블라디보스톡 주변 연안 퇴적물의 인공 방사능 핵종 함량 분석을 통하여 러시아 극동 해군 핵폐기물 처리 현황을 감시함.

Ⅳ. 硏究開發의 結果 및 活用에 대한 建議

1. 한 · 일 · 러 3국 공동조사

· 선상간이조사

선상간이 방사능 측정은 감마방출핵종에 한하여 실시되었으며 해수중 용존상태의 ^{137}Cs 은 흡착제로 농축시키고 해저퇴적물은 건조, 어류와 새우는 머리와 근육부분으로 나누어서 감마 스펙트로미터로 ^{137}Cs 등 감마 핵종을 정량분석하였다. 또한 감마검출기를 직접 표층수, 또는 수심 200 m 까지 투하하여 현장 감마 방출 핵종 분석도 실시하였다. 선상간이 측정결과 표층해수의 용존 ^{137}Cs 은 3~5 mBq·kg^{-1} 이고 표층퇴적물의 ^{137}Cs 농도는 3 mBq·kg^{-1} 이하이었다.

· 육상 실험실 정밀조사

조사지점의 표층수 및 해저인접수층의 ^{137}Cs, ^{90}Sr 과 ^{239,240}Pu 농도는 각각 2.6～3.3 와 0.5～1.6 mBq·kg^{-1}, 1.1～2.5 와 0.4～1.4 mBq·kg^{-1}, 7 ～26 와 15～29 μBq·kg^{-1} 이다. 각 핵종별 수직 분포 형태는 ^{137}Cs 과 ^{90}Sr 은 표층에서 최대값, 해저인접수층에서 최소값을 가지며 수심의 증가에 따라서 그 농도는 감소한다. 그러나 ^{239,240}Pu 은 수심 750 m 에서 극대값 (40 μBq·kg^{-1}) 을 갖는 수직 분포 형태로서 이는 일반적인 북태평양에서의 농도분포형태와 일치한다.

해저퇴적물은 그랩형채니기로 채취하여 표층퇴적물과 저층퇴적물이 상당부분 혼합되어서 ^{137}Cs, ^{90}Sr, ^{238}Pu, ^{239,240}Pu 함량이 매우 낮게 나타난다. 일반적으로 대륙사면에서 높고 심해저 평원에서 낮다. ^{137}Cs 은 1.4 이하～2.7 Bq·kg^{-1} , ^{90}Sr 은 0.2 이하～0.3 Bq·kg^{-1} , ^{239,240}Pu 은 11～856 mBq·kg^{-1} 이다. ^{238}Pu 은 2～3 mBq·kg^{-1} 이다. 이는 대체로 북서태평양 수준의 농도로서 구쏘련 및 러

시아 핵폐기물 투기에 의한 영향은 뚜렷하지 않다. 그러나 본 조사와 같은 개괄 조사로서는 러시아 핵폐기물의 투기 영향을 명확히 규명할 수 없을 것이다. 다만 정치적으로는 러시아가 핵폐기물 해양 투기를 재개하지 못하도록 하는 국제적인 압력행사라는 소기의 성과를 거둔 것으로 사료된다.

2. 동해 전체의 하계의 ^{137}Cs 농도는 3.1 ± 0.2 mBq·kg^{-1} 으로서 동해 전반에 결쳐서 매우 균일하다. 또한 $^{239,\ 240}$Pu 은 6~10 μBq·kg^{-1}이다. 동해표층수의 ^{137}Cs 과 $^{239,\ 240}$Pu 함량 결정요인은 대기를 통한 낙진과 황사 등 대륙 분진 유입과 해수 수직 혼합으로 사료된다.

3. 동해의 동물플랑크톤 중 $^{239,\ 240}$Pu 평균 함량은 약 0.4 Bq·kg^{-1} (건조무게)로서 Copepode 가 Euphausiide나 Hyperriide 보다 더 많이 함유하고 이는 북서태평양 동물플랑크톤의 Pu 함유량과 비슷하다.

4. 한반도 중부 지방 토양에 축적된 ^{137}Cs 은 311 mBq·cm^{-1} 로서 일본에서 1988년 이전까지 관측한 대기낙진량의 83 % 에 해당된다. 그리고 습식 및 건상 낙하 모두 5월과 10월에 높게 나타나서 대기 순환, 지화학적 추적자에 의하면 주로 중국대륙으로부터 기인하는 것으로 사료된다.

5. 블라디보스톡 부근 해역 방사능 조사 결과는 러시아 자체조사에서 챠즈마만에서는 ^{60}Co 이 16~66 Bq·kg^{-1}, 한국해양연구소 분석 결과는 아무르스키만에서 ^{137}Cs, $^{239,\ 240}$Pu, ^{90}Sr 은 각각 17, 1.15, 1.60 Bq·kg^{-1} 이다.

Summary

I. Tittle

Active Watch on the Artificial Radionuclides Contamination in the East Sea

II. Objectives and Significance

This work is aimed to estimate the impact of Russian sea disposal of nuclear wastes on the marine environment and marine ecosystem of the East Sea, because the Russian dumping activities in the past thirty years have not been reported through the proper international organization. This is a first stage of work to investigate the impact of Russian dumped radioactive wastes in the East Sea, Sea of Okhotsk, and Pacific Ocean off the Kamchatka Peninsula through the joint effort of Korea, Japan, and Russia. The second half of the work will be carried out during the year 1995. The Japanese dumping sites and Korean dumping sites will be also included in the second stage. The International Atomic Energy Agency has also took part in this work to guarantee the objectiveness of this governmental investigation. This trilateral governmental investigation will deter the Russian intention of dumping nuclear wastes in the East Sea and the Northwest Pacific Ocean.

In order to complement the limited sampling program of the trilateral governmental investigation, various ongoing sampling programs were utilized. In order to monitor the artificial radionuclide contamination in the sea effectively, the necessity of research is demonstrated here.

III. Contents and Scope

1. Korean-Japanese-Russian joint governmental expedition was carried out in the Russian nuclear waste disposal sites during the period of 18 March 1994 to 6 April 1994 of the northern part of the East Sea. Seven sampling stations were occupied in the Russian designated dumping areas of 1, 2, 5, 6, and 9 except 10 which is in the North Korean claimed zone. At all sampling stations, seawater, bottom sediment, and zooplankton samples were collected. Seawater samples were collected both in the surface and in the near bottom. Water samples at intermediate depths were also collected in the Russian designated dumping area of 9 where the largest amount of liquid and solid nuclear wastes had been disposed in the East Sea. All the samples were subject to determining the contents of ^{90}Sr, ^{137}Cs and ^{239,240}Pu.

2. Information on Russian practices on nuclear wastes handling in the harbor, sea disposal, nuclear material related accidents in the Russian Far Eastern Seas has been briefly reviewed.

3. In order to provide a perspective on estimation of the impact of Russian sea disposal of nuclear waste in the context of the whole East Sea, ^{137}Cs and ^{239,240}Pu activities in the surface waters were determined.

4. Artificial radionuclide contents in zooplankton were determined using the archive specimens collected from the East Sea.

5. Atmospheric input of artificial radionuclides on the surface soil in the middle of Korean Peninsula was estimated in order to provide an input function into the East Sea.

6. Bottom sediments of the Peter the Great Bay were available for determination of the artificial radionuclides contents.

IV. Results and Recommendation

1. Korean-Japanese-Russian trilateral governmental investigation

On board preliminary radiometric measurements were made on the ^{137}Cs adsorbents, bottom sediments (dried), fish and shrimp obtained by chance. In situ gamma spectrometric measurements were also made at the surface and 200 m depths. The dissolved ^{137}Cs contents in the surface waters are 3- 5 mBq kg^{-1} and ^{137}Cs contents of bottom sediments and biota are less than 3 Bq kg^{-1}.

A more comprehensive radiometric analysis were made in the laboratory. The dissolved ^{137}Cs, ^{90}Sr and ^{239,240}Pu contents in the surface and near bottom waters were 2.6-3.3 and 0.5-1.6 mBq kg^{-1}, 1.1-2.5 and 0.4-1.4 mBq kg^{-1}, 7-26 and 15-29 μBq kg^{-1}, respectively. Vertical profile of ^{137}Cs and ^{90}Sr shows a maximum at the surface and minimum at the near bottom, however, ^{239,240}Pu shows a subsurface peak (40 μBq kg^{-1})at ca. 750 m depth.

Since bottom sediments were collected using a grab sampler, interface between water and sediment were not preserved. Therefore, artificial radionuclides contents in the surface sediments are very low. In general, artificial radionuclides are more enriched in the slope areas than in the basin plain. Concentration ranges of ^{137}Cs, ^{90}Sr and ^{239,240}Pu are less than 1.4 to 2.7 Bq kg^{-1}, less than 0.2 to 0.3 Bq kg^{-1} and 11 to 856 mBq kg^{-1}, respectively. ^{238}Pu contents vary from 2 to 3 mBq kg^{-1}.

The values and depth distribution patterns of these artificial radionuclides are very similar to those of the Northwest Pacific. Therefore, it may be concluded that the impact of Russian disposal of nuclear wastes are not significant in the region, however, due to the limitation on the sampling program and access of the Russian designated area, it is still premature to estimate the environmental impact of the past thirty years of Russian radioactive waste dumping practice in the region.

2. Surface water samples were collected for determination of ^{137}Cs and ^{239,240}Pu contents during summer. The ^{137}Cs concentration in the surface waters are quite homogenous in the entire East Sea (3.1±0.2 mBq kg^{-1}). $^{239, 240}$ Pu concentrations are 6-10 μBq kg^{-1}. Surface water concentrations of ^{137}Cs and ^{239,240}Pu are appeared to be controlled by the atmospheric input through direct fallout and the soil dust input from the adjacent lands including the Yellow Dust and vertical mixing of water during winter.

3. Contents of ^{239,240}Pu in the zooplanktons are about 0.4 Bq kg^{-1}, which are similar to those in the North Pacific Ocean. Copepods appears to enrich more ^{239,240}Pu than Euphausiide and Hyperiide in the East Sea.

4. In the middle of the Korean Peninsula, a significant amount of wet deposition of ^{137}Cs were observed in May (5-12 mBq m^{-2} d^{-1})and significant amount of dry deposition of 137Cs were observed in May (4.0 Bq kg^{-1}) and October (3 Bq kg^{-1}) when the Yellow Dust prevails and the continental air mass prevails the Korean Peninsula, respectively. The total deposition of ^{137}Cs in soil is 311 mBq cm^{-2}.

5. Coastal sediments in the Peter the Great Bay still shows a trace of Chazma Bay accident occurred in 1985.

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제 1 장 서론

동해, 오호츠크, 캄챠카 해역 러시아 핵폐기물 투기에 따른 우리나라 주변 및 국외 해역 방사능 오염

제 2 장 3국 공동조사보고서

CONTENTS

Chapter 1. Overview on the past practice and present status of the nuclear wastes handling of Former Soviet Union and Russia in the Russian Far Eastern Region and artificial radionuclides contamination in the world ocean.

Chapter 2. Korean-Japanese-Russian Joint governmental investigation in the Russian nuclear waste disposal sites in the northern part of the East Sea

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제 1 장 서 론

동해 · 오호츠크 · 캄차카 해역 러시아 핵폐기물 투기에 따른 우리나라 주변 및 국익 해역 방사능 오염

목 차

1. 서론

인공방사능 물질은 지금까지 알려진 오염물질 중 전세계 육지 및 해양 모두에 존재하는 유일한 물질이다. 따라서 모든 해양 오염 관련 문헌에 해양인공방사성 핵종의 분포가 수록되어 있다[1]. 1993년 3월 러시아연방영토 부근해역 핵폐기물 투기에 관한 러시아연방의 보고서(일명 야블로쿠프 보고서)가 발간되어 러시아가 공식적으로 과거 30여년간 미공개리에 러시아 영토 부근해역 주로 무르만스크의 카라해와 비렌트해 등지와 블라디보스톡 인근 해역인 동해와 오호츠크, 캄챠카 해역에 중·고준위방사성 폐기물을 투기한 사실을 자인하였다[2]. 이로 인하여 전세계는 물론이고 우리나라, 일

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1) 홍기훈, 1993, 핵개발에 따른 해양 환경 방사능 오염, 해양정책연구, 8:439-472.

2) 야블로코프 등, 1993, 러시아 연방 부근 해역 핵폐기물 해양 투기에 관한 진상 및 문제점, 1992. 10. 24. 러시아 연방 대통령령 613조에 의해 설치된 핵폐기물 해양투기에 관한 정부위원회 보고자료(번역, 홍기훈, 김석현, 정창수, 강동진, 한국해양연구소, 112p). 백서에는 러시아북부함대 핵폐기물 처리 및 투기 현황에 비하여 극동함대의 핵폐기물 처리 및 투기 현황은 정보의 부족으로 빈약하다.

러시아 백서가 1993년 출판된 이후 1995년 1월 러시아 극동 해군 핵폐기물 담당자가 기존 백서의 내용을 일부 수정하였다(Danilyan, N.A. and V.A. Vysastsky, 1995, Nuclear Waste disposal practices in Russia's Pacific Ocean Regin. 9p. Japan-Russia-United States Study Group in Dumped Nuclear Waste in the sea of Japan, Sea of Okhotsk and the North Pacific Ocean. Biloxi, MS, 12-13 January 1985, Center for International Security and Strategic Studies, University of Mississippi).

이 보고서의 저자들은 실제 94년 한·일·러 3국 공동 해양 조사에 참여하였다. 사안의 중요성을 감안하여 보고서의 주요내용을 발췌하여 싣는다.

1. 구소련은 핵폐기물은 주로 육상처리시설에서 처리후 저장하였음. 다만 핵선박과 핵고장수리 폐기물은 수거하여 연안및 해양에 투기함.
2. 핵폐기물투기장소의 선정기준
   - 액체와 고체폐기물은 지정된 장소에만 국한하여 투기함.
   - 움직일 수 없는 물체 (선박에서 사용된 세탁물, 수건 등)로부터 기인한 액체 저준위 폐기물은 해안으로부터 10-30해리 내해에 투기함. 그외 핵폐기물은 해안으로부터 50해리 바깥해역에 투기함.
   - 고체폐기물은 용기에 담아서 투기함. 다만, 큰구조물은 포장하지않고 그대로

투기함.

- 투기폐기물은 방사성핵종별량과 방사능량으로 규제되었다.
- 핵폐기물투기해역은 방사생물조사가 정기적으로 수행되었다.

3. 미해군의 경우 항구, 내만, 하구에 투기되는 핵폐기물은 0.2-6.0 큐리 (Ci)를 능가할 수 없고, 핵추진선박은 1-12해리 바깥에서는 1회에 1,000 Ci까지 허용되었고, 포장용기없이 500 Ci 까지 어장밖에서 투기하는 것이 허용되었다 (1959년 보고서).
4. 러해군은 허용치 (permissible genetic dose by nuclear wastes)의 1/25 이하로 제한하였으나 영국, 미국, 일본은 1/10 이하로 제한함.
5. 현재 러해군의 입장에서는 해양투기를 당분간 전혀 배제하기는 불가능하기 때문에 해양에서의 방사능조사영향을 최소화하면서 해양투기를 시행하는 방안을 강구중이다.
6. 구소련과 IAEA 기준에 의하여 동해, 오호츠크해, 캄챠카남동해안의 10곳이 투기해역으로 선정되었다.
7. 동해의 1, 2, 오호츠크해의 3, 캄챠카근해의 4 해역에서 투기는 전혀 행하여지지 않았다.
8. 과거 30년동안 고체폐기물투기는 동해의 6,9,10 해역과 캄챠카의 8해역에서만 행하여졌다. 총 누적 액체폐기물투기는 허용치의 7% (동해 9해역), 총누적 고체폐기물투기는 허용치의 5% (캄챠카반도 주변 8해역)에 지나지 않는다. 즉 허용치를 넘는 핵폐기물투기는 없었다.
9. 러해군에 의하여 투기된 저·중준위 방사성폐기물은 총 6,979 Ci (258 TBq) 이다. 이는 6,868개의 액체용기, 38척의 선박, 100개이상의 대형물체이다. 총액체폐기물은 12,298 Ci(455 TBq)이고 태평양에 투기된 총량은 19,265 Ci(714 TBq) 이다.
10. 러투기해역 10개중 캄챠카근해의 4해역을 제외하고 9개는 IAEA 와 런던협약 (LC)의 수심, 내해, 위도 등의 조건을 만족하지 않는다.
11. 러극동함대의 화학의학전문가그룹(Chemical and Medical Services specialists)은 해군중앙의학연구소 (Navy Central Medical Laboratory)와 국가수리기상위원회 (State Hydro-Meteorological Committee)와 합동으로 3-5년을 주기로 투기해역의 주요 인공방사능농도를 조사하였으나 바탕값을 넘지 않았다.

표. 1. 러 극동지역 해군투기해역특성

번호	해역	해안으로부터의 거리 (마일)	수심 (m)	사용연한 (년)	총액체폐기물투기량 (Ci)	년간액체폐기물허용량(Ci/yr)	총고체폐기물투기량 (Ci)	년간고체폐기물투기허용량 (Ci/yr)	* 93년러백서. 총액체투기량 (Ci)	* 93년러백서 총고체투기량 (Ci)
1	동해	90	3000-3400	불사용	-	-	-	-	1.5	-
2	동해	160	2800-3400	불사용	-	-	-	-	0.9	-
5	동해	25	1100-1500	62-93	117	500	-	-	117	-
6	동해	50	1900-3300	67-90	-	-	969	2000	489	869
9	동해	120	3300-3400	74-93	10840	5000	3234	2000	10840	2230
10	동해	120	2900-3300	74-84	536	1000	721	2000	536	721
3	오호츠크	160	1200-1300	불사용	-	-	-	-	0.1	-
4	캄챠카	160	4700-5300	불사용	-	-	-	-	0.2	-
7	캄챠카	20	1400-1500	62-92	361	500	-	-	352	-
8	캼챠카	25	2000-2600	69-92	-	-	2993	2000	-	3062

주 *: 참고항으로 삽입한 것임(원문에는 없음).

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12. 한국-일본-러시아 조사에서도 같은 결론에 도달함.

13. 장기간의 방사생태 조사결과 함정의 세탁물로부터 배출된 방사성폐기물은 환경에 해를 미치지 않음.

14. 그러나 1985년 샤즈마만에서의 핵사고로 인하여 샤즈마 (Chazma) 스테록(Strelok), 우수리스크(Ussuriysky)만의 해수및 해저퇴적물의 Co-60오염사고발생. Co-60 오염해역은 확대되지 않고 안정되어 있으며, 붕괴반감기와 퇴적물과정등을 고려하면 현 단계로서는 자연적으로 치유되도록 기다리는 방도를 취함.

15. 사할린섬 주변 오호츠크해에서 1987년 RTG (핵전지) 유실사고는 러해군에 의하여 발생함. 밀봉선원은 Sr-90 으로 350,000 Ci를 함유. 밀봉구조는 생물학적으로 안전하며, 극동함대가 행한 1987-1990년 조사에 의하면 오염은 없는 것으로 판단됨.

16. 최근의 극동함대의 핵폐기물투기는 동해의 제 9해역에서 1993년 10월 행하여짐. 투기는 러시아 자연부에서 허가함. 투기는 자연부와 해군전문가 감독하에 행하여짐. 약 0.38 Ci (^{137}Cs-76%, ^{60}Co-1.5%, ^{134}Cs-1.5%)가 투기됨.

17. 투기는 표층과 수심 2m에서 행하여 졌으며 30해리, 폭 200-400m 규모로 행하여짐. 투기후 10-20분에는 ^{137}Cs 이상치는 0.4-1.2 Bq/l 로서 러해군의 허용기준치를 초과하지 않았음.

18. 러극동해군 전문가의 난류확산 (turbulent diffusion)계산에 의하면 투기폐기물은 투기후 15-20시간이내에 바탕값으로 환원됨.

19. 위의 예와 마찬가지로 액체폐기물의 투기에 의한 부정적인 영향은 국지적이고 일시적이었음. 극동함대의 투기해역의 깊은 수심과 심층해류는 폐기물을 신속히 확산시키고, 그결과 해양생물에 해를 끼치거나 해저퇴적물에 축적되지도 않았음.

20. 해양 동식물에 대한 방사능오염은 고독성 고체 폐기물의 영향으로 발생할 수 있음. 그러나 심해에서 발생하는 경우 현재 인간활동에 영향을 미치지 않음. 그러나 이는 과학조사의 대상임.

21. 러극동함대는 1992년 이후 고체폐기물을 투기하지 않았음.

22. 러시아 수리기상센터가 1988-1994년 동안 조사한 자료에 의하면 극동해역의 방사능 오염은 주로 대기중 핵실험 낙진에 의한 것이며, 핵폐기물 투기에 의한 기여는 총 오염물질의 극히 일부에 지나지 않음.

23. 일본이 요구한 러시아의 핵폐기물 관련 국제법 준수는 긍정적 진보이나, 실제 이를 수행하는 데는 러시아 해군의 입장에서 어렵다.

24. 러시아가 약속한 태평양에서의 핵폐기물 투기의 중지는 러시아로부터 재정지원을 전혀 받지 못하였다.

25. 문제는 고체와 액체 폐기물 저장고의 부족, 적합한 처리공장, 수송수단, 방사능 감시기장비의 부족이다.

26. 러극동함대는 16,000 m^3 의 고체폐기물과 5,000 m^3 의 액체폐기물을 보유하고 있다. 이중 약 70-90%는 연해주에 있다. 함대운영계획을 보면 향후 10-15년 동안 약 2,000 m^3 의 액체폐기물과 5,000m^{3}의 고체 폐기물이 누적된다.

본 등 당사국의 러시아의 국제법 위반과 신의 상호존중원칙 위배에 대한 항의와 계획된 방사성폐기물의 해양투기 행위를 중지하여 줄 것을 요청하였다.

우리나라 정부는 4월 긴급 정부합동조사반을 편성하여 동해 해안 인근 해역의 방사능 오염현황을 조사하였다. 또한 정부는 5월에 제1차 한·러 회담을 통하여 동해상의 과거 구소련 및 러시아의 핵폐기물 투기현황을 객관적으로 입증할 한 ·일·러 3국간의 합동조사를 실시할 것을 제의하였고 러시아도 원칙적으로 수락하였다. 그러나 러시아 국내 경제 전반의 악화로 방사성 폐기물 저장 및 처리시설을 야블로코프 보고서에서 계획한 대로 마련하지 못하였고 1993년 10월 17일 러시아 해군이 0.38 Ci 의 방사성폐기물을 동해북부에 재투기하는 현장이 범세계적인 극우환경보호 단체인 그린

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27. 극동함대본부의 현재 저장시설에서 초과되는 분량을 감소시키려는 사업은 이 문제를 해결하는 데 불충분하다.

28. 동해에 핵폐기물을 투기하는 것을 중지하려는 임무는 핵폐기물을 처리할수 있는 "Pinega" 탱커 투입이 반년이나 연기되고 있기 때문에 수행하기가 어렵다. 일본이 이 탱커를 러측에 투입하는 사업은 1995년 말 이전에는 실현되기가 어려울 것이다.

29. 현재로서는 함대는 누적된 액체 폐기물을 액체염액상태 (liquid brine condition)으로 부피를 감소하는 방책을 시행하고 있다. 이러한 기술은 러 기술진 Exaton이 Sharya-04라는 두 가지 기술을 개발하여 461 m^3의 액체폐기물을 허용수준으로 정제하였다 (하나는 연해주, 다른하나는 캄챠카반도에 있음). 염액(brine)을 정제하는 기술은 매우 효과적 (시간당 0.5 m^3)이나 이는 오히려 고염의 고준위액체폐기물을 생성하게 된다.

30. 액체폐기물의 양이 막대하기 때문에 이처리 사업은 여전히 방대하다. 극동함대는 국제수준에 부합하기 위하여 핵폐기물의 저장, 이용, 처리 기술을 개발하여야 한다.

31. 위의 사업이 시행되기 전의 과도기에는 저준위 액체폐기물을 해양에 투기하는 수 밖에 없다. 방사능량은 해수에서 최대허용치가 될 것이다.

32. 극동함대기술센터로부터 십여 km에 위치한 동해의 특성은 야생동식물보호구역, 휴양지, 어로활동해역이다. 러시아 환경입법체계는 방사성폐기물을 포함한 모든 종류의 폐기물 투기에 관하여 매우 엄격하다.

33. 그러므로 극동함대 기술센터에서의 액체폐기물의 처리는 궁극적으로 원양 (open areas)에 저준위 액체폐기물을 투기하도록 요구할 것이다. 캄챠카의 경우도 마찬가지이다.

34. 따라서, 태평양에서의 저준위 핵폐기물의 투기에 관한 기준과, 관련 국가들을 만족시킬 수 있도록 생태계 변화를 조절하고 평가하고 예측하는 방법도 아울러 개발하는 것은 매우 중요하다.

피스에 의하여 포착됨으로서 투기 비디오 화면이 전세계에 방영되게 되었다. 이에 정부는 또한 긴급 정부합동조사반을 편성하여 투기해역 부근(투기해역은 러시아 경제수역임)에서 표층부터 저층까지의 각 수심별 해수, 해저퇴적물, 해양생물 시료를 채취하여 방사능오염정도를 파악하였다. 또한 정부는 러시아, 일본과 일련의 연쇄회담을 통하여 동해와 그외 극동해역의 핵폐기물 투기에 따른 방사능 오염 실태를 조사하기로 합의하였다. 3국 정부간 합동으로 1994년 3월 18일부터 4월 16일까지 동해북부 러시아 투기 해역조사를 시행하였다. 근대 문명의 설립 이후 동해 인접 국가인 우리나라, 일본, 러시아 3국이 정부간 차원에서 한가지 목적을 위하여 그것도 환경보전을 위하여 합의한 것은 이번이 최초이며 이는 외교사적으로도 의미를 가질 것이다.

또한 1993년 10월 17일 러시아 해군의 방사성 폐기물 해양 투기 재개는 런던 협약으로 더 널리 알려진 "폐기물 및 기타 물질의 투기에 의한 해양 오염 방지에 관한 협약" 의 1993년 11월에 열린 제 16차 당사국 회의가 협약 부속서 개정을 통해 지난 10여년간 논란이 되어 온 저준위 방사성 폐기물 투기를 전면 금지하기로 하는 결의를 유발시켰다. 이는 해양 환경 보전에 대한 국제 사회의 압력과 이에 따른 예방적 조치의 중요성을 반영하는 것으로 앞으로 해양으로 유입되는 모든 오염원으로부터의 규제가 더욱 엄격하게 다루어질 것을 예고하는 것이다. 우리나라도 1994년 2월에 런던협약에 가입하였다. 이는 리우회담으로 국내에서도 잘 알려진 유엔 환경과 발전 회의의 Agenda 21에서도 강조된 바와 같이 해양은 어느 특정 국가의 소유물이 아니며 따라서 특정행위가 용인되기 위해서는 그 행위가 해양에 위해를 미치지 않는다는 것이 입증되지 않고는 용인되기 어려워지고 있음을 의미한다. 방사성 폐기물의 해양투기 전면 금지 결의도 이러한 영향의 결과라고 볼 수 있다[3].

본 소고에서는 러시아 방사성폐기물의 동해 및 극동 투기현황을 러시아 백서 자료 및 최근 러시아당국 및 민간 연구소의 발표 자료에 근거하여 살펴보고 핵 강대국인 러시아, 일본, 중국 그리고 북한으로 둘러 싸여 있는 우리나라가 환경보전 차원뿐만 아니라 국가민방위 차원에서 장기적이고 투기적인 해양환경 방사능감시망의 구축가동을 제안하려 한다.

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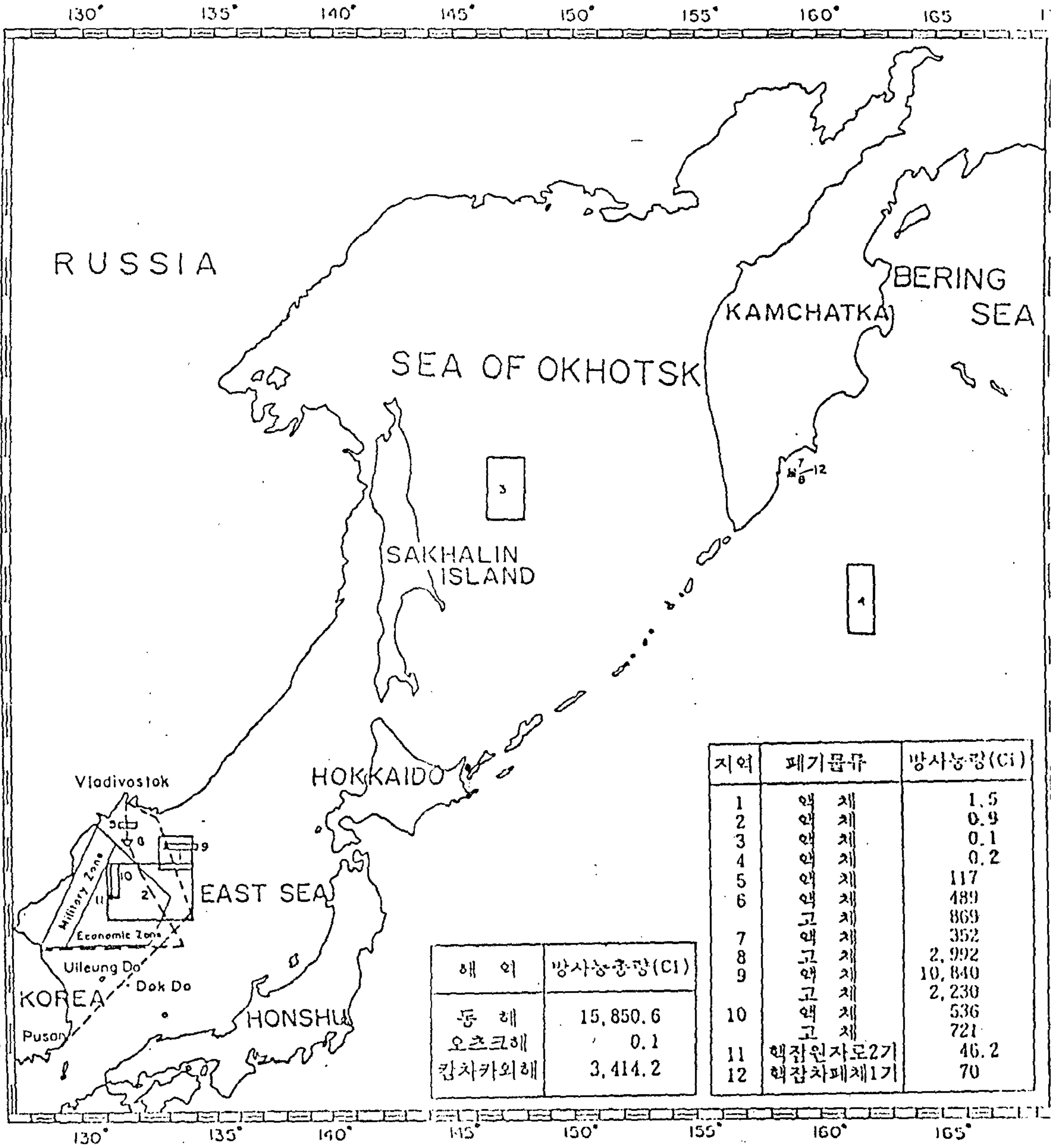
3) 백진현. 1994. 방사성폐기물 투기 규제에 대한 국제법과 정치. 한국해로연구회.

러시아핵폐기물해양투기
극동해역 위치도



해 역	방사능총량(CI)
동 해	15,850.6
오츠크해	0.1
캄차카외해	3,414.2

지역	폐기물류	방사능량(Ci)
1	액 체	1.5
2	액 체	0.9
3	액 체	0.1
4	액 체	0.2
5	액 체	117
6	액 체	489
	고 체	869
7	액 체	352
8	고 체	2,992
9	액 체	10,840
	고 체	2,230
10	액 체	536
	고 체	721
11	핵잠원자로2기	46.2
12	핵잠차폐체1기	70

그림 1. 구소련 및 러시아 핵폐기물 해양투기 극동해역 위치도

2. 구소련 및 러시아 방사성폐기물 해양투기 은폐

런던협약은 1972년 채택되어 1975년 부터 발효되었고 구소련은 1976년에 가입하였다. 런던협약에 의하면 서명국은 인간건강을 위협하거나 해양의 생물자원과 해양생물을 손상시킬 수 있는 폐기물과 기타 물질의 투기에 의한 해양오염 방지를 위해 가능한 모든 조치를 취할 의무를 지니고 저준위(100 KBq/ℓ, 26 μCi/ℓ 미만) 및 중준위(100 KBq/ℓ, 26 μCi/ℓ 이상이고 15 GBq/ℓ, 0.14 Ci/ℓ 미만) 핵폐기물의 해양투기는 적격한 국제기구에서 파견된 참관인이 투기 작업을 하는 선박에 승선하고 아래 3가지 국제원자력기구 요구 사항을 준수하는 조건하에서 국제해사기구 (IMO)에 통고하고 이의 특별 허가로서 허용된다. 아래 3가지 사항은 다음과 같다. (1) 투기장소는 대륙붕단, 내해 및 주변부해역 이외의 해역이여야 하며 (2) 투기 지점의 수심은 4000m 이상되어야 하며 (3) 위도는 남북위 50°이내여야 하고 50° 이북의 고위도 해역은 제외된다. 러시아 연방의 경우 위 3가지 요건을 갖춘 해역은 극동의 캄차카 외해역 뿐이다. 1985년 런던협약 제9차 당사국협의회의에서는 핵폐기물 투기가 인간건강, 해양환경 및 생물에 미치는 영향의 모든 측면에 대한 완전한 평가가 이루어질 때까지 모든 형태의 핵폐기물 해양투기를 자발적으로 중지하자는 내용의 결의문이 채택되었다. 이 회의에서 구소련은 핵폐기물을 해양에 투기해 오지 않았으며 투기하지 않고 있고 투기하지 않을 계획이라고 주장하였으며 이 "제로보고서"는 국제해사기구에 송부되었고 1989년 국제원자력기구(IAEA) 설문에서도 구소련은 이를 재확인하였다. 그러나 구소련은 런던협약이 구소련에 적용되기 이전인 1959년부터 저준위 폐기물(20 mCi)을 백해에 투기한 것을 비롯하여 1993년 10월 까지도 동해 북부해역에서 해양투기를 계속하여온 것이다.

3. 구소련 및 러시아 핵폐기물 처리 방법 및 현황4)

3.1. 사용후 핵연료 처리 방식

블라디보스톡과 캄챠카 핵잠함기지에서의 핵잠함의 핵연료 장착과 사용후 핵연료 탈착은 서비스선박인 PM선이 수행하는 데 그 작업과정은 다음과 같다. PM선은 잠함에서 사용후 연료를 탈착하여 PM선의 사용후 핵연료 보관창고에 옮기고, PM선의 새연료 보관창고로부터 새연료를 잠함에 정착시킨다. 대체로 사용후 연료 탈착작업에 1개월이 소요되고 장착작업에 2-3개월이 소요된다. 연료장착이 끝나면 PM선을 쇼코토보 기지로 이동하고 부두에서 사용후 핵연료를 하선하여 트럭으로 임시저장소로 운반하고, 임시저장소에서는 특수 컨테이너(TUK)에 포장하여 우랄지방에 위치한 핵폐기물 처리소인 Chelyabinsk로 기차로 운송한다. 기차 후송시 1회분 수송량은 핵잠함 1회분이다. 핵잠함지원기지와 핵잠수함의 원활한 운영을 위하여서는 연 7-8척분의 사용후 핵연료를 Chelyabinsk로 후송하여야 하나 수송량은 1990년에 5-6회, 1991년에 3-4회, 1992년에 2회로 감소되었으며 1993년 이후 후송횟수는 알려져 있지 않다.

3.2. 고체폐기물처리(SRW) 방식

과거 SRW는 해양에 투기하든가 극동지역 2 곳의 처리기지의 매립시설에 매장하였다. 그러나 현재 해양투기는 금지되어 있어서 해군기지나 조선소에 보관중이다. 또한 이온교환수지물질은 액체폐기물 전용 보관선인 TNT에도 보관중이다.

3.3. 액체폐기물 처리방식(LRW)

과거 LRW는 잠함기지나 조선소에서 TNT 탱커선에 임시보관하였다가 해양에 투기하였다. 현재 해양투기는 러시아정부에 의하여 금지되고 있으므로 TNT탱커선에 주로 보관하나, PM선에도 보관하고 Bolshoi Komen과 Zveda 조선소에서는 전마선(PEK)

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4) 주로 Handler, J. 1995. The radioactive waste crisis in the Pacific Area. Japan-Russia-United States Study Group in Dumped Nuclear Waste in the Sea of Japan, Sea of Okhotsk, and the North Pacific Ocean. Biloxi, MS, 12-13, June, 1985, Center for International Security and Strategic Studies, University of Mississippi. 에서 발췌한 것임.

에 보관중이다. 그러나 TNT-5 탱커선은 선체누출이 심하여 침몰위기에 처하고 있다. 1991년 해군은 1시간에 LRW 0.5 ㎥를 처리하는 휴대 LRW 처리기 2기를 태평양함대에 투입하였다. 이 처리기는 TNT 탱커선에 보관중인 LRW 300톤을 고염액 5-9 톤으로 부피를 줄일 수 있는 것으로 보고되고 있으나 아직 운영결과는 알려져 있지 않다.

3.4. 핵잠함 퇴역 현황

러시아 의회보고서에 의하면 1992년에 35척이 퇴역하고, 1994년 말까지는 53척이 퇴역한다. 그리고 10여척이 10년 이내에 퇴역하게 된다. 핵잠함의 평균수명은 약 20-30년이다. 핵잠함이 퇴역되면 원자로로부터 사용후 핵연료를 탈착하고 탈오염 작업을 수행한다. 원자로는 핵잠함으로부터 분리하여 생태적으로 안전한 장소에 보관한다. 이 중 가장 큰 문제는 사용후 핵연료 탈착과 처리이다. 퇴역잠수함은 연해주와 캄차카반도의 조선소에 정착중이다. 퇴역핵잠함의 1/3은 사용후 핵연료의 Chelyabinsk로의 후송지연과 PM선박의 부족, Mayak 회사(핵연료재처리회사)대금지불 연기 등으로, 사용후 핵연료를 그대로 지니고 있다. 사용후 핵연료를 탈착한 핵잠함 중에서도 5, 6척만 세정(Scrapping)작업을 가한 상태이다.

1992년까지 퇴역작업은 잠함운영경비로 지원되었으나 1992년부터는 요구량의 15% 밖에 지원받지 못하여 핵잠함의 수명을 단축시키고 있고 또 조기퇴역이 불가피하여 극동해군의 핵폐기물 문제는 더 악화되고 있다. 최근 의회보고서에 의하면 해군예산이 1993년 수준으로 동결되면 핵추진 유도탄 발사잠함은 운영자체가 불가능해진다.

4. 구소련 및 러시아 해양투기 핵폐기물 특성[5]

4.1. 핵폐기물 연간 생산현황

현재 핵잠함과 핵추진선박(표층)으로부터 핵폐기물(RW)생산량은 연간 LRW는 20,000㎥, SRW는 6,000t이다. 그리고 LRW중 70%는 저염냉각수로서 10^{-6} Ci/ℓ준위이고 15%는 특별세척수로 10^{-9} Ci/ℓ, 그리고 나머지 15%는 탈오염수, 사용후 핵연료풀 냉각수($10^{-3\sim-2}$ Ci/ℓ)로 구성되어 있으며 총 연간 30 kCi/yr에 해당한다. SRW는 냉각수(loop waters)를 정제하는 데 사용한 이온교환수지, 여과잔류물, 증발잔류물로서 대체로 10 Ci/㎥(중준위)이다. 경수로의 저준위폐기물(LLW)와 중준위폐기물(ILW)배출량은 무게비로 LLW/ILW = 4:1 이고 비방사능(Specific activity)로는 LLW/ILW = 1:0.01 이다. SRW 중 저준위 금속 폐기물은 약 30%를 차지한다. 따라서 SRW의 평균밀도를 1t/㎥ 로 가정하면 SRW중 ILW는 10 kCi/yr이고 LLW는 500 Ci/yr가 생산된다.

4.2. 고체핵폐기물(SRW)의 방사능세기

일반적으로 고체핵폐기물(SRW)는 3-4㎜ 두께의 강철용기에 봉하여 해양에 투기하였다. 극동해역에 투기한 양은 연평균 250 Ci/yr 이다. 백서의 SRW 방사능세기는 ^{90}Sr 대등량(^{90}Sr equivalent)로서 경수로의 SRW중 ^{90}Sr은 약 50%를 차지하므로 극동해역 연 평균투기량은 5000 Ci/yr 이고[6] 이는 러시아 정부 금용기준치, 1M Ci/yr 보다는 훨씬 작은 양이다.

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[5] Gnedenko, V.A. and S.A. Bogatov. 1995. Preliminary assessments of the radiological significance of radwaste dumped in the seas adjacent to the territory of the Russian Federation and some problems of nuclear wastes management. Japan-Russia-United States Study Group in Dumped Nuclear Waste in the Sea of Japan, Sea of Okhotsk, and the North Pacific Ocean. Biloxi, MS, 12-13, June, 1985, Center for International Security and Strategic Studies, University of Mississippi.

[6] 야블로코프 등, 1993.(전게서)

5. 러시아 극동함대 핵폐기물 관련 기지현황[7]

러시아극동함대는 연해주 블라디보스톡 부근과 캄챠카반도 2 곳에 핵연료를 핵잠함에 장착시키고 사용후 핵연료를 탈착시키는 시설, 핵폐기물의 임시보관, 지하 매립 처리, 운반 등의 시설과 같이 방사선 측정 센터를 보유하고 있다. 이 핵관련기지는 핵연료 장착/탈착 작업선박(PM)과 LRW를 보관하는 탱커선 (TNT, 대략 1,000톤)을 보유하고 있다. TNT탱커선은 탑재한 LRW를 해양에 투기하는 데 사용하였다. 연해주와 캄챠카 핵폐기물 처리 및 저장소 현황은 다음과 같다.

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[7] Handler (전게서)

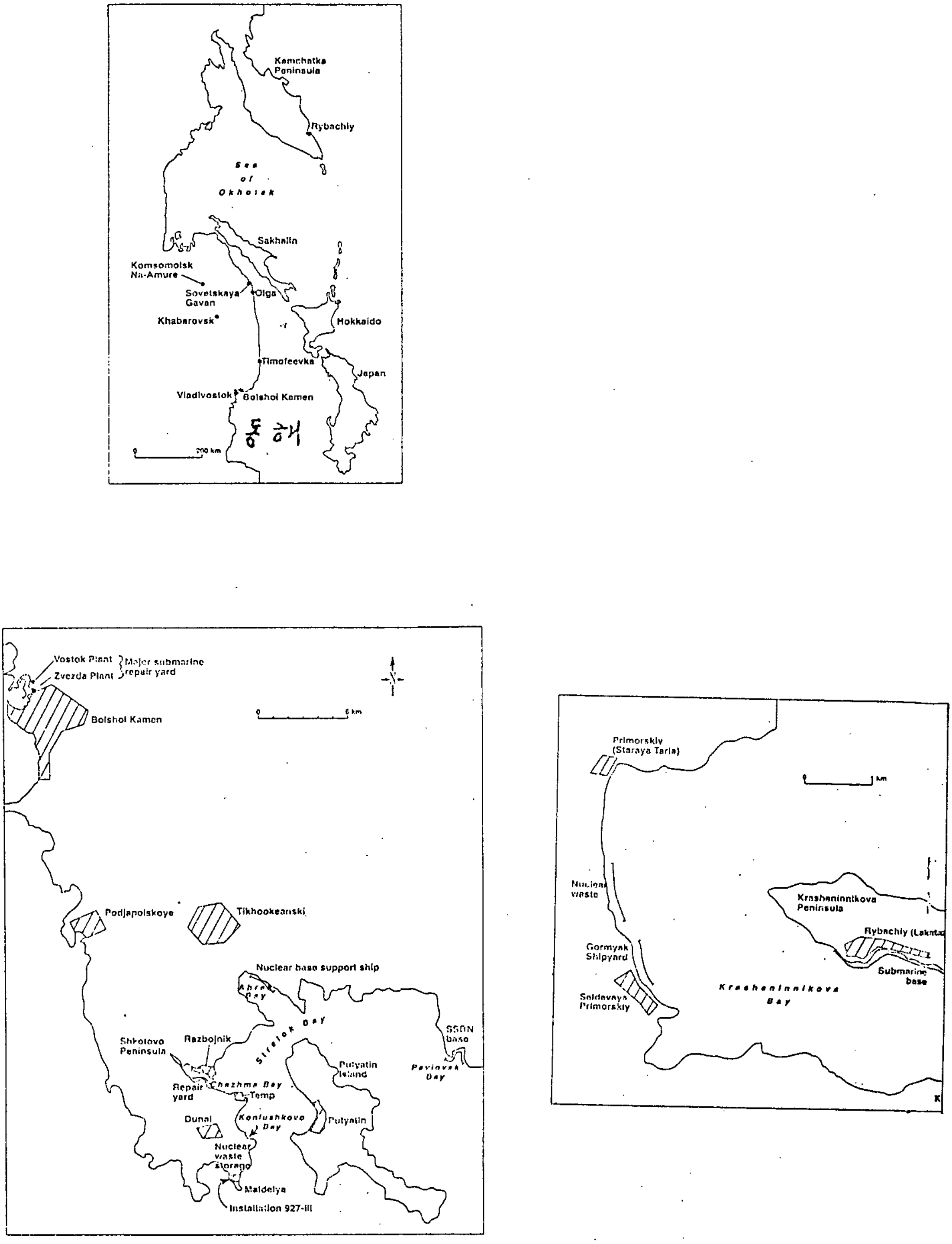

그림 2. 극동함대 핵폐기물 처분장 위치도

5.1. 블라디보스톡 부근

기지명	쇼코토보 기지
위치	블라디보스톡 남동부 Shokotovo 반도
면적	250 ㎢
가동시기	1960 년 이후
주요업무	핵연료 보관, 사용후 핵연료저장, 핵폐기물 매립
주사원(수)	760명 (M/U 40752)
서비스선박	-갯수 총 3척 (PM-80, PM-125, PM-133) -상태 PM-80 : 가동중지(기탑재된 손상된 핵연료 118개 다발 제거 불가) PM-133 : 1985년 차즈마사고 복구에 사용되어 심각히 오염되어 있음. PM-125 : 양호
탱커선박	-갯수 총 2척 -상태 TNT-5 : 운항불가, 선체누수 TNT-27 : 자체운항불가, 선체오염심각
옥상저장시설	-임시 LRW 보관용 탱크 : 갯 수:3 보관량 : 6톤 -사용후 핵연료 보관시설 : 갯 수 : 3개(No. 5, 29, 30) 상태 - No. 29, 30에 사용후 핵연료 1200여개 다발 보관가능 (Chelyahenisk(우랄)로의 수송량감소로 현재 보관한계 97%) - No. 5: 1986년 이후 2개 수조(Pool) 손상으로 사용불가
옥외매립시설	-면적 : 2.5-3㎢ -갯수 : 8개 -상태 : 제 1~5 매립시설: 위치, 매립물질미상 제 6 매립시설(No. 31) : 고준위 SRW 용(이온교환수지, 제1차냉각계통기기) 주위환경으로 방사능 누출 제 7 매립시설(No. 32) : 저준위 SRW 용(이온교환수지 및 저준위 SRW) 제 8 매립시설(No. 7) : 챠즈마만 사고후 손상연료봉 등 처리물질 매립, 주위 환경으로 방사능 누출

5.2. 캄챠카 반도

기지명	캄챠카 기지
위치	Ribachiy 잠함기지, Gornyak 조선소 부근 krasheninnikova 만
면적	50 ㎢
가동시기	1963 년 이후
주요업무	핵잠함지원(핵연료 장착 및 탈착, 핵폐기물처리, 매립)
주사원(수)	500명 (M/U 95051)
서비스선박	-갯수 : 총 3척 (PM-48, PM-124, PM-74) 모든 선박이 불량한 상태임. -상태 PM-48 : 1987년 이후 37개의 손상된 사용후 핵연료 탈착 불가로 가동 불가 PM-124 : 1990년 초 노후화로 운영불가 PM-74 : 1986년 진수되었으나 엔진 분해검사 미실시로 노후화됨
탱커선박	-갯수 : 총 2척 -상태, 정박위치 : 미상
옥상저장시설	미 상
옥외매립시설	-면적 : 4-5 ㎢, 해안선에서 200m 이내 거리 -갯수 : 총 3 개 1개: 핵연료 저장 2개: 이온교환수지물질 등 저준위 SRW (고체핵폐기물) -상태 : 1990년 콘크리트벽 균열, 방사능 물질 누출(최고 8 mR/h 측정됨) 1994년 6월 눈녹은 물이 매립지로부터 방사능 물질을 Seldevaya 만으로 이동시킴(최고 8 mR/h 측정됨).

6. 구소련 및 러시아 방사성 폐기물 극동해역 투기 현황

6.1. 과거 핵폐기물 투기 개요

구소련 해군은 동해 북부를 비롯한 오호츠크, 캄챠카 등 극동해역에 10개 구역을 액체 및 고체 핵폐기물 투기해역으로 지정하였다(그림 2). 액체와 고체폐기물의 총 투기량은 동해에 15,850.6 Ci, 오호츠크해에 0.1 Ci, 그리고 캄챠카 외해에 3,414.2 Ci 를 투기하였고 청진 동쪽 200 km 해상에 위치한 제 9 해역에 동해 투기 액체폐기물의 90%인 10,840.38 Ci 를 그리고 동해 투기 고체폐기물의 69%인 3,054.8 Ci 를 집중투기 하였다.

구소련 지정 방사성폐기물 투기 해역중 제 4 해역만이 위치와 수심에 관한 국제원자력기구의 기준을 만족시키고 있다.

구소련은 1966년부터 1993년 최근까지 매년 극동해역의 지정된 9곳의 해역에 액체 핵폐기물을 투기하였다. 부피면에서 볼 때 대부분의 액체 핵폐기물은 캄챠카 반도 남동 해역의 제 7 해역에 투기되었고 방사능 세기면에서는 동해 북부 제 9 해역에 투기되었다. 총량면에서 보면 대부분의 액체 핵폐기물은 1986-1987 년 사이에 투기되었다. 액체 핵폐기물은 지난 1993년 10월 17일의 투기 행위에서 목격하였듯이 해양표층에 선박의 스쿠루로 희석하면서 해상에 투기하였을 가능성이 높다.

고체핵폐기물은 1968년부터 총 10개의 지정 해역 중 4개의 해역에 정기적으로 행하여졌다. 고체 핵폐기물은 부피면에서 볼 때 동해의 제 9 해역에 가장 많이 투기되었고 방사능 총량면에서는 캄챠카 남동 해역인 제 8 해역에 가장 많이 투기되었다.

극동해역에 투기한 핵잠수함 원자로 투기에 관한 입수 가능한 자료에서는 다행히도 사용후 핵연료가 장착된 원자로의 투기 행위는 극동해역에서는 없었다고 러시아 백서는 주장하고 있다[8]. 그러나 위에서 추정된 방사성 폐기물의 총량은 최근 퇴역 핵잠수함 원자로를 블라디보스톡시에 전기 공급을 위한 장치로 전환하는 공사중 사고로 샤르마만이 방사능 오염 위기에 처하고 있다는 보도와 같은 사고로 인한 방사

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8) 전게서 3)

능 유입은 포함되지 않은 것이다.

1985년 블라디보스톡 북동 40 ㎞ 이내에 위치한 스코토보-22 도시(실제 블라디보스톡도 개방된 지 수 년에 지나지 않으며 러시아 연해주에는 많은 도시가 군사시설 소재 등의 이유로 폐쇄된 도시이다)부근 챠즈마만에서의 핵잠수함 원자로 연료재충전 과정에서 핵안전 기준 준수미비로 통제 불능의 우라늄분열 연쇄반응 즉 열폭발이 일어나서 핵잠수함 선두 및 선미의 기계실과 격납고가 파괴되었으며 새로운 핵연료로 충전된 노심이 원자로로부터 날아가버렸다. 이 사고로 연소산물, 핵분열 및 유도 방사능 물질, 슬러리 형태의 미반응 연료 화합물 등은 파손된 핵잠수함에서 반경 50-100 m 내에 투기되었고 이 사고 결과 에어로졸 입자 낙진은 사고 지점으로부터 30 ㎞ 바깥에서도 검출이 되었다. 폭발사고직후 단 반감기 핵종들의 방사능 세기는 해수중에서 74 TBq/ ℓ 이었고 해양 생물체에는 670 Bq/kg 이었다. 이 사고로 290명이 방사능에 오염되었으며 이 중 10명은 상해로 사망하였고 10명은 심각한 방사능 질병을 얻었으며 39명은 방사능 이상 반응을 나타내었다.

6.2. 연도별 투기 현황

① 액체폐기물

동해	제 1 해역	연도별 자료 없음	
	제 2 해역	연도별 자료 없음	
	제 5 해역	66-74, 86-92	총 14년
	제 6 해역	86-87	총 2 년
	제 9 해역	74-78, 84-93	총 15년
	제10 해역	79-84	총 6 년
오호츠크	제 3 해역	연도별 자료 없음	
캄챠카	제 4 해역	연도별 자료 없음	
	제 7 해역	66-75, 77-78, 80-92	총 25년
	제 8 해역	연도별 자료 없음	

② 고체폐기물

동해	제 6 해역	68-71, 73, 86-88	총 8년
	제 9 해역	74-78, 84-92	총 14년
	제10 해역	78-83	총 6년
오호츠크	해당없음		
캄챠카	제 6 해역	연도별 자료 없음	총 8년
	제 8 해역	69-78, 80-92, 80-83, 85-92	총 22년

6.3. 해역별 투기 현황

단위 : Ci

동해		액체 폐기물(%)	고체폐기물(%)
	제 1 해역	1.5(0.01)	
	제 2 해역	0.9(0.01)	
	제 5 해역	117(0.98)	
	제 6 해역	489(4.08)	868.9(19.08)
	제 9 해역	10840.38(90.45)	3054.8(67.07)
	제10 해역	536(4.47)	630.97(13.85)
	소계	11984.78	4554.67
오호츠크	제 3 해역	불사용	
캄챠카	제 4 해역	0.2(100)	
	제 7 해역	352(100)	
	제 8 해역		2992(100)
	소계	352.2	2992

7. 동해 러시아 투기해역 한·일·러 3국 공동조사

7.1. 개요

조사시기 : 1994. 3. 18. - 4. 16.

조사해역 : 동해 북부 러시아 투기해역 제 1, 2, 5, 6, 9 해역 7개 조사정점
북한 인접 제 10 해역은 제외됨.

조사참여국 : 한국, 일본, 러시아, 국제원자력기구(해양환경연구소)

조사대상시료 : 해수(표층수, 해저인접수), 수심별 시료채취는 제 9 해역
1개 정점에서만 실시, 해저퇴적물, 해양생물

조사결과보고서 : 선상간이 보고서 : 1994. 4. 5. 발표[9]
최종 3국 합동 보고서 : 1995. 4. 30.(예정)

7.2. 94년 한·일·러 3국 공동조사 결과

94년 3월 동해북부에서 수행된 3국 공동조사시료의 육상 실험실 정밀 방사능 분석결과는 정부 채널을 통하여 1995년 4월 30일 공식 발표될 예정이다. 선상간이 측정 결과는 다음과 같다. 선상간이 방사능 측정은 감마 방출 핵종에 한하여 실시하였으며 해수는 ^{137}Cs 흡착제로 농축시키고, 해저퇴적물은 건조시키고, 어류 및 새우는 머리와 근육부분으로 나누어서 감마스펙트로미터로 ^{137}Cs 등 감마핵종을 분석하였다. 또한, 감마검출기를 직접 표층수, 또는 수심 200 m 까지 투하시켜 현장감마 방사선 분석도 실시하였다. 선상간이 측정 결과 표층해수의 용존 ^{137}Cs은 3~5 mBq/kg 이고 표층퇴적물의 ^{137}Cs 농도는 3 Bq/kg 이하이었다. 이는 대체로 북태평양 수준의 농도이다.

7.3. 제 2 단계 한·일·러 3국 공동조사

94년 제 1 단계 한·일·러 3국 공동조사가 동해 북부 러시아 투기해역에

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[9] Preliminary report on the first Japanese-Korean-Russian Joint Expedition to radioactive waste dumping Areas. 1994. 105p. R/N. Ocean.

국한되어 실시되었고 3국정부간 합의에 의하여 제 2 단계 3국 공동조사를 오호츠크, 캄챠카, 러시아 투기 해역과 토쿄 남방의 일본 저준위 고체폐기물 투기해역, 한국 동해 울릉도 남방의 저준위 폐기물 투기해역을 대상으로 실시하는 실무 문제를 외교경로로 3국간에 교섭중이다. 조사의 객관성 보장을 위하여 국제원자력기구의 초청이 확실시된다.

8. 해역별 방사능 오염 현황

1944년부터 1962까지의 대규모 대기중 핵무기 폭발실험의 결과로 전세계 지구표면은 인공방사능 물질로 오염되어 있다. 또한 1950년경부터 핵재처리시설의 상업적 가동, 원자력 발전소의 상업적 가동, 1946-1982년 기간동안의 저준위폐기물고체포장 해양투기, 핵추진 우주선의 궤도진입 실패로 인한 방사능 오염, 핵추진 선박 및 잠수함 사고, 러시아의 핵폐기물 해양투기 등으로 전세계 해역은 인공방사능 물질로 오염되어 있다. 편의상 전세계 해양을 핵시설 부재 해역, 핵재처리소 영향권 해역, 러시아 투기해역으로 나누어 보면 다음과 같다.

8.1. ^{137}Cs 방사성 핵종 해역별 분포현황

① 핵시설 부재 해역

북서태평양 : 대기중 핵무기 폭파시험이 최고에 달한 56-62년에는 태평양에서 최고 180 mBq/ℓ 함유되어 있었으나 대기중 핵 실험 금지조약 체결 이후 계속 감소하여 현재는 3 mBq/ℓ 내외 수준으로 연도별 변화는 거의 없다.10)11)

해 역	관측수심 (m)	세기 (mBq/ℓ)	관측 년도
북서태평양	표층수	3.5-5.5	1956-1974
황해남부(35°N)	표층수	4.6	1987
동중국해	표층수	3.0	1987
오키나와해구	표층 0-550 심층 1000-2000	3-6 0.2-1.0	1987 1987

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10) Hirose. K., Y.Suginura and M.Aoyama. 1992. Plutonium and ^{137}Cs in the western North Pacific Estimation of residence time of plutonium in surface waters. Appl. Radiat. Isot. 43:349-359.

11) Nagaya, Y. and K. Nakamura. 1992. Pu-239, 240 and Cs-137 in the East China and the Yellow Seas. J. Oceanography. 48:23-35.

② 핵 재처리소 영향권 해역(영국 셀라필드)12)13)14)15)

해 역	관측수심 (m)	세기 (mBq/ℓ)	관측 년도
서부스코틀란드 해역	표층 표층	227 718	1976 1978
북해북부	표층 표층	80 167	1976 1978
노르웨이해역	표층 2,000 표층	5 0.5 52	1976 1978 1978
덴마크 Zealand 해역 발틱해	표층 표층	72 103	1991 1991

③ 러시아 핵투기해역

해 역	관측수심 (m)	세기 (mBq/ℓ)	관측 년도
러시아북부해역 (카라해)	표층 저층(20-323)	3.3-8.1 4.4-20.4	1992 1992
동해(러시아투기해역 부근 및 분포지대)	표층 저층	3.0-3.5 0.2	1993 1993

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12) Livingston, H.D., V.T. Bowen and S.L.Kupferman. 1982. Radionuclides from Windscale discharges II:Their dispersion in Scottish and Norweigian circulation. J.Mar. Res. 40:1227-1258.

13) 덴마크 해양 환경 방사능 보고서

14) 아일란드 해양 환경 방사능 보고서

15) Joint Russian-Norwegian Expert Group for Investigation of Radioactive Contamination in the Northern Seas. 1994. A survey of artificial Radionuclides in the Kara sea. Results from the Russian-Norwegian 1992 Expedition to the Barents and Kara Seas. 70p. 한국해양연구소 자료

8.2. $^{239,240}Pu$ 방사성 핵종 해역별 분포 현황

8.2.1. 해수

① 핵시설 부재 해역

해 역	관측수심 (m)	세기 (mBq/ℓ)	관측 년도
북서태평양	표층수	4-8	1979-1987
	중층수 400-800	60-80	1978-1982
황해남부(35°N)	표층수	3	1987
양자강 입구	표층수	80	1987
대마난류	표층수	4	1987
오키나와 해구	표층 0-3000	1-6	1987
	중층수 400-1500	18-19	1987
	심층수 2000	7	1987

② 핵 재처리소 영향권 해역(영국 셀라필드)

해 역	관측수심 (m)	세기 (mBq/ℓ)	관측 년도
서부스코틀랜드 해역	표층	96	1976
		315	1978
북해북부해역	표층	44	1976
		92	1978
노르웨이 대서양 연안	표층	17	1976
	2200	8	1976
	표층	24	1976

③ 러시아 핵폐기물 투기 해역

해 역	관측수심 (m)	세기 (mBq/ℓ)	관측 년도
러시아북부카라해 바렌츠해	표층	2-7.5	1992
	저층 20-323	5-16	1992
동해(러시아투기 해역부근일본분지)	표층	3-8	1993
	중층(500-1000)	33-41	
	심층(3000)	25	

8.2.2. 해저퇴적물

① 핵시설 부재 하역

해 역	관측수심 (m)	퇴적물 깊이 (cm)	세기 (mBq/g)	관측 년도
북서태평양	5,500	0-2	1.10	1980
		16-18	0.22	1980
황해남부(35°N)	37	0-2	0.13	1987
양자강 입구	42	0-2	0.21	1987
		4-8	0.28	1987
오키나와 해구	2,170	0-2	0.11	1987

② 핵 재처리소, 핵무기 폭파시험 영향권 해역16)

해 역	관측수심 (m)	퇴적물 깊이 (cm)	세기 (mBq/g)	관측 년도
태평양마샬군도		표층	38	1982
무로라 환초		표층	31	1989
발틱해		0-5	5.7	1986
아이래해	200	표층	213	1981

③ 러시아 핵폐기물 투기 해역

해 역	관측수심 (m)	퇴적물 깊이 (cm)	세기 (mBq/g)	관측 년도
러시아북부카라해	230-323	표층	4.6-11.6	1992
동해(러시아투기 해역부근일본분지)	1,500-3,500	0-1	1.1-2.2	1993

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16) Kershaw, P.J., R.J. Pentreath, D.S. Woodhead and G.J. Hant 1992. A review of radioactivity in the Irish Sea. A report prepared for the marine pollution monitoring management group. Directorate of Fisheries Research. U.K. 65p.

9. 결 론[17]

졸속한 계획, 재원의 부족, 보건 및 환경 보전 문제의식의 결여 등으로 러시아 해군은 유래없는 핵잠함 운영에 따른 핵폐기물 문제에 봉착하고 있다. 폐기물 처리 시설은 이미 처리 및 저장 한계에 도달하여 있으나 1세대, 2세대 핵잠함의 대량퇴역과 신형잠함의 계속적인 가동은 현재의 위기 상황을 더욱 악화시키고 있다. 한편 핵잠함이외에 현재 운항 불가능한 2척의 핵추진 표층선박(순양함, 기함)의 퇴역에 따른 핵폐기물 처리 또한 큰 문제이다.

1993년 10월 이후 모든 액체(LRW)와 고체(SRW) 핵폐기물의 해양투기는 전면금지되고 있으나 해안에 위치한 방사성폐기물은 동해와 캄차카 부근 해역의 환경재해로 새로이 등장하고 있다. 이들 핵폐기물의 소재지(선박, 해안 부근 지하매설지, 부두, 옥상시설)들은 범람, 해일, 지진 등 자연재해에 매우 취약하다(캄챠카의 화산활동과 일본열도의 지진은 동해안 해일을 일으킬 수 있음).

해안에 위치한 핵폐기물 문제를 해결하기 위하여서는

1. 사용후 핵 연료 건조 저장시설 건설
2. 손상된 사용후 핵 연료 탑재 핵잠함의 연료 탈착 방법 강구
3. 퇴역 핵잠함으로부터 사용후 핵연료 탈착 작업 과정을 기존 핵잠함-서비스선박-해안시설에서 핵잠함-해안시설로 단순화하여 사고 위험 감소 방안 강구
4. 해군의 방사능 감시인력 확충
5. 해안시설(핵폐기물 처리, 보관시설, 조선소, 해군기지)의 방사생태환경 정밀조사
6. 핵잠함 운영, 작전, 수요 감소로 핵폐기물 생산력을 감소시켜야 함.

그러나 불행하게도 모든 강대국과 마찬가지로 러시아는 1994년 가을에도 Oscar급 유도탄발사핵잠함을 캄챠카에 새로이 배치함으로서 핵잠함의 숫자를 감소시킬 의사가 없음을 과시하였다.

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[17] Handler(전게서)

10. 제 언

10.1. 전국 해양 방사능 감시망 구축의 필요성

한반도 주변 해역은 핵 강대국인 러시아, 중국, 일본, 북한 등으로 둘러 싸여 있다. 따라서 선박 및 항공기(군수용 포함)를 이용한 핵물질의 운반, 연안에 위치한 핵시설 운전, 핵추진 선박 및 잠수함 운항에 따른 방사성 폐기물 배출 및 비고의적, 고의적 방사능 누출 사고의 위험이 상존하고 있다. 1960년대 이전 출생자들은 비가 오면 중국의 핵무기 폭발 시험에서 발생한 방사성 낙진에 직접 노출이 되지 않게 꼭 우산을 쓰도록 정부에서 경고한 사실을 기억할 것이다.

동해는 소련 핵잠수함의 주 통로였을 뿐만 아니라 1992년 말에 공표된 바에 의하면 핵폐기물 해양 투기해역으로 과거 30여년간 소련에 의하여 이용되어 왔으며 발표된 투기량은 그 일부에 지나지 않고 그간 국제 사회에 공개되지 않은 많은 핵물질 관련 사고들이 다수 존재할 개연성은 매우 크다. 러시아는 동해 북부의 블라디보스톡에 대규모 군항을 유지하고 있으며 200여척이상의 핵잠수함 등 핵 추진 선박과 상당수 핵무기를 보유하고 있고 제 1, 2 세대 핵잠수함의 연속적인 폐기가 우려되며 또한 계속 새롭고 더욱 강력한 핵잠수함을 진수시키고 있다.

중국은 황해 중부의 청도에 잠수함 기지를 유지하고 있다. 1992년에는 청도 기지를 출발한 HAN급 핵 추진 공격용 잠수함이 황해에서 실종된 바 있다고 언론에 보도되기도 하였다. 중국의 최근 해군력 증강은 이미 일반에 널리 알려져 있다. 그리고 현재 핵무기 개발에 상당한 노력을 하고 있다. 1992년 5월 21일 1000 kt(히로시마 투하 원자폭탄의 70배 크기)의 핵 폭발 시험을 신장 지구의 지하 핵 실험장에서 실시하였고 이 때 지하 핵실험장에서 누출되어 나온 방사성 가스가 대기권에 진입하여 6월 11일 경에는 동해 상공으로 운반되어 동해상의 방사성 가스 구름이 존재하는 것이 미 정보기관에 의하여 탐지되었다고 보도되었다.

또한 일본은 지난 1992년말 프랑스로부터 세계 사상 최대 규모인 히로시마 원자폭탄의 150배에 해당하는 플루토늄 1.3t을 수입한데 이어 95년에는 14t을 수입키로 하여 수송선박 통과해역 국가들로부터 심한 반발을 받았으며 국제환경보호기구인 그린피스가 선박을 동원하여 수송선박의 안전 항해를 감시하기로 결정하였다.

북한의 핵개발 가능성과 안전성 시비는 워낙 널리 알려져 있다. 이러한 지정학적 위치때문에 한국 해역의 인공방사능 감시는 민방위차원에서도 반드시 필요하다. 스웨덴, 핀란드가 인근 해역의 환경 방사능 감시를 해온 이유중의 하나는 구소련의 핵사고 위험성에 대비한 것으로 볼 수 있다[18]. 그리고 일본도 60년대부터 본격적인 해양환경 방사능 감시를 일본 국익해역 전역에 걸쳐서 시행하고 있으며 중국도 70년대부터 연 2회 황해·동중국해 등에서 해양환경 방사능 감시를 하고 있다[19]. 한국의 해양환경방사능 감시망의 구축운영은 인접 국가들의 핵물질의 평화적 사용을 증진시킬 것이다. 이는 마치 군대가 평화시에도 필요한 이유와도 같다. 또한 주기적으로 해양의 인공방사능을 조사함으로써 해안에 설치된 원자력발전소의 안전 운전을 간접적으로 도울 수가 있고 또한 원자력발전소에 대한 국민의 이해를 증진시킬 수도 있다. 지난 1993년 4월 정부는 육상 부분의 방사능 감시망을 전국 해양으로 확대시키기로 하였다.

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[18] ① Ilus, E., S. Klemola, K.-L. Sjöblom and T.K.Ikaheimonen. 1988. Radioactivity of Fueus Vesiculosus along the Finish Coast in 1987. 36p. Finnish Center for Radiation and Nuclear Safety. Finland.

② O'Grady, J., L. Currivan, C. McEnri, M.O'Colmain, P.A. Colgan, J.D. Cunningham. 1991. Radioactivity monitoring of the Irish Marine Environment, 1988-1990. 46p. Nuclear Energy Brard, Ireland.

③ Delfanti, R., V. Fiore, O. Lavarello, C. Papucci, 1986, La distribuzione del ^{137}Cs negli ambienti costieri italiani. Acqua-Aria. 6:579-585.

④ Ikaheimonen, T.K., E.Illus and R. Saxén. 1988. Finnish Studies on Radioactivity in the Baltic Sea in 1987. 35p. Finnish Center for radiation and Nuclear Safety. Finland.

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IAEA-TECDOC-481. 1981. Inventories of selected radionuclides in the Oceans. 181p.

[19] ① Hammin, E. L. Shuqing, W. Fushou, S. Fuju, L. Qinglin, Y. Wenchun. 1991. Radioactivity in the coastal waters of the Bohai and Yellow Seas of China J. Environ. Radioactivity. 14:193-209.

② Gu, Hangkan. 1990. Marine Chemistry of the Bohai Sea, Yellow Sea and the East China Sea. Science Press, Beijing. 458p.

③ Li, Po-q., Y.-t. Yu. and Y, Wu. 1994. The development of marine radiochemistry in China. Zuou Di et al.(ebs). Oceanology of China Seas. v.1:189-200. Kluwer Academic Publ.

10.2. 해양환경 방사능 감시망 운영 방안

해양으로 유입되는 방사성 물질의 유입경로와 해양에서의 이동과정은 다음과 같다. 해양으로 들어온 여러 방사성 핵종들은 그 특성에 따라 해수속에서 해류 등을 통한 확산, 이동 및 먹이사슬을 통한 이동, 축적과정을 거친다. 따라서 해양에서의 방사성 핵종의 감시를 위해서는 해수의 유동, 먹이사슬의 구조 및 퇴적물에서의 이동가능성 등 모든 과정이 함께 검토되어야만 한다.

해양 환경방사능 감시망은 첫째, 해양 환경을 구성하는 해수, 해저퇴적물, 해양생물, 해양대기 등 해양환경 각 부문의 방사능 오염현황, 오역이력과 다른 해역과의 비교 해석 분야, 둘째, 해양 환경내에서의 방사능 오염 물질·이동 재분배를 지배하는 과정 연구 즉 해수순환, 해저퇴적물 축적 및 이동, 생물농축 조사분야, 셋째, 방사능 오염물질의 이동·재분배, 생물농축을 예측하기 위한 수치모델 개발분야, 넷째, 환경 및 인체 유해성 여부를 판단하기 위한 위험부담율 평가분야로 나눌 수 있다.

현재 황해에서는 ^{239,240}Pu은 대부분 해저퇴적물에 존재하나 ^{137}Cs은 50-80% 가 해저퇴적물에 존재하고 나머지는 해수중에 존재한다[20]. 그러나 오카나와 해저곡 부근의 대양에서는 방사성 Pu과 Cs 모두 해수 중에 존재하고 있다. ^{137}Cs 방사능은 북쪽에서 남쪽 방향으로가면서 감소하고 있으며 ^{239,240}Pu은 반대로 남쪽 방향으로가면서 오히려 증가하고 있다. 그 이유는 다음과 같다. 육상에 낙하한 ^{137}Cs이 미세입자에 흡착하게 되고 이는 황하를 통하여 황해로 막대하게 유입이 된다. 그리고 황해로 유입되는 황하기원 미세입자의 2%가 조석이나 연안류를 타고 남하하게 된다. 한편 하천 입자에 흡착된 ^{239,240}Pu 은 하구에서 해수와 접하게 되면 곧 입자로부터 유리되어 널리 확산되나 다시 해양성 입자에 부착되어 해저로 침강하게 된다.

양자강 하구 부근의 ^{239,240}Pu 총량은 총 낙진량보다 많으며 ^{239,240}Pu은 양자강이 주 근원인 것으로 사료된다. 그리고 ^{137}Cs 총량은 낙진량 보다 적으며 이는 ^{137}Cs이 황해 대륙붕에서 태평양 외해로 이동하기 때문이다. 이러한 해양환경내의 방사성 물질의 재분배에 관한 조사연구는 인위적인 방사성 물질 해양투기를 탐지하는 데 필수적이다.

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[20] 전게서 12 참조

제 2 장 3국공동조사 보고서

2.1. 조사계획서

PROGRAMME
FOR THE RUSSIA-JAPAN-KOREA JOINT EXPEDITION TO STUDY RADIOACTIVE POLLUTION IN THE AREAS OF RADIOACTIVE WASTE DISPOSALS IN THE FAR EAST SEAS

1. Expedition purpose

Joint expedition is carried out to the areas of radioactive waste disposals according to the same programme and is consisted of two stages.

Purpose of expedition is to investigate marine environment radioactivity in the sea areas of common concern by the Japanese, Korean, and Russian sides.

The first stage of expedition is carried out in accordance with the cruising chart in Appendix 1.

After finishing the first stage, second stage is planned to study marine environment radioactivity in the areas of radioactive waste disposals by Republic of Korea, Japan and Russian Federation.

The second stage is to be implemented in accordance with the same principles as the first stage.

2. Field observations

2.1. Basic observations

2.1.1. Sea water sampling from the surface at each station by pumping aboard R/V "Ocean" in quantities sufficient for every country.

2.1.2. Sea water sampling from bottom layer at each station (500 l or more if excess sampling time will be available).

2.1.3. Sea water sampling (500 l or more) from the intermediate layers (200, 500, 1000, 2000 m) at station N 2.

2.1.4. Bottom sediment sampling at all sampling stations.

2.1.5. Selective benthos sampling from each sediment sample if excess sediment material will be available.

2.2. Optional observations

2.2.1. Plankton net sampling from 0-500 m or 0-200 m layer (depending on weather conditions) at each sampling station.

2.2.2. Preliminary spectrometric measurements of gamma-emitters in the surface layer.

2.2.3. Concentration of radionuclides by adsorbents or by co-precipitation from surface sea water pumped aboard the ship and preliminary spectrometric measurements of gamma-emitting radionuclides by each country.

2.3. Standard meteorological and oceanographical observations

2.3.1. Regular meteorological observations at 00, 06, 12, 18 GMT.

2.3.2. Regular receiving and analysis of facsimile weather maps, weather forecasting for ship's captain and chief of the expedition.

2.3.3. CTD casts from the surface to the bottom at all sampling stations.

3. Expedition route and duration

3.1. The first stage is carried out in the areas of radioactive waste disposals by Russian Federation in accordance with the cruising chart in Appendix 1 in February-March 1994.

The second stage will be carried out in the areas of radioactive waste disposals by Japan, Korea and Russian Federation in Summer 1994. A map which shaws areas where Japan, Korea and Russia dumped radioactive wastes is presented in Appendix 2.

3.2. The first stage duration is maximum 31 days. Plan for observation operations is presented in Appendix 3.

Investigations are carried out at seven basic sampling points and 1-3 additional background stations in accordance with the cruising chart in Appendix 1 (station coordinates are presented in Appendix 4).

Two port calls to Niigata and one port call to Tonghae are planned to board and get-off specialists, equipment and materials.

4. Data and sample treatment

4.1. Sea water samples will be devided equally into three or four parts (upon IAEA request). After the expedition, gamma-emitters, Sr-90 and Pu will be analysed.

4.2. Bottom sediment samples also will be devided into three or four parts (upon IAEA request). After the expedition, the same radionuclides will be measured.

4.3. Plankton and benthos samples also will be devided in three parts.

4.4. Oceanographical and meteorological information will be processed aboard R/V "Ocean" using personal computers according to the standard techniques.

4.5. Programmes and techniques of laboratory analysis in each country will be discussed before the expedition.

5. Intercomparison

During the expedition, sample of bottom sediment will be taken to organize intercomparison of Japan, Korea and Russia techniques of radionuclide analysis. Which country will be responsible for standard sample preperetion will be decided during the expedition. The country which prepares standard sample pays the expences to prepare this sample and sends subsamples to the other countries.

6. Data exchange

6.1. Meteorological data after their processing will be distributed among all participating parties.

6.2. Oceanographical data after their processing also will be provided to all participating parties.

6.3. Data on preliminary measurements aboard R/V "Ocean" will be exchanged between the participating parties after discussion.

6.4. Data on accurate redionuclide analysis will be exchanged via diplomatic channels approximately six months after the expedition.

6.5. Further data interpretation and publication will be carried out after consultations between participating parties.

7. Report on the expedition

7.1. The first announcements of the results of preliminary measurements aboard R/V "Ocean" will be made in each country after the expedition.

7.2. Three participating parties will prepare and sign draft of joint report during the expedition which will contain results of preliminary measurements aboard R/V "Ocean".

In one month after the expedition, each country can prepare high-quality edition (based on this draft absolutely).

7.3. After the finishing of all laboratory analyses and joint evaluation of the results, all participating parties will prepare joint final report within one year after the expedition. Preparation of this report will be discussed by expedition participants.

8. Participants of expedition

Total number of expedition participants (Appendix 5) is 92 including crew - 55, scientific stuff - 37 (including IAEA representative). Final expedition stuff will be approved during the signing of contract.

9. Equipment and materials

Equipment and materials for the expedition is provided by russian, Japanese and Korean sides. Taking into account possible equipment failures, some devices are doubled. Final list of equipment and materials will be approved during the signing of contract.

Notes:

1. Top priority should be given to keeping safety of all experts and crew members. It is possible to change the duration, schedule, route and sampling if the weather becomes bad.

2. The Consultative Group consisting of the heads of each party and the captain of the R/V "Ocean" will be established to secure normal operation of the joint expedition and to cope with the unexpected circumstances during the cruise.

3. R/V "Ocean" will contact with Japan and Korea during the expedition by radiocommunicating system.

4. Some changes of the Program are possible after mutual agreement of participating sides.

5. Final report on the results of the expedition will be provided to interested Ministries and Organisations of Russian Federation and countries participating in the expedition.

Appendix 1: Cruise route chart (first stage).
Appendix 2: Map of Japan, Korea and Russia radioactive dumping sites.
Appendix 3: Investigations schedule (first stage).
Appendix 4: Sampling point positions (first stage).
Appendix 5: Participants of the expedition.

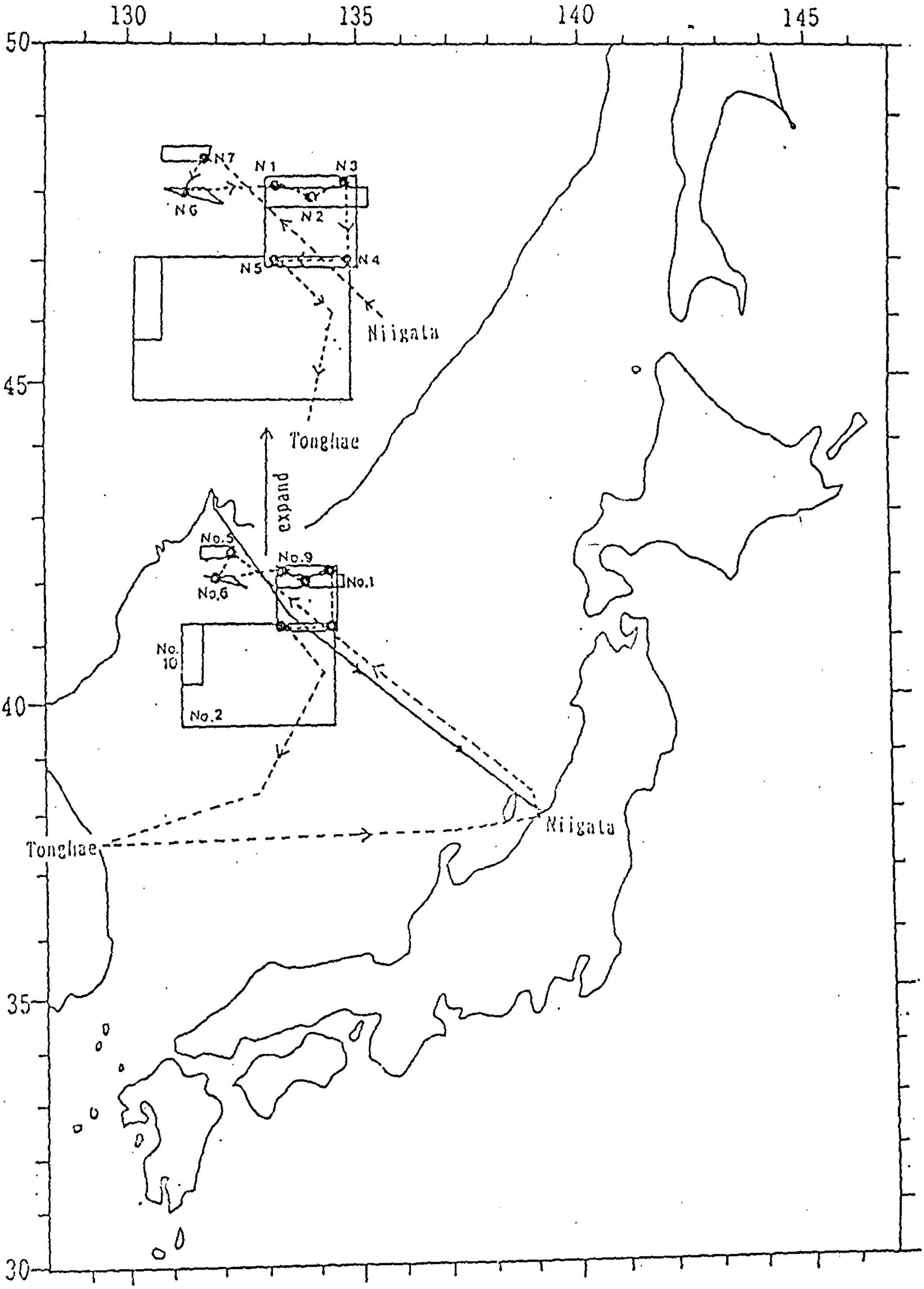


Fig. 2. 1. Cruise route chart (first stage)

Appendix 3

Plan for observating operations
(first stage)

Port of dep. and arrive	Sailing dist. (miles)	Sailing time (hr)	St. N.	Obs. time (hr)
Dep. Vladiv., arrive Niigata	480	48		
Stay Niigata		48		
Dep. Niigata to N 7	525	53		
Obs. at N 7			7	21
N 7 to N 6	30	3		
Obs. N 6			6	18
N 6 to N 1	60	6		
Obs. at N 1			1	21
N 1 to N 2	30	3		
Obs. at N 2			2	48
N 2 to N 3	30	3		
Obs. at N 3			3	19
N 3 to N 4	50	5		
Obs. at N 4			4	19
N 4 to N 5	50	5		
Obs. at N 5			5	20
N 5 to Tonghae	360	36		
Stay Tonghae		24		
Tonghae to Niigata	480	48		
Stay Niigata		48		
Niigata to Vladiv.	570	57		
		387		166

27 days + 4 days (including weather reserve and background stations)

Appendix 4

Sampling point positions
(first stage)

St. N	Latitude (north)	Longitude (east)	Depth	Area No.
1	41°55	133°15	3200	No. 1
2	41 40	133 50	3200	No. 1, 9
3	41 55	134 20	2500	No. 1
4	41 05	134 20	3100	No. 1, 2
5	41 05	133 15	3400	No. 1, 2
6	41 55	132 00	3100	No. 6
7	42°19	132°19	2500	No. 5

Background stations (1-3) will be situated in the area shown in Annex 1 (circle with the center at 38°00' N and 135°00' E)

Appendix 5

Preliminary list of the expedition participants
(first stage)

Total number of the expedition participants - 92

1. Crew	55
2. Scientific staff	37
2.1. Russian participants including:	15
FERHRI	4
NAVY	5
Hydrometservice	2
SPA "Tayphoon"	4
2.2. Japanese participants	9
2.3. Korean participants	7
2.4. IAEA representative	1

2.2. 선상조사 보고서

ACT

on Completion of the Contract on Preparation and Implementation of the Expedition in Accordance with the "Japanese-Korean-Russian Joint Expedition Program (First Stage)"

This act confirms the following:

1. Ministry of Science and Technology (MOST) of the Republic of Korea organized payment to Far Eastern Regional Hydrometeorological Research Institute (FERHRI), Russian Federation, 173,333.0 $ (one hundred seventy three thouthand three hundred thirty three US dollars) in accordance with the Contract to prepare and implement the joint expedition, and carried out it´s obligations in accordance with the Contract.

2. The expedition was prepared and executed, all kinds of work were implemented as scheduled. The Japanese and Russian sides carried out their obligations. The Korean side has not claims to the Japanese and Russian sides. The Japanese and Russian sides have not claims to the Korean side.

From Korean side: Sang Duk Sa

S.D.SA, Assistant Director, Radiation Safety Division,
Ministry of Science and Technology

From Japanese side: Y. Seto

Y.SETO, Head, Marine Pollution Laboratory, Hydrographic
Department, Maritime Safety Agency

From Russian side:

YU.N.VOLKOV, Director, Far Eastern Regional
Hydrometeorological Research Institute, Federal Service of
Russia on Hydrometeorology and Environmental Monitoring

April 5, 1994

R/V "OCEAN"

Distribution: Limited

PRELIMINARY REPORT

ON THE FIRST JAPANESE-KOREAN-RUSSIAN JOINT EXPEDITION TO RADIOACTIVE WASTE DUMPING AREAS

From Korean side: Sang Duk Sa

S.D.SA, Assistant Director, Radiation Safety Division,
Ministry of Science and Technology

From Japanese side: Yoshio Seto

Y.SETO, Head, Marine Pollution Laboratory, Hydrographic
Department, Maritime Safety Agency

From Russian side:

YU.N.VOLKOV, Director, Far Eastern Regional
Hydrometeorological Research Institute, Federal Service of
Russia on Hydrometeorology and Environmental Monitoring

From IAEA:

H.B.L.PETTERSSON, Research Scientist, Radiometrics Section,
Marine Environment Laboratory, IAEA

April 5, 1994

R/V "OCEAN"

CONTENTS:

Introduction

Background: The first Japanese-Korean-Russian joint expedition to the radioactive waste dumping areas is the result of the concerted efforts by the Governments of Japan, the Republic of Korea and the Russian Federation. The Contract among representatives of Science and Technology Agency (STA) and the Cooperation Committee of Japan, Ministry of Science and Technology (MOST) of the Republic of Korea, and Far Eastern Regional Hydrometeorological Research Institute (FERHRI) of the Federal Service of Russia on Hydrometeorology and Environmental Monitoring was signed on February 12, 1994 to prepare and implement the expedition. This joint expedition has been conducted in accordance with the "Japanese-Korean-Russian Joint Expedition Program (First Stage)" attached to the record of discussion among the representatives of the Ministry of Foreign Affairs of Japan, the STA of Japan, the MOST of the Republic of Korea, and the FERHRI of the Federal Service of Russia on Hydrometeorology and Environmental Monitoring on February 11-12, 1994 in Vladivostok. The IAEA was informed and invited to participate in the expedition.

Purpose: To investigate marine environmental radioactivity in the areas of radioactive waste disposed off by former Soviet Union and Russian Federation and to provide an estimation of the present consequences of radioactive waste disposals.

Area: Areas of radioactive waste disposed off by former Soviet Union and Russian Federation, south of Vladivostok according to the coordinates presented in the White Book (Materials for a Report by the Government Commission on Matters Related to Radioactive Waste Disposal at Sea, Created by Decree No. 613 of the Russian Federation President, October 24, 1992). Cruising chart is presented in Annex 1.

Ship: R/V "Ocean" (FERHRI, Federal Service of Russia on Hydrometeorology and Environmental Monitoring).

Partcipants: See Annex 2 and Annex 3.

Departure: March 18, 1994, Vladivostok, Russia.
Arrival: March 20, 1994, Niigata, Japan.
Departure: March 22, 1994, Niigata, Japan.
Arrival: April 06, 1994, Tonghae, Korea.
Departure: April 09, 1994, Tonghae, Korea.
Arrival: April 11, 1994, Niigata, Japan.
Departure: April 14, 1994, Niigata, Japan.
Arrival: April 16, 1994, Vladivostok, Russia.

Reporting: The results from this expedition will be reported in two steps.

First, this preliminary report containing description of techniques of sampling and sample handling, as well as the results of preliminary spectrometric measurements aboard R/V "OCEAN".

Second, after completing analysis on land in the three countries and IAEA, a joint evaluation of the data, an estimation of present effects of radioactive contamination on the environment will be reported in a final joint publication within one year after completion of the expedition.

1. Sampling and observation procedures

1.1. Station works.

According to the Programme of the joint expedition, sea water was sampled from surface and near-bottom layers at each station, and at station N 2 also from 200, 500, 750, 1000 and 2000 m depths. Due to lack of instrument for accurate determination of the distance between the water sampler and the sea bottom, all sides agreed to adopt a distance of about 100 m above the bottom as a near-bottom horizon.

Because of the ship drift during the sampling operations, all sides agreed to adopt a 5-mile radius around the sampling point as a working area for each station. If the ship drifted outside this circle, the process of sampling was interrupted, and the ship returned to the original sampling point to continue sampling.

At each station, CTD casts were done up to 1500 m depths using a Russian CTD from the bowside deck. Russian specialists performed conductivity determinations for several water samples on board.

At each station except the first background one, XBT (expendable bathythermograph) measurements were done up to 700-800 m depths, using a Japanese XBT system from the stern deck.

Regular meteorological observations has been carried out at 00:00, 06:00, 12:00 and 18:00 GMT. Regular receiving and analysis of facsimile weather maps from Tokyo RMC (surface, analysis, AT850, AT500, forecast maps) were made. Weather forecasts were performed for one and two days.

1.2. Water sampling and handling.

a) Surface water.

Surface water for subsequent distribution among the four parties was sampled by the Russian side. For this purpose, a vibrating pump was immersed below the sea surface. Water was pumped through a filtration unit for the separation of suspended matter. A combined filters were used: the first a fabric filter (FPP-15-1,5) and the second a paper filter ("blue tape"). The pore size of the combined filter was about 1 µm, and the flow rate was about 12 l/min. Filtered water was distributed between the participating sides in sufficient quantities. Information on the sample volumes is given in Annex 4. All the surface water samples were collected from the stern side deck.

When the distribution of filtered water was finished, the total pumped water volume was determined. Filters were removed from the filtration unit, placed in plastic bags and passed to Japanese and Korean representatives (according to a joint agreement) for future radionuclide analysis in shore laboratories.

Russian specialists performed preconcentration of radionuclides from filtered water onboard, according to procedures described below in Chapter 2 of this Report.

For the sample storage onboard and for transportation to shore laboratories, 20 l plastic containers (Cubitainers) were used. To avoid sorption of radionuclides on the walls of the containers during storage, 40 ml of concentrated HCl was added to each container.

In addition to the above mentioned operations, Japanese, Korean and Russian specialists undertook pumping of large volumes of surface water by means of submersible pumps. This water was pumped through special units for radionuclide sorption (see Chapter 2 and Annex 4).

At some stations Russian specialists collected subsurface water at 100 m depths, and then filtered and passed through the sorbents for determination of radiocaesium.

Japanese specialists used the following procedure for the treatment of surface water. Surface water was pumped at a flow rate of about 2 l/min into a large plastic container (300 l) with an immersed HPGe detector for the direct spectrometric analysis.

b) Deep water.

Deep water samples were taken by means of a large volume water sampler with a soft envelope provided by the Russian side and operated by the Russian team. About 250-300 l of sea water was collected per one cast. The participating sides agreed to perform three successful casts of water sampling to each horizon, with the following distribution of deep water:

IAEA	120 l
Japan	160 l
Republic of Korea	160 l
Russia	the rest, up to 450 l.

Deep water samples were pumped through the filtration unit provided by the Russian side and operated by the Russian team according to the same procedure as for the surface water. Filtered water was pumped into two plastic tanks (500 l each) provided by the Japanese side. Each tank was filled with one half of the sample volume after each cast to ensure sample homogeneity for further water distribution. As for the surface water, the Russian team undertook onboard preconcentration of radionuclides.

Japanese, Korean and IAEA specialists used 20 l plastic containers for sample storage and the same sample treatment procedure as for surface water. The filters from deep water filtering were packed into plastic bags and passed to the Japanese and Korean sides according to a joint agreement for radionuclide analysis in shore laboratories.

1.3. Bottom sediment sampling and handling.

Bottom sediment samples were collected at each station using a modified Petersen grab sampler ("Ocean-0,25" provided by the Russian side and handled by the Russian team) from the bowside deck. Sediment samples were taken from an area of about 0.25 m^2 and had a thickness of about 10-15 cm.

According to a joint agreement the following treatment of the grab samples was performed. After inspecting the condition of the surface layer of the sediment, if the surface layer was undisturbed, the top 3 or 5 cm was well mixed in a plastic vessel, placed in small plastic cans and distributed to the four parties. The rest of the grab sample (subsurface layer) was well mixed in a stainless steel vessel and then placed in 5 l plastic bottles and distributed. The approximate wet weights of surface and subsurface sediment samples are given in Annex 4.

Russian specialists divided their samples into two parts. The first one was packed into a plastic container for transportation to shore laboratories. The second one was dried and measured by onboard gamma-spectrometer, and then packed into a plastic container for transportation to shore laboratories.

1.4. Biota sampling and handling.

a) Zooplankton.

Zooplankton samples were collected by a Juday plankton net (diameter 37 cm, mesh 168 µm) from 200 m depths to the surface (6 casts). Immediately after collection, zooplankton samples were mixed, concentrated and divided to the Japanese and Korean sides. Samples were kept in refrigerator. The individual sample weights were about 10-20 grams (wet weight).

For the Russian side, zooplankton was collected from the following layers: 0 - 200 m, 0 - 25 m, 25 - 50 m, 50 - 100 m, 100 - 200 m, 200 - 500 m. These samples were preserved by formaldehide solution (4 %).

b) Benthos.

The remaining sediment (after four parties subsampling for radionuclide analysis) was sieved through a 1 mm mesh. Macrobenthos organisms were preserved by formalin solution (4 %).

Species composition of benthos will be determined on land, in the FERHRI laboratory.

Japan and Korean sides kept biota samples frozen for the analysis on land.

c) Fish and shrimps.

On March 27, we received samples of fish (Walleye pollack, flatfish, etc.) and shrimps catched by a Russian fishing boat near the point N 7. Fish species were divided into three parts: heads, edible parts and internal organs. The radioactivity of fresh edible parts of fish and shrimps was measured on board. For shrimps, crusts were also measured.

2. Methods of onboard preconcentration of radionuclides

2.1. Japan.

Surface sea water was directly pumped up at the flow rate of about 2 l/min into a radionuclide collection system, which was composed of a combination of one filter column (0.45 μm pore size) to collect suspended radionuclides and two columns with acrylic fiber, impregnated with KCFC {Potassium hexacobalt ferrate, $K_2[CoFe(CN)_6]$} to collect dissolved radionuclides.

Surface sea water was also pumped up at the flow rate of about 2 l/min directly into a radionuclide collection system which was composed of a combination of one filter column (0.45 μm pore size) and two columns with acrylic fiber, impregnated with MnO_2.

2.2. Republic of Korea.

Surface water for Cs determinations was pumped directly to a filtering system consisting of three consecutive cartridge filters, the first one to remove suspended matter >1 μm and the following two with Cs-adsorbent, $Cu_2Fe(CN)_6$. A flowmeter mounted at the outlet of the third filter registered the amount of water filtered (about 2 l/min). As much surface water as time permitted was run through the filter system.

2.3. Russian Federation.

Russian specialists performed the preconcentration of cobalt and caesium from sea water samples by two methods: sorption and precipitation. Preconcentration of plutonium was carried out also by two different techniques.

2.3.1. The procedure of plutonium preconcentration from sea water samples.

a) The filtered sea water sample was acidified to pH=2 by adding concentrated HCl during mixing, followed by addition of Pu-242 tracer and 200 g of sodium sulfite per 100 l of water. The sample was mixed periodically during 12 hours, then $FeCl_3$ solution was added (1 g Fe^{3+} per 100 l sample) and the sample was mixed again periodically during 2-3 hours.

During good mixing, a solution of sodium alkali was added in steps up to pH=8.5-9.5. The sample was left standing for 12-24 hours to have a fully clear supernate. The supernate was decanted and the precipitate was filtered.

b) Preconcentration of plutonium was carried out by precipitation at pH=3-4 with zirconium phosphate from 100 l of sea water acidified by HCl. The supernate was decanted, and precipitate was filtered, dried and kept until anlysis on land.

2.3.2. The procedure of strontium onboard preconcentration from sea water samples.

Samples of deep water were taken with a large-volume sampler and the surface water with a hose connected to pump. A 11-12 l plastic bottle was filled with filtered water (filter pore size 1 um). A 0.5 l subsample was taken from this bottle and transferred to a small glass or plastic bottle for stable strontium determination. The water volume in the larger bottle was adjusted to 10 l and then 120 g of Na_2CO_3 was added. The bottle content was mixed (15-20 min) up to the point of dissolution of the Na_2CO_3 and then the bottle was left standing for 24 hours.

After the precipitation, the supernate was decanted carefully by means of a rubber hose. The precipitate was filtered in a Buhner funnel and washed with 20 cm³ of deionized water. The filtered precipitate was then packed into plastic bags.

2.3.3. Preconcentration of Cs from water samples.

a) Surface water was pumped by an immersible pump; first through the filtration unit (1 µm pore size) and then through the fiber sorbent impregnated with $Cu_2Fe(CN)_6$ (flow rate about 1.5-2.0 l/min).

b) A large tank was filled with filtered deep water, then water was pumped through the fiber sorbent impregnated with $Cu_2Fe(CN)_6$ (flow rate about 1.5-2.0 l/min).

2.3.4. Preconcentration of Co, Cs, Ce and Sr from sea water.

Preconcentration of Co and Cs was carried out by precipitation with potassium ferrocyanide, and Ce and Sr with sodium carbonate from the same sample (100 l). Determination of carrier yield will be performed by atomic absorption spectrophotometry on land.

3. Methods of preliminary spectrometric analysis on board

3.1. Japan.

3.1.1. Surface sea water.

The surface sea water was pumped up directly into a large plastic container (300 l) and measured in situ by gamma-spectrometry with a Ge detector immersed into the sea water. The detection limits (10000 sec counting time) were 0.3 Bq/l for ^{137}Cs, 0.2 Bq/l for ^{134}Cs and ^{60}Co, and 4 Bq/l for ^{40}K.

3.1.2. Sorbents.

After collection of radionuclides from sea water (about 1000 l except for the N 2 point of about 5000 l), the KCFC fiber was placed in a 4 l Marinelli beaker or 1350 ml plastic container for preliminary determination of the collected radionuclides. The same procedure was applied to the MnO_2 fiber.

The spectrometric system was based on a 22 % HPGe detector with a peak resolution (FWHM) of 2 keV at 1.33 MeV, ^{60}Co, which was enclosed in a 5 cm thick Pb shield. The detection limits (10000 sec counting time) were 0.8 mBq/l for ^{137}Cs, 2 mBq/l for ^{134}Cs and ^{60}Co for KCFC fiber, and 0.9 mBq/l for ^{60}Co for MnO_2 fiber.

3.1.3. Sediments.

After homogenization of the sediment samples, about 0.1-0.6 kg (dry weight) was placed in a 170 ml or 500 ml plastic container for preliminary determination of the radionuclide concentrations.

The spectrometric system used was described in the section of 3.1.2. The detection limits were 4-7 Bq/kg for ^{137}Cs and 3-9 Bq/kg for ^{134}Cs and ^{60}Co, respectively.

3.1.4. Biota samples.

After homogenization of the biological samples, about 0.5-1.4 kg (fresh weight) was placed in a 170 ml or 500 ml plastic container for the preliminary determination of the radionuclide concentrations.

The spectrometric system used was described in the section of 3.1.2. The detection limits were 1-2 Bq/kg for ^{137}Cs, ^{134}Cs and ^{60}Co.

3.2. Russian Federation.

3.2.1. Surface sea water.

Direct spectrometric analysis of radioactivity of surface sea water was performed in situ with a NaI (Tl) detector (400 mm length and 200 mm in diameter) immersed at 50, 100, 150 and 200 m depths. The detection limits (12000-19000 sec counting time) were 6-8 mBq/l for ^{137}Cs, 4-5 mBq/l for ^{60}Co and 30-40 mBq/l for ^{40}K.

3.2.2. Sorbents.

After collection of radionuclides from sea water (about 500-6000 l), the $Cu_2Fe(CN)_6$ fiber was placed in a 100 ml Marinelli beaker for preliminary determination of collected radionuclides.

The spectrometric system was based on a NaI (Tl) detector (63 mm length and 63 mm in diameter) enclosed in a 8 cm thick Pb shield. The detection limits (6600-19700 sec counting time) were 0.3-0.8 mBq/l for ^{137}Cs and 0.3-0.9 mBq/l for ^{60}Co.

3.2.3. Sediments.

After homogenization of the sediment samples, about 0.2-1.5 kg (dry weight) was placed in a 100 ml or 1000 ml plastic container for preliminary determination of the radionuclide concentrations.

The spectrometric system was based on a NaI (Tl) detector (63 mm length and 63 mm in diameter) enclosed in a 8 cm thick Pb shield. The detection limits (6600-13100 sec counting time) were 2-3 Bq/kg for ^{137}Cs and 3-4 Bq/kg for ^{60}Co.

3.2.4. Biota samples.

After homogenization of the biological samples, about 0.5-1.4 kg (fresh weight) was placed in a 1000 ml plastic container for the preliminary determination of the radionuclide concentrations.

The spectrometric system was based on a NaI (Tl) detector (63 mm length and 63 mm in diameter) enclosed in a 8 cm thick Pb shield. The detection limits (6600-13100 sec counting time) were 2-3 Bq/kg for ^{137}Cs and 3-4 Bq/kg for ^{60}Co.

4. Methods of radionuclide analysis on land

The list of radionuclides that will be analysed on land is presented in Annex 8.

4.1. Japan.

4.1.1. Gamma emitters.

a) Sea water.

Gamma emitting radionuclides (cobalt-60, cesium-137 and others) will be collected from sea water samples using ammonium phosphomolybdate and manganese dioxide. Then the radionuclides in the precipitate will be measured by gamma-ray spectrometry using a germanium detector.

b) Sediment.

Sediment samples will be dried and reduced to a powder. Then the radionuclides in the powder will be measured by gamma-ray spectrometry using a germanium detector.

c) Sorbents.

Sorbents will be dried and reduced to ashes at 400°C. Then the radionuclides in the ashes will be measured by gamma-ray spectrometry using a germanium detector.

4.1.2. Strontium.

a) Sea water.

^{90}Sr will be collected from sea water samples by a precipitation method. Then ^{90}Y produced from ^{90}Sr will be measured with a low background beta-ray detector.

b) Sediment.

After drying and reducing to a powder, strontium will be extracted from the sediment powder to an acid solution. Strontium will be collected by a precipitation method, and the ^{90}Y produced from ^{90}Sr will be measured with a low background beta-ray detector.

4.1.3. Plutonium.

a) Sea water.

After adding ^{242}Pu tracer to the acidified sample, plutonium will be collected from sea water by a co-precipitation method using iron. Then the plutonium will be purified by an ion exchange resin column method. After the electrodeposition of plutonium on a stainless steel disc, it will be measured by alpha-ray spectrometry using silicon semi-conductor detector.

b) Sediment.

After adding ^{242}Pu tracer to the powder, sediment will be dried and reduced to a powder. Plutonium will be extracted from the powder to a acid solution, and then purified by an ion exchange resin column method. After the electrodeposition of plutonium on a stainless steel disc, it will be measured by alpha-ray spectrometry using silicon semi-conductor detector.

4.2. Republic of Korea.

4.2.1. Gamma emitters.

a) Sea water.

Gamma emitting radionuclides (^{60}Co, ^{137}Cs and others) will be adsorbed onto AMP and MnO_2 from sea water samples. Then the precipitations will be measured by gamma-ray spectrometry.

b) Sediment.

After drying and reducing to a powder, the radionuclides in the powder will be measured by gamma-ray spectrometry.

c) Sorbents.

Sorbents will be dried and reduced to ash at 450°C. Then the radionuclides in the ashes will be measured by gamma-ray spectrometry.

4.2.2. Strontium.

a) Sea water.

^{90}Sr will be collected from sea water samples by a precipitation method. Strontium recovery will then be determined by ^{85}Sr gamma-counting or atomic absorption spectrometry. ^{90}Y produced from ^{90}Sr will be measured with a low background beta-ray detector.

b) Sediment.

After drying and ashing the samples at 450°C, strontium will be extracted to an acid solution. Strontium will then be separated from other elements by a precipitation method. ^{90}Y produced from ^{90}Sr will be measured with a low background beta-ray detector.

4.2.3. Plutonium.

a) Sea water.

After adding ^{242}Pu tracer to the acidified sample, plutonium will be collected from the sample by a co-precipitation method using iron or MnO_2. Then the plutonium will be purified by an ion exchange resin column method. After the electrodeposition of plutonium on a stainless steel disc, it will be measured by alpha-ray spectrometry using silicon semi-conductor detector.

b) Sediment.

The sediment will be dried and reduced to a powder. After adding ^{242}Pu tracer to the powder, plutonium will be extracted to an acid solution. Plutonium will then be purified by an solvent extraction and ion exchange resin column method. After the electrodeposition of plutonium on a stainless steel disc, it will be measured by alpha-ray spectrometry using silicon semi-conductor detector.

4.3. Russian Federation.

4.3.1. Gamma emitters.

a) Sea water.

Gamma emitting radionuclides (^{60}Co, ^{137}Cs and others) which are coprecipitated aboard from 100 l of sea water will be measured by gamma-ray spectrometry using a germanium detector.

b) Sediment.

Sediment samples will be dried and reduced to a powder. Then the radionuclides in the powder will be measured by gamma-ray spectrometry using a germanium detector.

c) Sorbents.

Sorbents will be dried and reduced to ashes at 400-450°C. Then the radionuclides in the ashes will be measured by gamma-ray spectrometry using a germanium detector.

4.3.2. Strontium.

a) Sea water.

^{90}Sr will be collected from sea water samples by a precipitation method. Then the ^{90}Y produced from ^{90}Sr will be measured with a low background beta-ray detector.

b) Sediment.

After drying and reducing to a powder, ^{90}Sr will be extracted from the sediment powder to an acid solution. Strontium will be collected by a precipitation method, and then the ^{90}Y produced from ^{90}Sr will be measured with a low background beta-ray detector.

4.3.3. Plutonium.

a) Sea water.

Plutonium will be collected from sea water by a co-precipitation method using iron. Then the plutonium will be purified by an ion exchange resin column method. After the electrodeposition of plutonium on a stainless steel disc, it will be measured by alpha-ray spectometry using a silicon semi-conductor detector.

b) Sediment.

Sediment will be dried and reduced to a powder. Plutonium will be extracted from the powder to an acid solution, and then purified by an ion exchange resin column method. After the electrodeposition of plutonium on a stainless steel disc, it will be measured by alpha-ray spectrometry using a silicon semi-conductor detector.

4.4. IAEA.

4.4.1. Sea water.

a) Gamma-emitters and Plutonium.

Carriers and yield determinants are added to the acidified sample, then MnO_2 precipitation of, e.g., Pu and Co, followed by Cs adsorption onto AMP. The combined ppt are then dissolved, evaporated and transferred to a container and analysed by gamma-spectrometry (HPGe). The sample is then processed by ion exchange separation of Pu (AG 1-X8), followed by electrodeposition and alpha-spectrometric analysis (Si-surface barrier detectors). Finally, ^{241}Pu is measured by LSC.

b) Strontium.

Carriers and yield determinants are added to the acidified sample, then oxalate precipitation of Sr, followed by conc. HNO_3 separation Sr/Ba and additional ppt for purification. Sr recovery is then determined by ^{85}Sr gamma-counting. Later, Y is separated from Sr and ^{90}Y counted on a low background beta-proportional detector or by LSC.

4.4.2. Sediment.

The sediments are freeze-dried, oven-dried, ground and homogenized.

a) Plutonium.

Oxalic acid is added, then sample dry-ashing at 550°C, followed by addition of yield determinant. Pu is then leached from 8M HNO_3 followed by Fe-hydroxide ppt. Pu is then separated and counted as described above for sea water.

b) Strontium.

The sample is dry-ashed at 550°C, and yield determinant is then added. Sr is leached from 8M HNO_3 followed by Fe-hydroxide and oxalate ppt. Sr and Y are then separated and counted as described above for sea water.

5. Preliminary results

5.1. Spectrometric analysis on board (Japanese results).

5.1.1. Sea water.

a) Direct measurements.

Table 5.1 shows the results from the direct spectrometric analysis of surface sea water at each point. Figure 5.1 shows the results for ^{40}K. Figure 5.2 shows the spectrum for samples taken at the BG 1 and N 2 stations. There are no statistically significant peaks except for ^{40}K (1460.7 keV). The concentration of ^{40}K ranged from 8.7 to 12.3 Bq/l, i.e. small fluctuations among the sampling points. ^{137}Cs, ^{134}Cs and ^{60}Co activities were below the detection limits. There were no spectrometric data at the points N 3, N 4 and BG 2, because of a trouble with the measurement system.

b) Sorbent measurements.

Table 5.2 shows the results from the spectrometric analysis of sorbents with radionuclides concentrated from surface sea water at each sampling point and figure 5.3 shows the results for ^{137}Cs. Figure 5.4 shows the spectra of KCFC sorbent for samples taken at the BG 1 and N 2 points. Figure 5.5 shows the spectra of MnO_2 sorbent for samples taken at BG 1 and N 2 points. The concentrations of ^{137}Cs from KCFC fiber ranged from 3.3 to 4.7 mBq/l, i.e only small fluctuations among the sampling points. ^{134}Cs and ^{60}Co activities were below the detection limits.

5.1.2. Sediments.

Table 5.3 shows the results from the spectrometric analysis of bottom sediments for each sampling point. Figure 5.6 shows the spectra of samples taken at the BG 1 and N 2 points, displaying the peaks for annihilation (511 keV),

Table5. 1 Results from direct spectrometric analysis of surface sea water

(Bq/L)

Sampling Point	BG1	N5	N6
Sampling Date	94/03/23	94/03/24	94/03/26
Sample Volume (L)	285	285	285
Counting Time(sec)	10000	10000	10000
K-40	9.1±1.5	8.7±1.4	10.1±1.5
Cs-137	ND(<3.1E-01)	ND(<3.1E-01)	ND(<3.3E-01)
Cs-134	ND(<2.5E-01)	ND(<2.5E-01)	ND(<2.2E-01)
Co-60	ND(<2.3E-01)	ND(<2.2E-01)	ND(<2.1E-01)
Remark	spectrum data is shown in Fig.5.2		

(Bq/L)

Sampling Point	N7	N1	N2
Sampling Date	94/03/27	94/03/28	94/03/29
Sample Volume (L)	285	285	285
Counting Time(sec)	10000	10000	10000
K-40	9.8±1.5	9.4±1.4	12.3±1.5
Cs-137	ND(<2.8E-01)	ND(<3.2E-01)	ND(<3.3E-01)
Cs-134	ND(<2.1E-01)	ND(<2.1E-01)	ND(<2.3E-01)
Co-60	ND(<1.9E-01)	ND(<2.0E-01)	ND(<2.2E-01)
Remark			spectrum data is shown in Fig.5.2

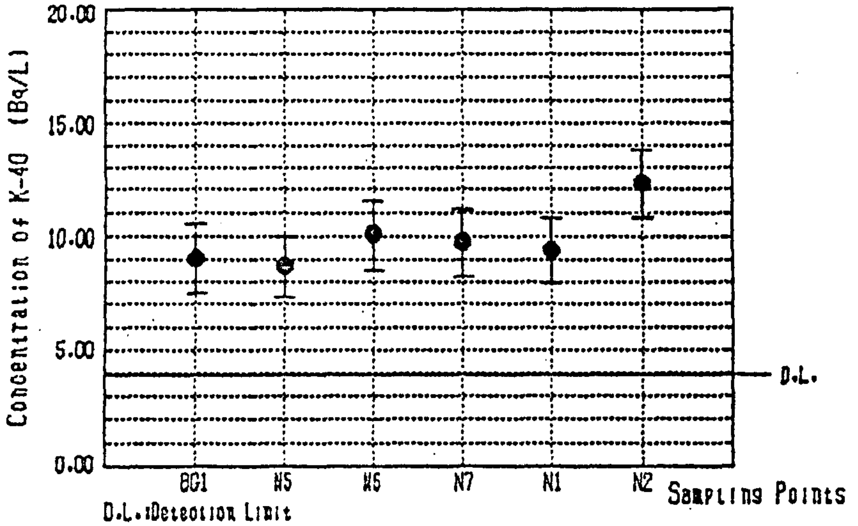


Fig.5.1 Determined Concentration of K-40 in Surface Sea Water at each Point

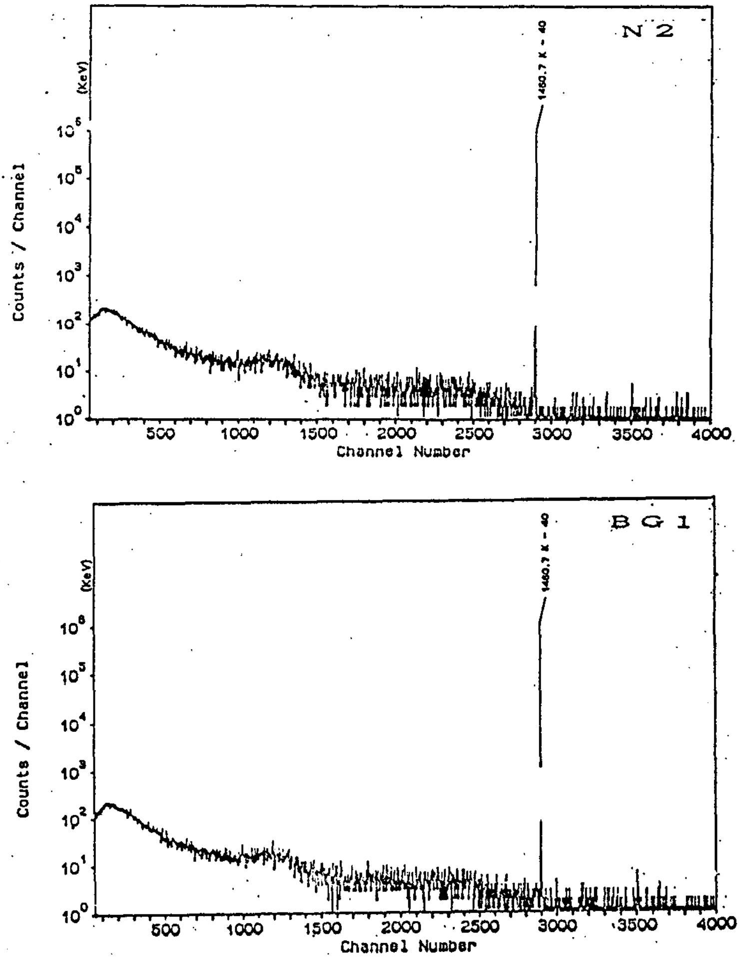


Fig. 5.2 Examples of γ-ray spectra
(surface sea water at the BG1 and
the N2 points)

Table5. 2 Results from the spectrometric analysis of sorbent

(Bq/L)

Sampling Point		BG1	N5	N6	N7	N1
Sampling Date		94/03/23	94/03/24	94/03/26	94/03/27	94/03/28
Sample Volume (L)		1012.3	1104.3	1228.6	779.9	1390.4
Counting Time(sec)		6000	6000	6000	30000	10000
	Cs-137	(3.5±1.3)E-3	(4.7±1.4)E-3	(3.6±1.3)E-3	(4.1±0.8)E-3	(4.7±0.9)E-3
	Cs-134	ND(<2.2E-3)	ND(<2.0E-3)	ND(<1.7E-3)	ND(<1.1E-3)	ND(<1.1E-3)
	Co-60	ND(<2.1E-3)	ND(<2.3E-3)	ND(<2.4E-3)	ND(<1.3E-3)	ND(<1.2E-3)
Remark		spectrum data is shown in Fig.5.4				

(Bq/L)

Sampling Point		N2	N3	N4	BG2	
Sampling Date		94/03/31	94/04/01	94/04/02	94/04/03	
Sample Volume (L)		5102.3	1445.0	1099.7	1291.3	
Counting Time(sec)		6000	6000	28400	12000	
	Cs-137	(3.3±0.5)E-3	(3.9±1.2)E-3	(4.4±0.6)E-3	(3.5±0.9)E-3	
	Cs-134	ND(<4.1E-4)	ND(<1.8E-3)	ND(<7.1E-4)	ND(<1.1E-3)	
	Co-60	ND(<4.7E-4)	ND(<1.6E-3)	ND(<7.8E-4)	ND(<1.3E-3)	
Remark		spectrum data is shown in Fig.5.4				

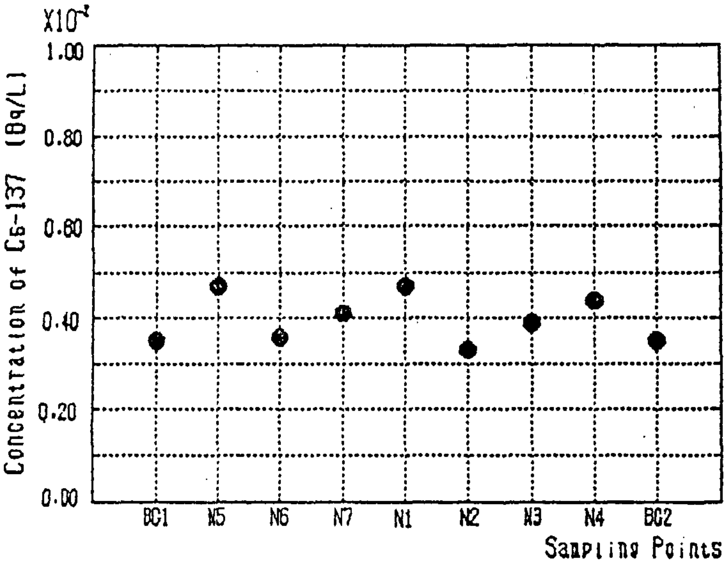


Fig.5.3 Determined Concentration of Cs-137 in Surface Sea Water at each Point.

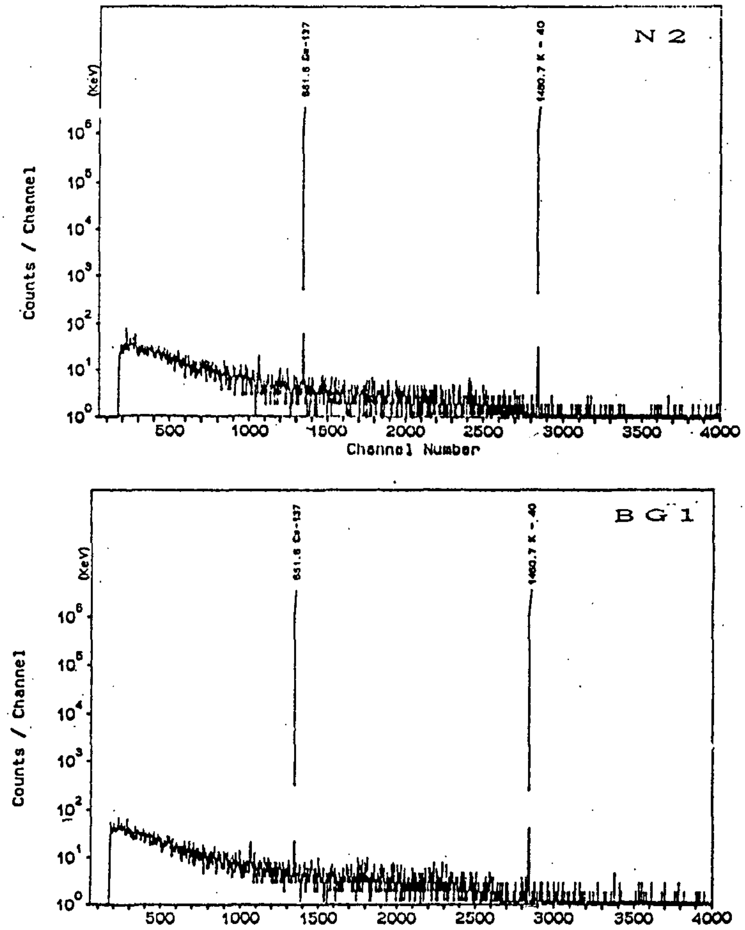


Fig. 5.4 Examples of γ-ray spectra
(KCFC at the BG1 and the N2 points).

Table5. 3 Results from the spectrometric analysis of sea bottom sediments

(Bq/kg)

Sampling Point	BG1	N5	N6	N7	N1
Sampling Date	94/03/23	94/03/24	94/03/25	94/03/27	94/03/27
Sample Weight (kg)	0.59	0.22	0.17	0.18	0.26
Counting Time(sec)	6000	6000	10000	6200	6000
Cs-137	ND(<3.6E-0)	ND(<4.2E-0)	ND(<4.9E-0)	ND(<4.7E-0)	ND(<4.5E-0)
Cs-134	ND(<3.3E-0)	ND(<4.3E-0)	ND(<5.0E-0)	ND(<4.8E-0)	ND(<4.8E-0)
Co-60	ND(<4.2E-0)	ND(<5.5E-0)	ND(<6.0E-0)	ND(<5.8E-0)	ND(<5.8E-0)
K-40	(6.5±0.6)E+2	(4.0±0.7)E+2	(6.9±0.8)E+2	(6.2±0.9)E+2	(7.1±0.8)E+2
Remark	spectrum data is shown in Fig.5.6				

(Bq/kg)

Sampling Point	N2	N3	N4	BG2	
Sampling Date	94/03/28	94/04/01	94/04/01	94/04/03	
Sample Weight (kg)	0.15	0.15	0.15	0.13	
Counting Time(sec)	10000	6000	6000	6000	
Cs-137	ND(<5.9E-0)	ND(<6.4E-0)	ND(<6.9E-0)	ND(<6.1E-0)	
Cs-134	ND(<6.2E-0)	ND(<6.8E-0)	ND(<6.9E-0)	ND(<6.8E-0)	
Co-60	ND(<6.7E-0)	ND(<9.1E-0)	ND(<8.3E-0)	ND(<7.9E-0)	
K-40	(9.6±0.9)E+2	(9.2±1.2)E+2	(1.0±0.1)E+3	(6.3±1.1)E+2	
Remark	spectrum data is shown in Fig.5.6				

uranium and thorium series nuclides and ^{40}K (1460.7 keV). The concentration of ^{40}K ranged between 400 and 1000 Bq/kg. Activities of ^{137}Cs, ^{134}Cs and ^{60}Co were below the detection limits.

5.1.3. Biota samples.

Table 5.4 shows the results from the spectrometric analysis of biota samples (meat and crust of shrimp and meat of fish of two species). Figure 5.7 shows the spectra with main peaks for annihilation (511 keV) and ^{40}K (1460.7 keV). The concentration of ^{40}K in meat ranged between 80 and 120 Bq/kg. Activities of ^{137}Cs, ^{134}Cs and ^{60}Co were below the detection limits.

5.2. Spectrometric analysis on board (Russian results).

5.2.1. Sea water.

a) Direct measurements.

Table 5.5 shows the results from the direct spectrometric analysis of surface sea water at each station. Figure 5.8 shows the spectrum for a sample taken at point N 2 (100 m depth). There are no statistically significant peaks except for ^{40}K (1460.7 keV). The concentration of ^{40}K ranged from 11.02 to 11.94 Bq/l, i.e. very small fluctuations among the sampling stations. Figure 5.9 illustrates the ^{40}K concentrations as a function of sea water salinity. The spectra of other measured sea water samples are presented in Annex 5. Activities of ^{137}Cs and ^{60}Co were below the detection limits.

b) Sorbent measurement.

Table 5.6 shows the results from the spectrometric analysis of sorbents with radionuclides concentrated from surface sea water, from 100 m depth and from bottom water at

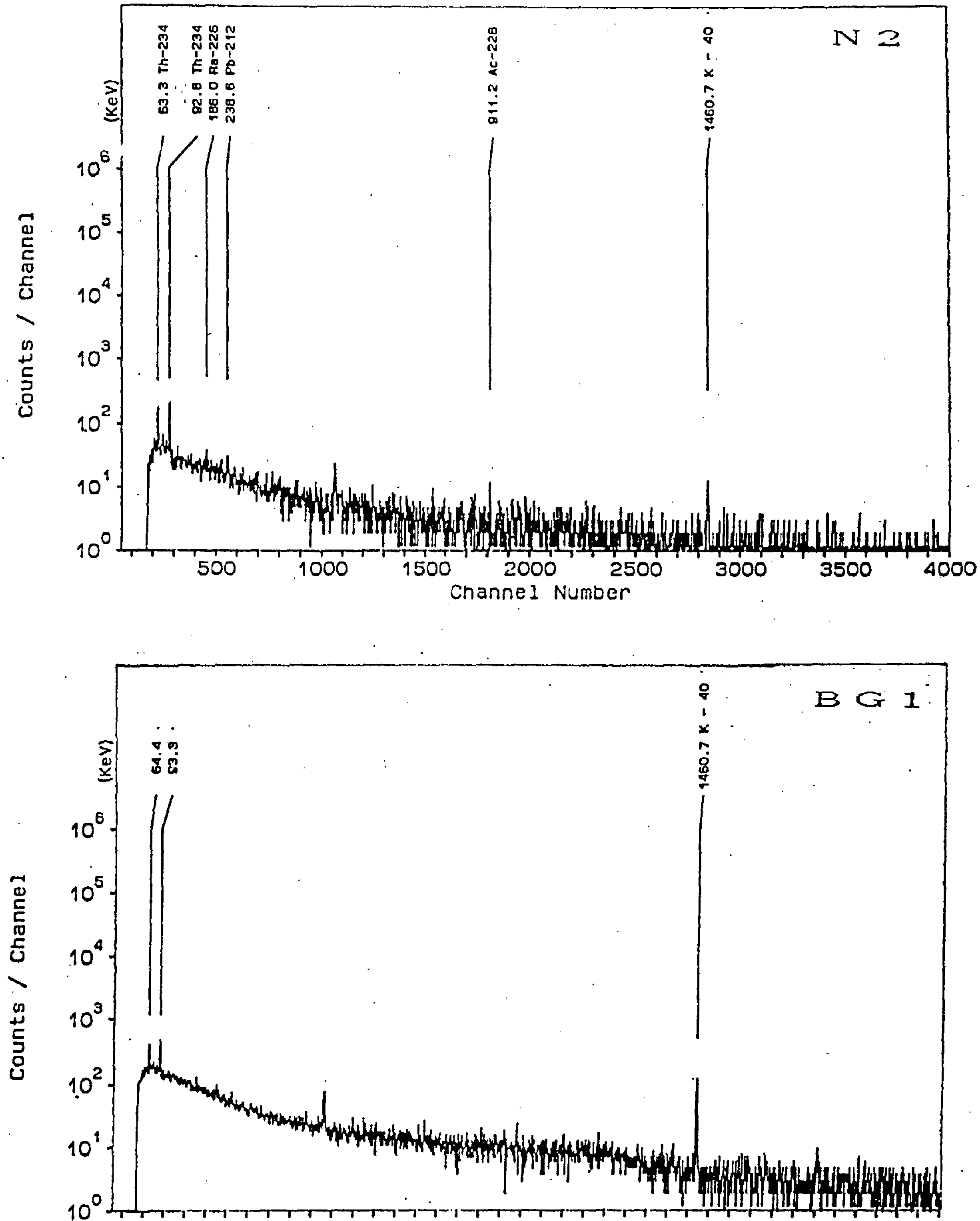


Fig. 5.5 Examples of γ-ray spectra
(MNO$_2$ at the BG1 and the N2 points).

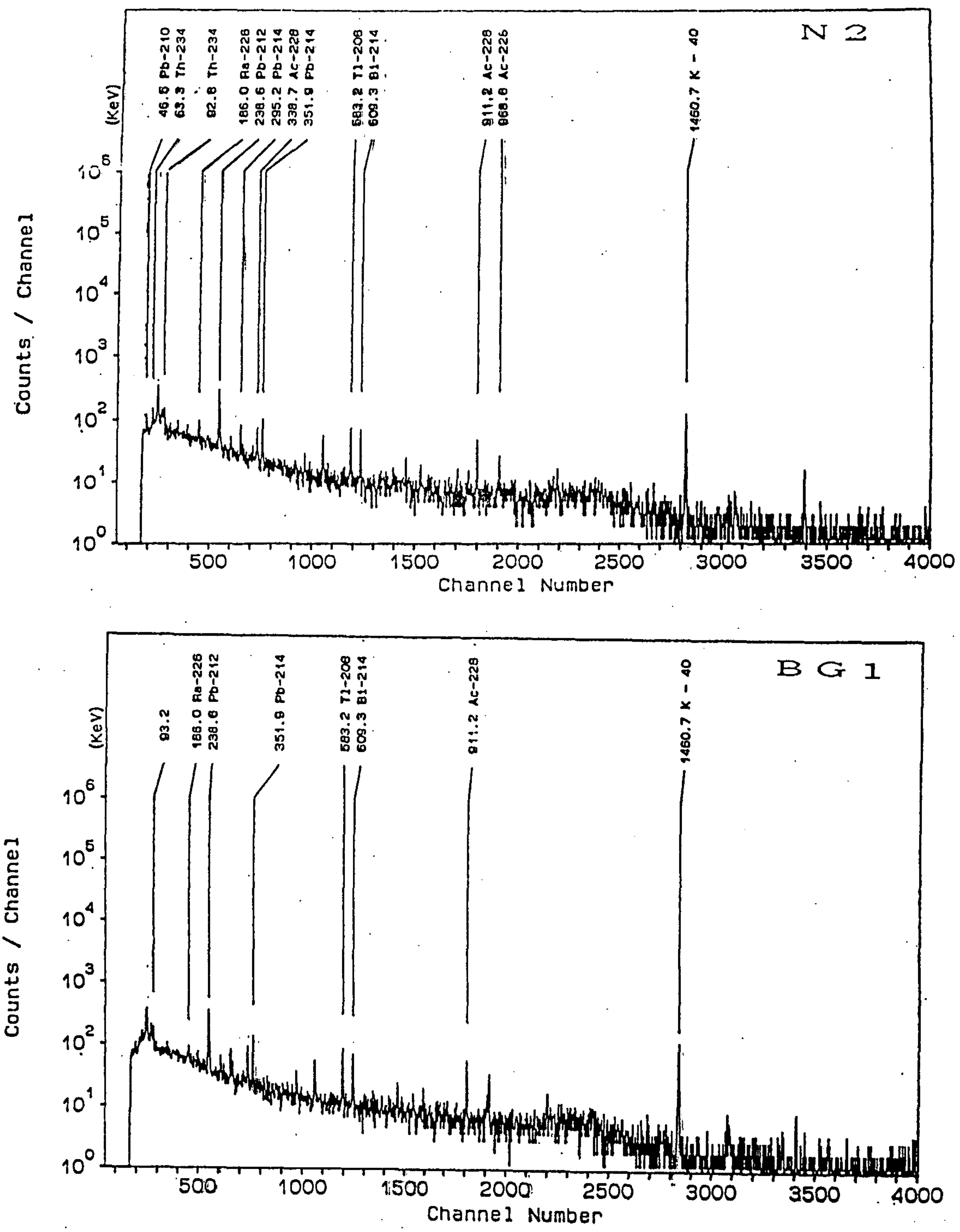
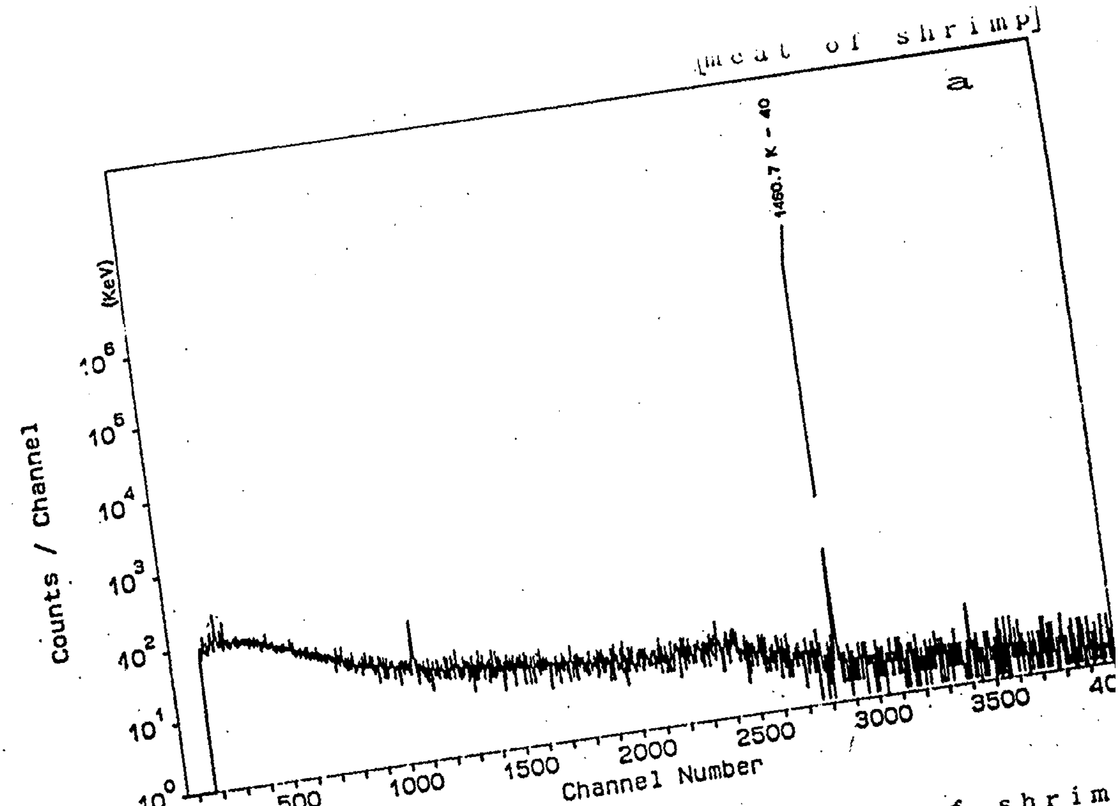


Fig. 5.6 Examples of γ-ray spectra
(sea bottom sediment at the BG1 and the N2 points)

Table5. 4 Results from the spectrometric analysis of biota samples

(Bq/kg)

Sample	Meat of shrimp at the N7 point	Crust of shrimp at the N7 point	Meat of flatfish at the N7 point	Meat of Hokke at the N7 point
Sample Weight (kg)	0.54	0.54	1.2	1.4
Counting Time(sec)	30000	30000	6000	6000
Cs-137	ND(<1.2E-0)	ND(<1.7E-0)	ND(<1.7E-0)	ND(<1.5E-0)
Cs-134	ND(<1.1E-0)	ND(<1.8E-0)	ND(<2.0E-0)	ND(<1.7E-0)
Co-60	ND(<1.1E-0)	ND(<1.9E-0)	ND(<2.1E-0)	ND(<1.8E-0)
K-40	(1.0±0.2)E+2	(1.1±0.2)E+2	(8.0±2.3)E+1	(1.2±0.2)E+2
Remark	spectrum data is shown in Fig.5.7	spectrum data is shown in Fig.5.7	spectrum data is shown in Fig.5.7	spectrum data is shown in Fig.5.7



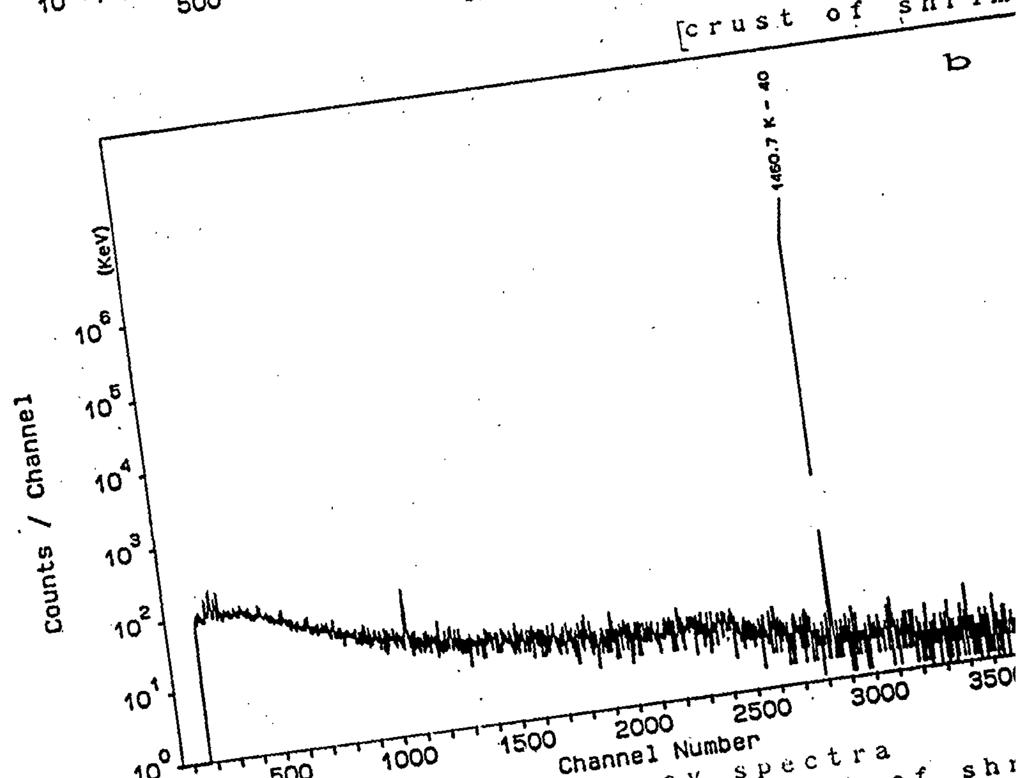
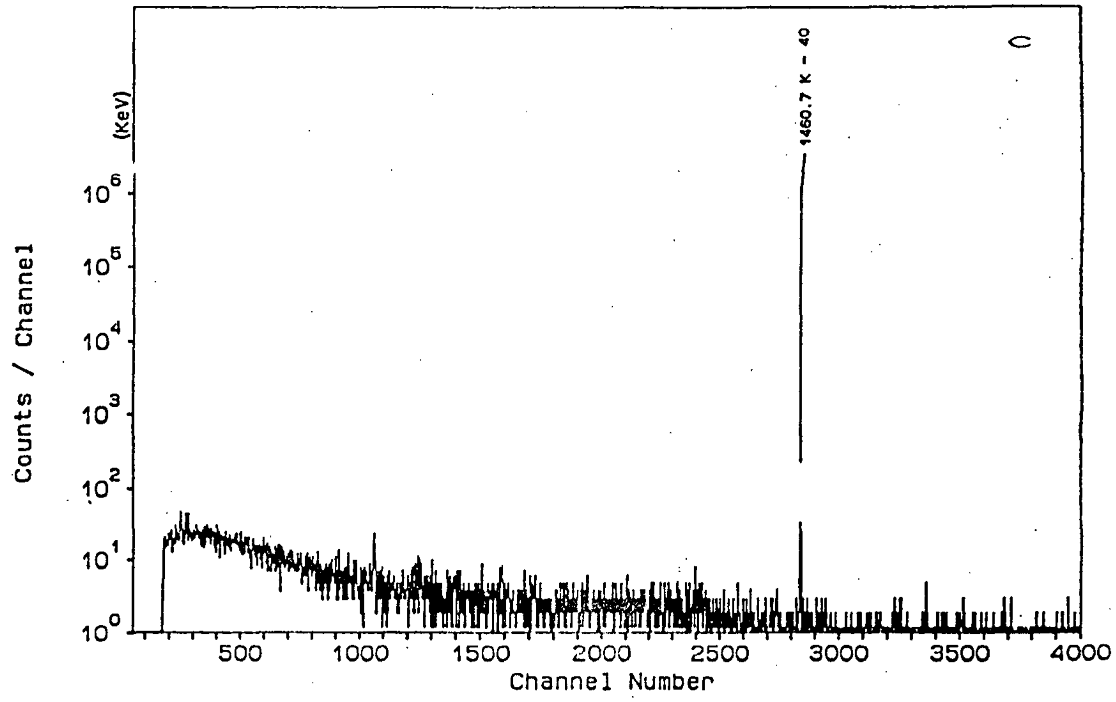


Fig. 5.7 Examples of γ-ray spectra
(a: meat of shrimp, b: crust of shr
c: meat of flatfish, and d: meat o
Hokke at the N7 po

[meat of flatfish]



[meat of Hokke]

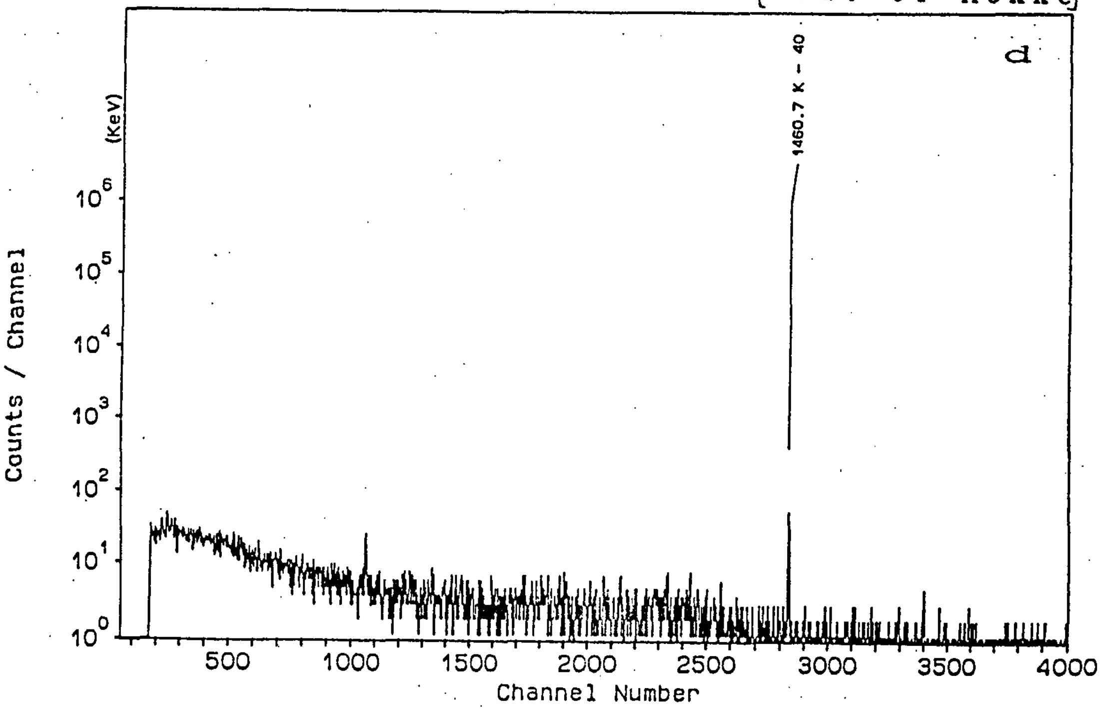


Fig. 5.7 Continued.

Table5. 5 Results from direct spectrometric analysis of surface sea water

(mBq/L)

Point (Date)	Depth(m)	Cs-137	Co-60	k-40 (E+3)
BG1 (94/03/23)	100	< 6.0	< 4.0	11.25±0.06
N5 (94/03/24)	50	< 7.0	< 5.0	11.09±0.07
	100	< 8.0	< 5.0	11.76±0.07
	150	< 7.0	< 5.0	11.53±0.07
	200	< 6.0	< 4.0	11.53±0.06
N6 (94/03/26)	50	< 7.0	< 5.0	11.34±0.02
	100	< 8.0	< 5.0	11.27±0.08
	150	< 7.0	< 5.0	10.96±0.02
N7 (94/03/27)	50	< 8.0	< 5.0	11.33±0.02
	100	< 6.0	< 4.0	11.33±0.06
	200	< 7.0	< 5.0	11.25±0.07
N1 (94/03/28)	50	< 7.0	< 5.0	11.21±0.07
	100	< 6.0	< 4.0	11.87±0.06
	200	< 7.0	< 5.0	11.75±0.07
N2 (94/03/29)	10	< 6.0	< 4.0	11.43±0.06
	50	< 6.0	< 4.0	11.43±0.06
	100	< 5.0	< 3.0	11.50±0.04
	150	< 6.0	< 4.0	11.30±0.06
	200	< 6.0	< 4.0	11.02±0.06
	300	< 6.0	< 4.0	11.94±0.06
N3 (94/04/01)	50	< 7.0	< 5.0	11.27±0.02
	100	< 8.0	< 5.0	11.59±0.08
N4 (94/04/01)	50	< 7.0	< 5.0	11.30±0.07
	100	< 7.0	< 5.0	11.43±0.07

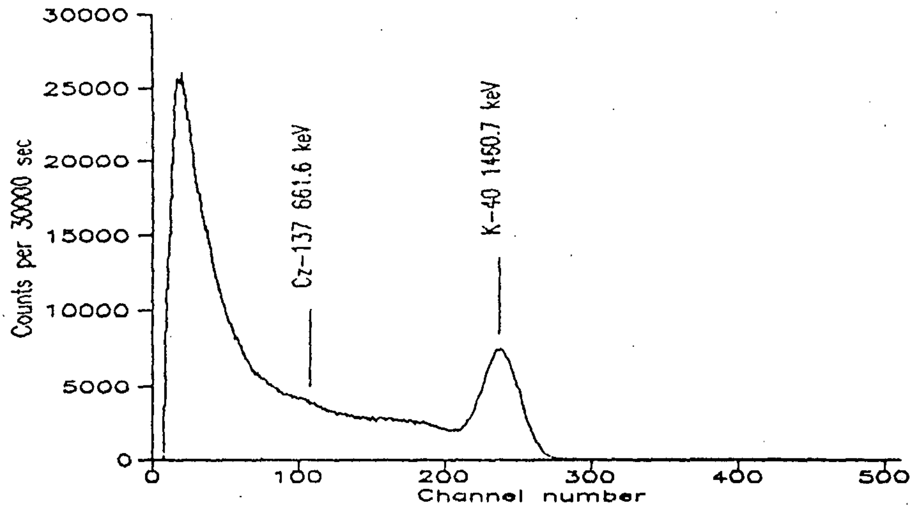


Figure 5.8

Gamma-spectrum of sea water at point N 2 at 100 m depth

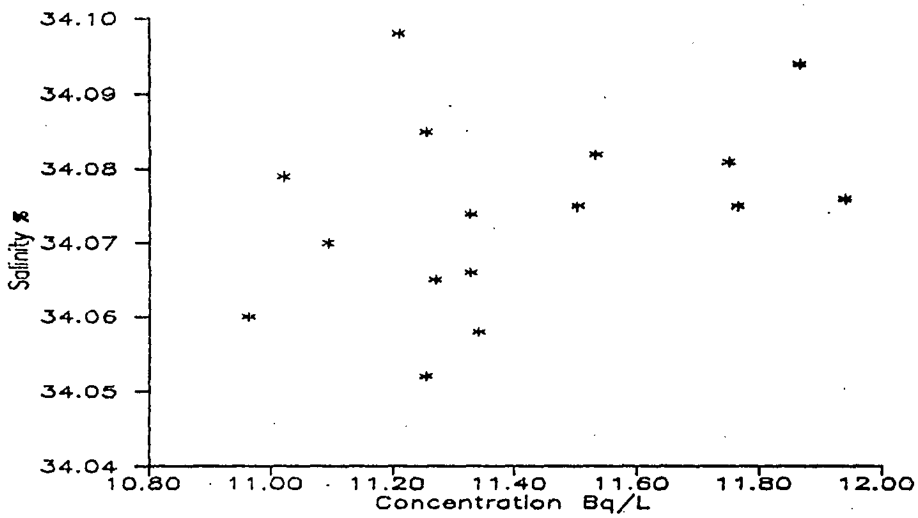


Figure 5.9

Variation of ^{40}K concentration and sea water salinity at points N BG1 – N 4 at depth 50–200 m

Table5. 6 Results from the spectrometric analysis of sorbents from sea water

(mBq/L)

Sampling Point			BG1	N5	N6	N7	N1	N2	N3	N4	BG2
Sampling Date			94/03/23	94/03/24	94/03/26	94/03/27	94/03/28	94/03/29	94/04/01	94/04/02	94/04/03
Depth (m)	0	Cs-137	2.9±0.9※	3.0±1.3※	3.0±1.0※	3.9±1.3※	4.2±1.4	4.1±1.3	4.3±1.3※	3.7±1.2※	3.0±1.0※
		Volume(L)	5166	5962	6040	3572	492	546	4382	4535	4502
	-100	Cs-137	4.2±1.4※	3.5±1.2※	-	3.5±1.2※	-	3.7±1.1	-	-	-
		Volume(L)	1573	2049	-	1801	-	1267	-	-	-
	+100	Cs-137	<3.0	<3.0	<3.0	<3.0	<3.0	<2.0	<3.0	<2.0	<2.0
		Volume(L)	90	91	110	120	140	264	136	245	275
Max Depth (m)			3245	3495	3290	3400	3580	3510	3630	3500	2900
Remark 1			Spectrum Data: Fig.5.10					Spectrum Data: Fig.5.10			
Remark 2			※ The results are given with a correction on a decrease of the sorbent efficiency on high volumes of water treated.								

Table5. 7 Results from the spectrometric analysis of sea bottom sediments

(Bq/kg)

Sampling Point			BG1	N5	N6	N7	N1	N2	N3	N4	BG2	EXP
Sampling Date			94/03/23	94/03/24	94/03/25	94/03/27	94/03/27	94/03/28	94/04/01	94/04/01	94/04/03	-
Radionuclides	Surface	k-40	8.6±0.6	5.2±0.8	7.0±0.8	5.1±0.6	6.0±0.9	7.3±0.8	9.0±0.8	8.5±0.6	6.0±0.4	E+2
		Cs-137	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	E-0
		Co-60	<4.0	<4.0	<4.0	<4.0	<4.0	<4.0	<4.0	<4.0	<4.0	E-0
	Subsurface	K-40	4.8±0.6	4.6±0.5	6.0±0.6	4.4±0.6	4.3±0.6	3.2±0.0	4.2±0.6	6.3±0.8	3.2±0.5	E+2
		Cs-137	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	E-0
		Co-60	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	E-0
Remark			Spectrum Data: Fig.5.11					Spectrum Data: Fig.5.11				

each sampling point. Figure 5.10 shows the results for ^{137}Cs at the stations BG 1 and N 2. An estimation of ^{137}Cs concentrations from $Cu_2Fe(CN)_6$ fiber ranged from 2.9 to 4.3 mBq/l for surface water (0-100 m) and was less than 4 mBq/l for bottom water.

5.2.2. Sediments.

Table 5.7 shows the results from the spectrometric analysis of surface (top 3 to 5 cm) and subsurface bottom sediments for each sampling station. Figure 5.11 shows the spectra of samples taken at the stations BG 1 and N 2, displaying the peaks of uranium and thorium series nuclides and ^{40}K (1460.7 keV). The spectra of other measured bottom sediment samples are presented in Annex 5. The concentration of ^{40}K ranged between 320 and 900 Bq/kg. Activities of ^{137}Cs and ^{60}Co were below the detection limits.

5.2.3. Biota samples.

Table 5.8 shows the results from the spectrometric analysis of biota samples. Figure 5.12 shows the spectrum with the peak for ^{40}K (1460.7 keV). The spectra of other measured biota samples are presented in Annex 5. The concentration of ^{40}K ranged between 80 and 180 Bq/kg. Activities of ^{137}Cs and ^{60}Co were below the detection limits.

5.3. Biota description.

5.3.1. Zooplankton.

Samples of zooplankton were collected from 9 stations (BG 1, N 1 - N 7, BG 2). Calanus cristatus (Crustacean) were dominant at most stations, except the N 7 station, where the predominant specimen was Amphipoda (Crustacean). The individual sample weights were about 10-20 grams (wet weight).

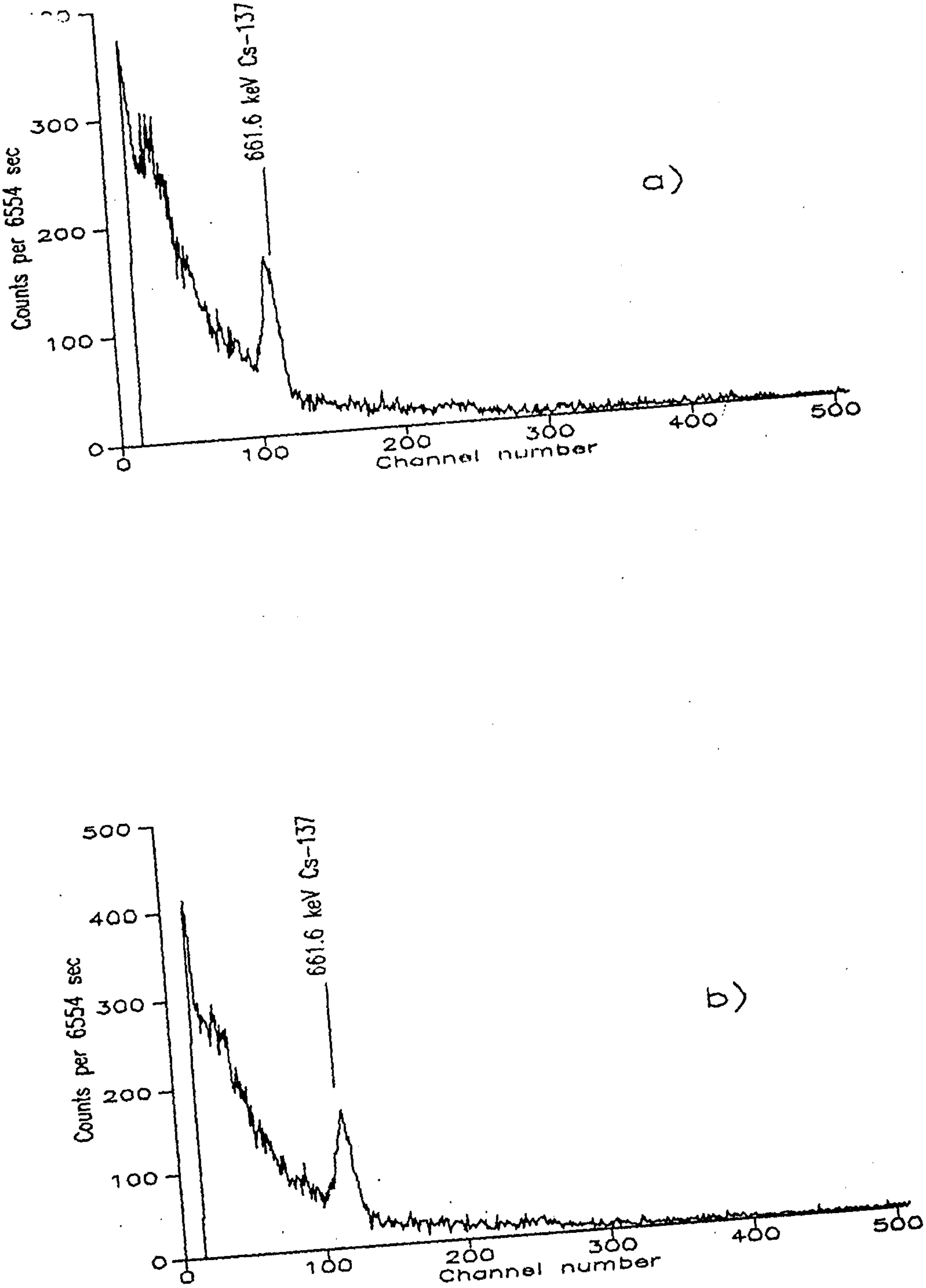


Figure 5.10

Gamma-spectra of sea water filtred by $Cu_2Fe(CN)_6$ sorbe
(point BG1, volume 5166L — a, point N 2, volume 5148

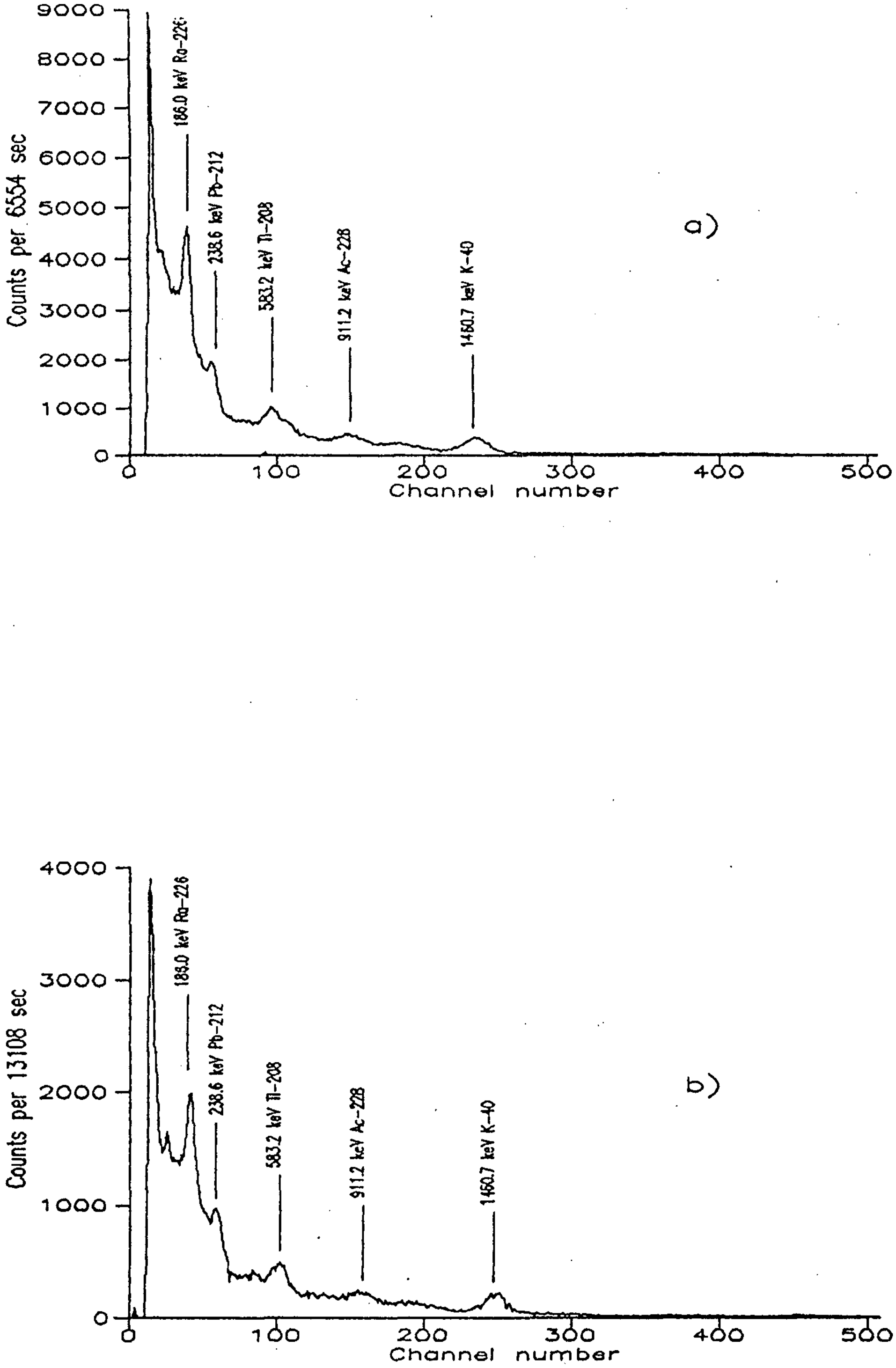


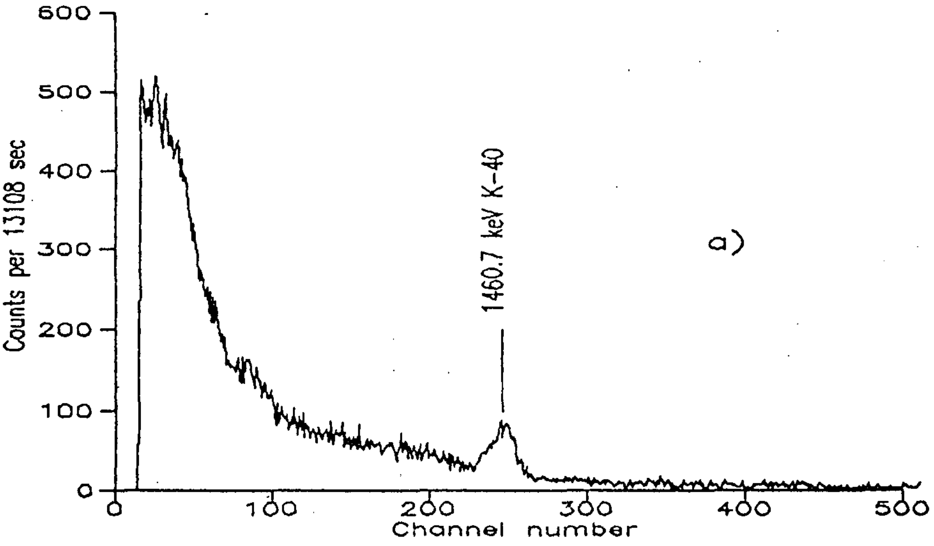
Figure 5.11

Gamma-spectra surface sediment at point BG1 (a) and point N 2 (b)

Table5. 8 Results from the spectrometric analysis of biota samples at point N7

(Bq/kg)

Biota Samples	Cs-137 (E-0)	Co-60 (E-0)	K-40 (E+2)
Meat of Shrimp	<3.0	<4.0	1.6±0.6
Crust of Shrimp	<3.0	<4.0	1.8±0.6
Meat of Flatfish	<2.0	<3.0	1.2±0.4
Head of Flatfish	<2.0	<3.0	0.8±0.5
Meat of Hokke	<2.0	<3.0	1.5±0.3
Head of Hokke	<2.0	<3.0	1.0±0.4



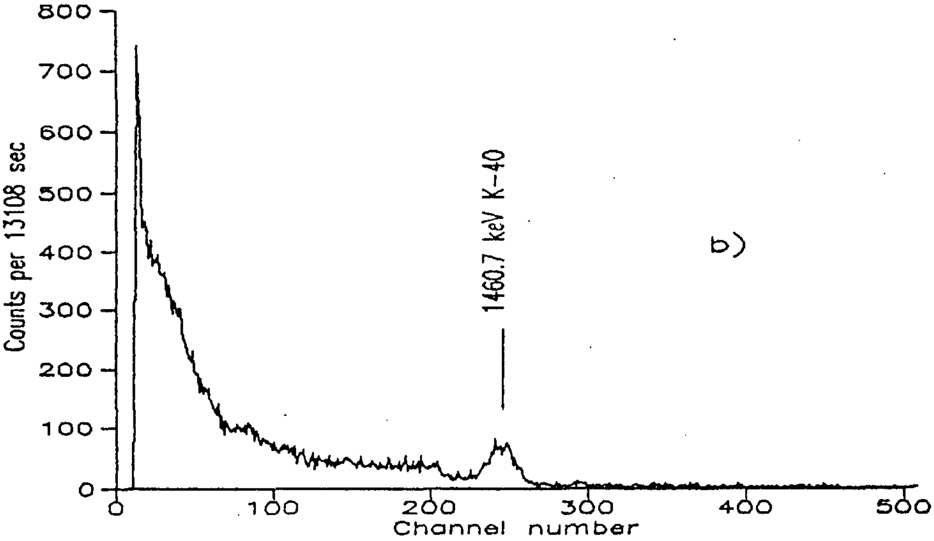


Figure 5.12

Gamma-spectra of meat of shrimps (a) and meat of flatfish (b) at point N 7

5.3.2. Benthos.

According to available data, the benthos biomass in the study area (at depths more than 3000 m) is very low, less than 10 g/m^2. The benthos density is also very small. The benthos organisms were recorded only in a few samples (at some stations quantity of bottom sediment for benthos sampling was very limited).

At the background station BG 1 and stations N 6, N 1, N 3 and N 4 benthos organisms were not found. At the station N 5 three marine benthos groups were recorded: Polychaeta (1 individual), Holothuroidea (1 ind.) and a piece of Spongia.

Two samples were collected at station N 7, situated on the continental slope, with elevated benthos biomass and density. The first sample was taken at the depth of 1600 m. Three benthos groups were found: small Bivalvia (4 ind.), Gastropoda (1 ind.), Polychaeta (3 ind.). The second sample taken at the 600 m depth contained five taxonomic groups: Asteroidea (one sea star with the disc diameter of about 5 cm and a few small individuals), Ophiuroidea (3 ind.), Polychaeta (3 ind,) and Bivalvia (3 ind.).

At station N 2 bottom invertebrate with oval shape and length about 2.5 cm was found. Identification of this organism aboard is difficult. At the BG 2 station Polychaeta (1 ind.), Aphroditidae g. sp. (1 ind.), and two Bivalvia were observed.

5.4. Oceanography.

Oceanographic conditions in the study area were characterised by winter type of stratification, i.e. by presence of upper homogenous layer (0-100 m) and by absence of well-developed thermocline. As a result of winter convective mixing, the temperature of the upper homogenous layer was about 1.5°C, and the salinity about 34.04-

34.08 °/oo. Water masses below 100 m depths were characterised by temperature decrease from 0.5°C to 0.16°C at 1500 m depth. Sea water salinity was almost constant from the surface to 1500 m depths (variations from 34.06 to 34.08 °/oo).

Salinity and temperature profiles (Russian CTD) at each station and Japanese XBT profiles (except BG 1 station) are given in Annex 6.

6. Intercomparison

To obtain reliable and objective information during the investigations of the radioactive waste disposal areas, intercomparison of different devices, methods of observations and measurements of participating parties was organized and performed aboard the ship.

6.1. Intercomparison of preliminary spectrometric measurements on board.

Intercomparison of the spectrometric analysis systems on board has been conducted between Russia and Japan using the same samples of Cs-sorbents, sediments and biological samples. The spectrometric analysis systems were described in the sections 3.1.2 and 3.2.2. Table 6.1 and Figures 6.1 - 6.2 show the results of the intercomparison on board. As shown, the ^{137}Cs values for the sorbents coincide satisfactory with each other, except for the N 1 values, which show very small discrepancy. ^{40}K values in sediments also agree with each othor oxcept for the BG 1 and N 2 values, which show very small discrepancy. ^{40}K values for biota samples also agree with each other.

6.2. Intercomparison of radionuclide analysis in bottom sediments.

In order to assess the quality of the results obtained in the different laboratory analysis on land, both precision (reproducibility) and accuracy (true value) should be tested. The reproducibility can easily be determined by internal measurements. To determine the accuracy, the following procedure will be adopted for this expedition:

Table [illegible] Results from the intercomparison on board

(Bq/L)

Sorbent	Nuclide	Japan	Russian
Point BG1 94/03/23 Russian Sorbent Surface Sea Water 5166L	Cs137	(1.8±0.3)E-3 *	(1.9±0.6)E-3 *
Point BG1 94/03/23 Russian Sorbent -100m Sea Water 1573L	Cs137	(2.8±0.7)E-3 *	(3.5±1.2)E-3 *
Point BG1 94/03/23 Japanese Sorbent (KCFC) Surface Sea Water 1012.3L	Cs137	(3.5±1.3)E-3	(3.8±0.8)E-3
Point N5 94/03/24 Russian Sorbent Surface Sea Water 5962L	Cs137	(2.1±0.3)E-3 *	(2.5±0.2)E-3 *
Point N5 94/03/24 Japanese Sorbent (KCFC) Surface Sea Water 1104.3L	Cs137	(4.7±1.4)E-3	(5.0±2.0)E-3
Point N6 94/03/26 Japanese Sorbent (KCFC) Surface Sea Water 1228.6L	Cs137	(3.6±1.3)E-3	(3.4±1.4)E-3
Point N7 94/03/27 Japanese Sorbent (KCFC) Surface Sea Water 779.9L	Cs137	(4.1±0.8)E-3	(4.8±0.9)E-3
Point N1 94/03/28 Japanese Sorbent (KCFC) Surface Sea Water 1390.4L	Cs137	(4.7±0.9)E-3	(2.8±0.5)E-3

* without taking into account the collection efficiency

(Bq/kg)

Sediment	Nuclide	Japan	Russian
Point BG1 94/03/23 Sediment Surface Sediment	K40	(6.5±0.6)E+2	(8.6±0.6)E+2
Point N5 94/03/24 Sediment Surface Sediment	K40	(4.0±0.7)E+2	(5.2±0.8)E+2
Point N6 94/03/26 Sediment Surface Sediment	K40	(6.9±0.8)E+2	(7.0±0.8)E+2
Point N7 94/03/27 Sediment Surface Sediment	K40	(6.2±0.9)E+2	(5.1±0.6)E+2
Point N1 94/03/27 Sediment Surface Sediment	K40	(7.1±0.8)E+2	(6.0±0.8)E+2
Point N2 94/03/28 Sediment Surface Sediment	K40	(9.6±0.9)E+2	(7.3±0.8)E+2

(Bq/kg)

Biota samples	Nuclide	Japan	Russian
Point N7 94/03/27 Shrimp Sample (Meat of Shrimp) Shrimp 538g	K40	(1.0±0.2)E+2	(1.6±0.6)E+2
Point N7 94/03/27 Fish Sample (Meat of Fish) Flat Fish 1.2kg	K40	(8.0±2.3)E+1	(1.2±0.4)E+2
Point N7 94/03/27 Shrimp Sample (Shell of Shrimp) Shrimp 540g	K40	(1.1±0.2)E+2	(1.8±0.6)E+2
Point N7 94/03/27 Fish Sample (Meat of Fish) Hokke 1.4kg	K40	(1.2±0.2)E+2	(1.5±0.6)E+2

Remark : Error corresponds to 2σ

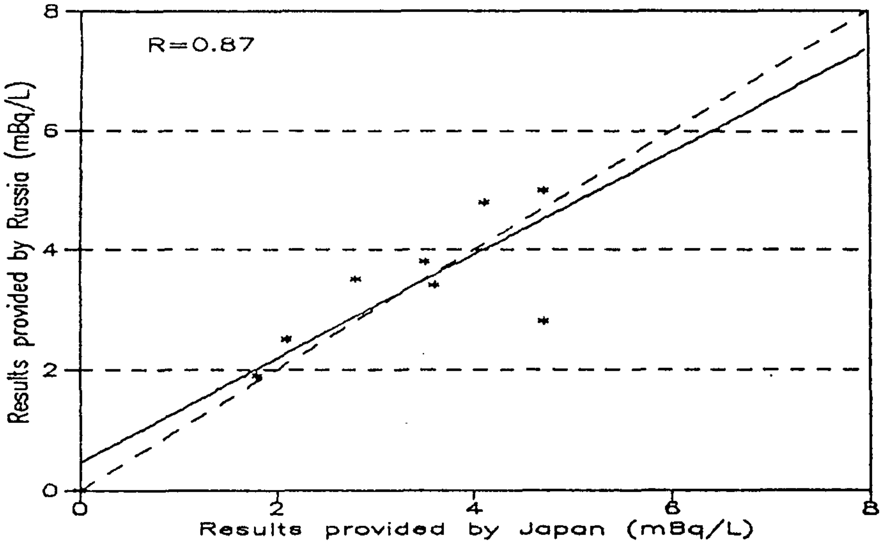


Figure 6.1
Results of intercomparison spectrometric of analysis between Russia and Japan for ^{137}Cs in sorbents
(——— theoretial line, ——— real line)

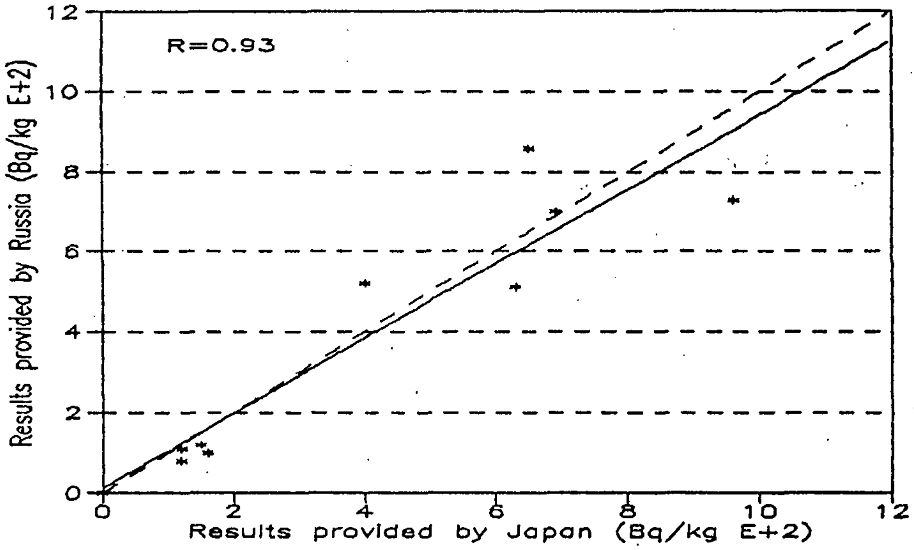


Figure 6.2
^{40}K in sediments and biota analysed by Russia and Japan
(——— theoretical line, ——— real line)

1) Control analyses with Reference Materials. IAEA provide each laboratory with a IAEA-135 sediment reference sample. This sediment has been exposed to radioactive discharge from the nuclear installations of Sellafield, hence, it serves as a reference for both anthropogenic and natural radionuclides in marine samples. By using this material in parallel with each analyses of sediments from this expedition, it will serve as an indicator of accuracy for that particular determination.

2) Participation in Interlaboratory Comparison Studies. Samples used in such intercomparison should be similar in composition and concentration to the expedition samples analyzed. From one of the sampling stations (N 2) bottom sediment has been collected for intercomparison studies. About 10 kg wet weight sediment will be transported to IAEA-MEL in Monaco. The sample will be freeze dried, then ground and passed to a 0.5 mm sieve and finally ground in a ball mill and homogenized in a stainless steel rotating drum for about 5 days. The homogeneity will be assured by measuring the activity of ^{40}K, ^{137}Cs and $^{239+240}$Pu in several samples from bottles taken at random. Samples will then, be distributed to all participating laboratories for analyses and results of the intercomparison will be included in the final report.

6.3. Intercomparison of ship position observation systems.

To obtain objective information, it was very important to have accurate measurements of the ship position during the investigations of radioactive waste disposal areas.

Observations vere performed using ship navigation system FURUNO FSN-200 (every hour readings) from the Russian side, ENSIGH GPS system (every 2 sec readings) from the Korean side and SONY PYXIS system (every 2 sec readings) from the Japanese side. The results of simultaneous observations of the ship position are presented in the following table.

Stations	Japan SONY PYXIS	Korea ENSIGH GPS	Russia FURUNO FSN-200
N 7	42°18'36 N 132°18'44 E	42°18'42 N 132°18'40 E	42°18'60 N 132°18'33 E
N 1	41°55'44 N 133°18'11 E	41°55'38 N 133°18'12 E	41°55'00 N 133°18'54 E
N 2	41°39'40 N 133°46'18 E	41°39'41 N 133°46'16 E	41°40'11 N 133°46'20 E
N 3	41°54'32 N 134°21'41 E	41°54'38 N 134°21'44 E	41°54'16 N 134°21'08 E
N 4	41°05'06 N 134°20'39 E	41°05'05 N 134°20'37 E	41°05'17 N 134°20'00 E

Maximum discrepancy between the different observation systems used was no more than 0.5 miles which allowed to ensure objective measurements of the ship position.

6.4. Intercomparison of CTD and XBT results.

Intercomparison of Russian CTD (precision 0.03°C) and Japanese XBT (precision 0.1°C) data have shown good agrement. Square root deviations (SRD) at each station ranged from 0.03 to 0.04°C, i.e. within the precision of the devices (see following tables).

Station N 1

Depth,	Temperature, T		
m	CTD	XBT	△ T
3	01.14	01.24	0.10
10	01.14	01.21	0.07
20	01.14	01.19	0.05
30	01.14	01.18	0.04
50	01.06	01.16	0.10
60	01.01	01.05	0.04
70	01.01	01.05	0.04
80	01.01	01.04	0.03
90	01.01	01.04	0.03
100	01.01	01.03	0.02
110	00.97	00.99	0.02
120	00.97	00.93	0.04
130	00.94	00.93	0.01
140	00.92	00.92	0.00
150	00.92	00.92	0.00
160	00.91	00.92	0.01
170	00.92	00.93	0.01
180	00.92	00.94	0.02
190	00.90	00.94	0.04
200	00.88	00.92	0.04
210	00.84	00.86	0.02
220	00.79	00.83	0.04
230	00.79	00.77	0.02
240	00.78	00.72	0.06
250	00.72	00.71	0.01
300	00.62	00.63	0.01
400	00.52	00.53	0.01
500	00.40	00.43	0.03
600	00.35	00.35	0.00
700	00.27	00.29	0.02
760	00.24	00.28	0.04

SRD = 0.03°C

Station N 2

Depth,	Temperature, T		
m	CTD	XBT	△ T
5	01.62	01.71	0.09
10	01.61	01.67	0.06
20	01.61	01.64	0.03
30	01.61	01.62	0.01
50	01.50	01.50	0.00
60	01.46	01.45	0.01
70	01.26	01.25	0.01
80	01.18	01.17	0.01
90	01.13	01.12	0.01
100	01.12	01.07	0.05
110	01.08	01.06	0.02
120	01.06	01.01	0.05
130	01.01	00.98	0.03
140	00.97	00.96	0.01
150	00.97	00.92	0.05
160	00.95	00.90	0.05
170	00.95	00.89	0.06
180	00.90	00.86	0.04
190	00.86	00.84	0.02
200	00.84	00.83	0.01
210	00.84	00.81	0.03
230	00.79	00.76	0.03
300	00.64	00.59	0.05
400	00.51	00.49	0.02
500	00.40	00.39	0.01
600	00.35	00.38	0.03

SRD = 0.04°C

7. Experience gathered during the cruise

Careful preparation of all participating parties allowed to organize and fulfill the joint expedition. At the beginning, Consultative Group, Programme and Preliminary Report Committees, and four Working Groups were established with participants from the three countries and IAEA.

The Consultative Group agreed on changes and additions of the cruise programme. For example, coordinates of background stations, optimum ship routes and additional measurements and sampling were approved by this group.

Members of the Programme Committee coordinated the sampling and sample handling techniques, intercomparison exercises, etc.

The Working Groups discussed, organized and performed all kinds of observations and sampling: onboard spectrometric measurements, CTD and XBT casts, sampling of surface and deep water, bottom sediments, benthos and zooplankton.

Members of the Preliminary Report Committee prepared, reviewed and redrafted the text of the Preliminary Report on board as scheduled and with good quality.

At the first station, all sampling and sample handling procedures were tested and the work and cooperation among different parties and the ship's crew was organized. As a result, it became possible to save some observation time.

Members of the ship's crew were informed on the expedition goals and status. Increased attention to scientific procedures was drawn. Regular scientific discussions and personal contacts also promoted successful work and a friendly atmosphere aboard the ship.

The success of this joint expedition was ensured by the appointment of coordinators for each kind of sampling, observations, report preparation, etc., optimum organization of sampling and sample handling, close cooperation between the participants, and finally the exchange and evaluation of data.

Suggestions for the next stage and future expeditions

The present expedition will provide data for an assessment of the anthropogenic radionuclide content in sea water and sediment, i.e., contributions from fallout and dumping. However, in order to properly assess the present radiological consequencies, extensive sampling and analyses of sea food items like fish, shrimps, sea weed, etc., should be implemented on the next stage and during future expeditions.

Regarding the sediment sampling, it would be useful to employ box core sediment sampling, not only for improving sampling of surface sediment layers, but also for the assessment of sedimentation rates and migration of radionuclides to deeper layers of sediments. This information is useful for predictions of the long-term radiological consequencies.

8. Conclusions

After careful preparation, participants from the Japan, Republic of Korea, Russian Federation and IAEA began investigations at the radioactive waste dumping sites on March 23, 1994. Fair weather conditions allowed to carry out more observations than was scheduled.

According to the cruise programme, the following basic observations have been carried out:

- surface and bottom sea water and bottom sediment samples were taken at all sampling stations in sufficient quantities;
- intermediate water layers were sampled from 200, 500, 1000 and 2000 m depths at station N 2. Additional water was sampled from 750 m depth at this station.

CTD casts up to 1500 m and XBT casts up to 700-800 m depths were made at all sampling stations by Russian and Japanese sides, respectively. Regular meteorological observations, weather map receiving and analysis and weather forecasting were also made. Results of meteorological observations are presented in Annex 7.

Additional measurements were performed at all stations: zooplankton sampling from 0-200 m depths, selective benthos sampling, in situ spectrometric measurements in 0-200 m depths and onboard spectrometric measurements of sorbents and sediments. At station N 7, fish and shrimp samples were obtained from fishing boat working in this area and spectrometric measurements were performed on board. During the expedition, intercomparisons of techniques used by participating parties were organized and performed.

Sampling and analytical techniques were exchanged among the participating parties and IAEA. Problems connected with sampling, sample handling, storage and subsequent analysis of sea water, bottom sediments and biota were reviewed, discussed and resolved. Data obtained aboard the ship were exchanged among the participants of the three countries and IAEA.

The expedition has fulfilled its main task: to obtain the information on radioactive contamination of the marine environment in the areas of radioactive waste disposal. The results of the onboard intercomparisons of techniques used by participating parties are satisfactory.

Preliminary results of onboard measurements allowed to make a first estimate of ^{137}Cs concentrations, radioecologically one of the most important radionuclides, in surface water: 3-5 Bq/m^3. Preliminary onboard measurements of surface bottom sediments using different types of spectrometric systems, did not allow to detect ^{137}Cs (detection limit of Japanese measurements with Ge detector was 4-7 Bq/kg dry weight, detection limit of Russian measurements with NaI detector was 3 Bq/kg dry weight). These ^{137}Cs concentrations do not differ from the background levels caused by the global fallout in the northwest Pacific Ocean.

Detailed analyses of samples of sea water, bottom sediments, zooplankton and benthos will be performed on land, in the laboratories of Japan, Republic of Korea, Russian Federation and IAEA. It will provide the necessary information to assess the marine environmental radioactivity in the study area.

Acknowledgments

The participating parties thank Captain Leonid Akimov and crew of R/V "Ocean" for their excellent workmanship. Special thanks are also given to the master chef who had a difficult task regarding colliding tastes between the East and the West.

9. ANNEXES

Annex 1. Cruising chart.

Annex 2. List of expedition participants.

Annex 3. Working groups.

Annex 4. Data logs.

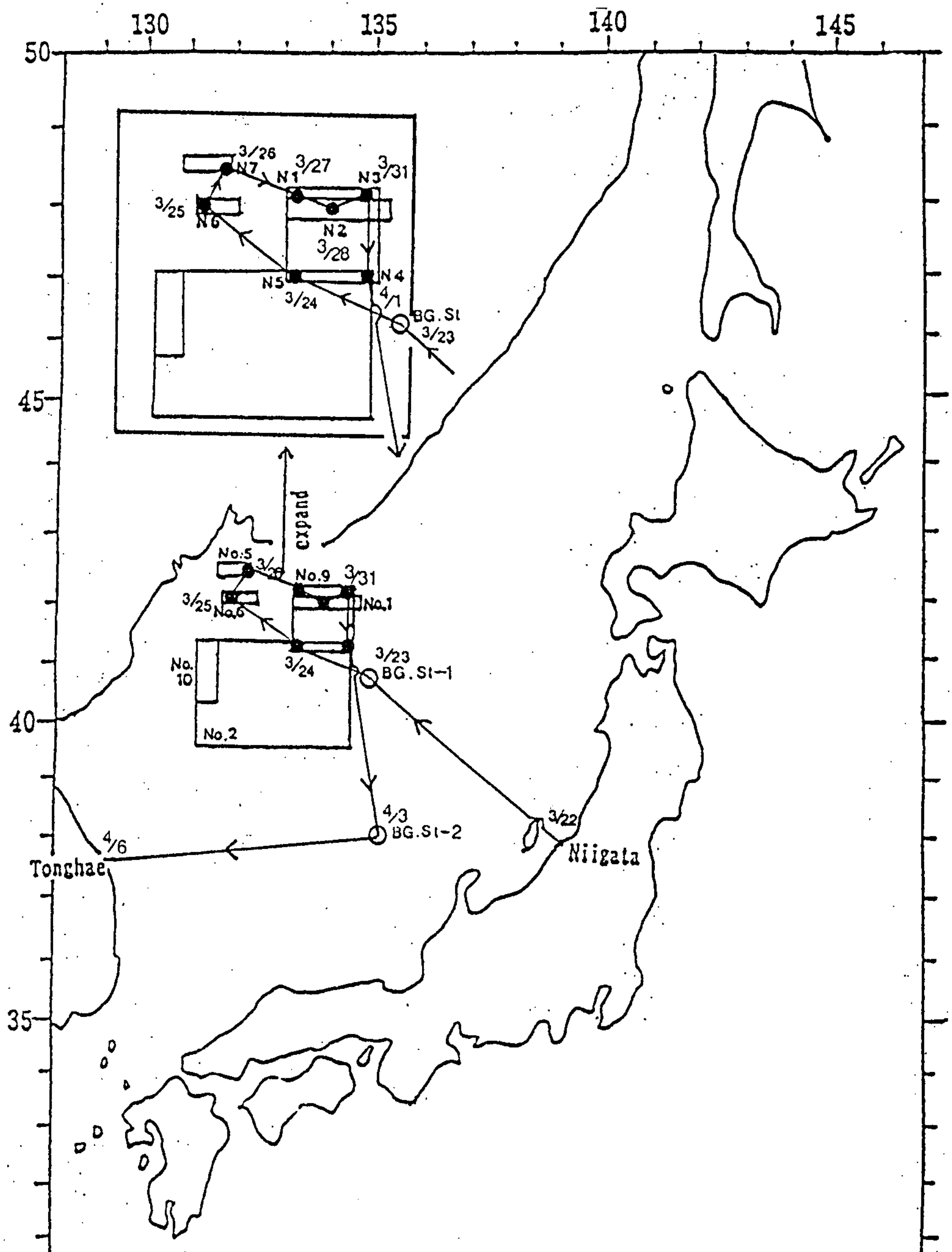
Annex 5. Results of preliminary radionuclide analysis of aerosols, sea water, bottom sediments and biota.

Annex 6. CTD and XBT data.

Annex 7. Meteorological data.

Annex 8. Joint agreement on the onland radionuclide analysis.

Cruising chart



Annex 2

LIST OF EXPEDITION PARTICIPANTS

INTERNATIONAL ATOMIC ENERGY AGENCY (IAEA)

Name	Affiliation	Position
Dr. PETTERSSON Håkan	Radiometrics Section, Marine Environment Laboratory	Research Scientist

JAPAN

Name	Affiliation	Position
Mr. SETO Yoshio	Marine Pollution Laboratory, Hydrographic Department, Maritime Safety Agency	Head of Laboratory
Dr. HIROSE Katsumi	2-nd Laboratory, Geochemical Research Department, Meteorological Research Institute, Meteorological Agency	Head of Laboratory
Mr. YUKIMATSU Yasuhiro	Office of Environmental Radioactivity, Nuclear Safety Buerau, Science and Technology Agency	Deputy Director
Mr. AMANO Hikaru	Department of Environmental Safety Research, Japan Atomic Energy Research Institute	Senior Research Scientist
Mr. YABUUCHI Noriaki	Nuclear Ship "Mutsu", Japan Atomic Energy Research Institute	Ship´s Engineer
Mr. ABE Toshio	Fisheries Agency	Interpreter
Dr. SUZUKI Eisuke	Radioecological Section, National Research Institute of Fisheries Sciences, Fisheries Agency	Senior Scientist
Mr. MORIMOTO Takao	Department of Analitical Chemistry, Japan Chemical Analysis Center	Senior Engineer
Mr. ODA Katsuyuki	Marine Pollution Laboratory, Hydrographic Department, Maritime Safety Agency	Senior Researcher

REPUBLIC OF KOREA

Name	Affiliation	Position
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Mr. KANG Chang Keun	National Fisheries R & D Agensy	Researcher
Dr. KIM Chang Kyu	Department of Radiochemical Analysis, Korea Institute of Nuclear Safety	Senior Researcher
Mr. CHO Yong Woo	Department of Radiochemical Analysis, Korea Institute of Nuclear Safety	Senior Technician
Dr. HONG Gi Hoon	Isotope Oceanography Laboratory, Korea Ocean R & D Institute	Senior Scientist
Mr. KIM Suk Hyun	Isotope Oceanography Laboratory, Korea Ocean R & D Institute	Senior Researcher
Mr. LEE Sang Han	Isotope Oceanography Laboratory, Korea Ocean R & D Institute	Researcher

RUSSIAN FEDERATION

Federal Service of Russia on Hydrometeorology and Environmental Monitoring

1. Far Eastern Regional Hydrometeorological Research Institute (FERHRI), Vladivostok

Name	Affiliation	Position
Dr. VOLKOV Yury	FERHRI	Director
Dr. TKALIN Alexander	Department of Ecological Monitoring	Head of Department
Mrs.BELAN Tatiana	Department of Ecological Monitoring	Senior Researcher
Mrs.LISHAVSKAYA Tatiana	Department of Ecological Monitoring	Leading Engineer
Mr. BORISOV Tatiana	Department of Ecological Monitoring	Leading Engineer
Dr. UDATOV Sergey	FERHRI	Leading Engineer

2. Regional Hydrometeorological Service, Vladivostok

Name	Affiliation	Position
Mrs. CHAYKOVSKAYA Emilia	Regional Radiochemical Laboratory	Head
Mrs. SYSOLIATINA Evgenia	Regional Radiochemical Laboratory	Leading Engineer

3. SPA "TYPHOON", Obninsk, Kaluga Region

Name	Affiliation	Position
Dr. NIKITIN Alexander	Laboratory for Monitoring of Water Bodies Radioactive Contamination	Head of Laboratory
Mr. CHUMICHEV Vladimir	Radiochemical Subdivision	Head of Subdivision
Dr. KATRICH Ivan	Laboratory for Monitoring of Water Bodies Radioactive Contamination	Senior Researcher
Mr. KABANOV Alexander	Laboratory for Monitoring of Water Bodies Radioactive Contamination	Engineer
Mr. PEGOYEV Nikolay	Laboratory for Monitoring of Water Bodies Radioactive Contamination	Engineer

RUSSIAN NAVY

Name	Affiliation	Position
Mr. DANILYAN Valery	Department of Radiological, Chemical and Biological Safety, Pacific NAVY	Head of Department
Dr. VYSOTSKY Valentin	Pacific NAVY	Head of Department
Mr. KULIK Anatoly	Department of Ecology, Ministry of Defence	Leading Specialist
Mr. LARICHEV Sergey	Central Medical Laboratory, Russian NAVY,	Head of Division
Mr. NOSKO Victor	Department of Radiological, Chemical and Biological Safety, Russian NAVY	Deputy Head of Department
Mr. ALEKSEENKO Sergey	Pacific NAVY	Deputy Head of Department
Mr. NUZHDENKO Anatoly	Pacific NAVY	Engineer-Programmer

Annex 3

CONSULTATIVE GROUP

Captain, Mr. Akimov
Dr. Sa
Dr. Pettersson
Mr. Seto
Dr. Volkov

Interpreters:

Mr. Abe
Dr. Tkalin

PROGRAMME COMMITTEE

Mr. Amano
Mr. Danilyan
Dr. Hong
Mr. Krainev
Dr. Nikitin

Dr. Pettersson
Dr. Sa
Mr. Seto
Dr. Suzuki
Dr. Tkalin
Dr. Volkov

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Mr. Amano
Mrs. Chaykovskaya
Mr. Chumichev
Mr. Danilyan
Dr. Hong
Dr. C.K.Kim
Mr. S.H.Kim
Dr. Nikitin

Dr. Pettersson
Dr. Sa
Mr. Seto
Dr. Tkalin
Dr. Volkov
Dr. Vysotsky
Mr. Yukimatsu

WORKING GROUPS

WG1: SURFACE WATER SAMPLING

Mr. Cho, Dr. Hirose, Mr. Kabanov, Dr. Katrich, Mr. S.H.Kim, Mr. Larichev (coordinator), Dr. Nikitin, Mr. Oda, Dr. Pettersson.

WG2: SEDIMENT AND BENTHOS SAMPLING

Mrs. Belan, Dr. Hong, Dr. C.K.Kim, Dr. Nikitin, Mr. Oda, Dr. Pettersson, Dr. Suzuki, Dr. Tkalin (coordinator).

WG3: ZOOPLANKTON SAMPLING

Mr. Borisov (coordinator), Mr. Kang, Dr. Suzuki.

WG4: PRELIMINARY SPECTROMETRIC ANALYSIS

Mr.Amano, Mrs.Chaykovskaya, Mr. Danilyan (coordinator), Dr. C.K.Kim, Mr. Pegoyev, Dr. Vysotsky, Mr. Yabuuchi.

DATA LOG 1 BG

Station 1 BG (BG - background)

Duration of station work: March 22 (22:25 GMT) - March 23 (15:08 GMT)

Latitude 40°47.7′ N Longitude 134°52′ E Depth 3245 m

	IAEA	JAPAN	KOREA	RUSSIA
Filtered surface water volume (l):	90-110	180	200	420
Filtered surface water pumped through the sorbents (l):	NO	a: 1012 b: 1018	745	5200
Filtered bottom water volume (l):	90-110	160	140	400
100 m depth water pumped through the sorbents (l):	NO	NO	NO	1570
Sediment samples (approximate wet weight, kg):				
- surface (3-5 cm)	1	0.7	1	2.0
- subsurface	2	1.0	3	2.5
Benthos samples:	NO	NO	NO	NO
Zooplankton samples (0-200 m):	NO	YES	YES	YES
Surface water pumped through the filters (total, l):		500		5860
Bottom water pumped through the filters (total, l):				
- first portion with suspended sediments				280***
- second portion free of suspended sediments				610***
Direct spectrometric analysis of surface sea water	NO	YES	NO	YES

***Filters were given to Japanese-Korean side for radionuclide analysis

DATA LOG 5

Station 5

Duration of station work: March 23 (21:00 GMT) - March 25 (04:44 GMT)

Latitude 41°05′ N Longitude 133°15′ E Depth 3493 m

	IAEA	JAPAN	KOREA	RUSSIA
Filtered surface water volume (l):	90-110	180	200	420
Filtered surface water pumped through the sorbents (l):	NO	a: 1104 b: 1140	1174	5962
Filtered bottom water volume (l):	90	150	160	320
100 m depth water pumped through the sorbents (l):	NO	NO	NO	2050
Sediment samples (approximate wet weight, kg):				
- surface (3-5 cm)	0.5	1	1	0.3
- subsurface	2.0	2	2	2.0
Benthos samples:	NO	NO	NO	YES
Zooplankton samples (0-200 m):	NO	YES	YES	YES
Surface water pumped through the filters (total, l):		500		6458/814***
Bottom water pumped through the filters (total, l):		410		772***
Direct spectrometric analysis of surface sea water	NO	YES	NO	YES

***Filters were given to Japanese-Korean side for radionuclide analysis

DATA.LOG.6

Station 6

Duration of station work: March 25 (11:25 GMT) - March 26 (10:10 GMT)

LLatitude 41°55′ N Longitude 132°00′ E Depth 3128 m

	IAEA	JAPAN	KOREA	RUSSIA
Filtered surface water volume (l):	90-110	180	200	420
Filtered surface water pumped through the sorbents (l):	NO	a: 1229 b: 1182	1313	6040
Filtered bottom water volume (l):	90-110	160	140	420
Sediment samples (approximate wet weight, kg):				
- surface (3-5 cm)	0.5	0.7	0.5	0.5
- subsurface	5.0	5.0	2.0	2.0
Benthos samples:	NO	NO	NO	NO
Zooplankton samples (0-200 m):	NO	YES	YES	YES
Surface water pumped through the filters (total, l):		500		6065/1111***
Bottom water pumped through the filters (total, l):				913***
Direct spectrometric analysis of surface sea water	NO	YES	NO	YES

***Filters were given to Japanese-Korean side for radionuclide analysis

DATA LOG 7

Station 7

Duration of station work: March 26 (12:35 GMT) - March 27 (05:48 GMT)

LLatitude 42°19′ N Longitude 132°19′ E Depth 1512 m

	IAEA	JAPAN	KOREA	RUSSIA
Filtered surface water volume (l):	90-110	180	200	420
Filtered surface water pumped through the sorbents (l):	NO	a: 780 b: 705	786	a: 618 b: 3572
Filtered bottom water volume (l):	90-110	180	160	485
100 m depth water pumped through the sorbents (l):	NO	NO	NO	1184
Sediment samples (approximate wet weight, kg):				
- surface (3-5 cm)	0.5	0.7	0.5	0.5
- subsurface	5.0	5.0	2.0	2.0
Shrimps (approximate wet weight, kg):	NO	1	1	1
Fish (approximate wet weight, kg):	NO	10	10	7
Benthos samples:	NO	NO	NO	YES
Zooplankton samples (0-200 m):	NO	YES	YES	YES
Surface water pumped through the filters (total, l):		500		4190/1081***
Bottom water pumped through the filters (total, l):		500		1048***
Direct spectrometric analysis of surface sea water	NO	YES	NO	YES

***Filters were given to Japanese-Korean side for radionuclide analysis

DATA LOG 1

Station 1

Duration of
station work: March 27 (10:15 GMT) - March 28 (03:59 GMT)

LLatitude 41°55′ N Longitude 133°15′ E Depth 3488 m

	IAEA	JAPAN	KOREA	RUSSIA
Filtered surface water volume (l):	90-110	180	200	420
Filtered surface water pumped through the sorbents (l):	NO	a: 1390 b: 1464	1410	a: 492 b: 4608
Filtered bottom water volume (l):	90-110	180	160	450
Sediment samples (approximate wet weight, kg):				
- surface (3-5 cm)	0.5	0.7	0.5	0.5
- subsurface	3.0	5.0	2.0	2.0
Benthos samples:	NO	NO	NO	YES
Zooplankton samples (0-200 m):	NO	YES	YES	YES
Surface water pumped through the filters (total, l):		500		5100/1151***
Bottom water pumped through the filters (total, l):		480		920***
Direct spectrometric analysis of surface sea water	NO	YES	NO	YES

***Filters were given to Japanese-Korean side for radionuclide analysis

DATA LOG 2

Station 2

Duration of
station work: March 28 (08:26 GMT) - March 31 (17:30 GMT)

Latitude 41°40′ N Longitude 133°15′ E Depth 3533 m

	IAEA	JAPAN	KOREA	RUSSIA
Filtered surface water volume (l):	90-110	180	200	420
Surface water pumped through the sorbents (l):	NO	a: 5102 b: 5121	4800	a: 546 b: 4638 c: 5148
Filtered bottom water volume (l):	90-110	160	NO	430
100 m depth water pumped through the sorbents (l):	NO	NO	NO	1270
Filtered intermediate water volume (liters):				
200 m	90-110	160	160	480
500 m	90-110	160	160	360
750 m	90-110	100	100	300
1000 m	90-110	160	160	368
2000 m	90-110	160	160	464
Sediment samples (approximate wet weight, kg):				
- surface (3-5 cm)	0.5+10	0.7	0.5	0.5
- subsurface	5.0	5.0	2.0	2.0
Benthos samples:	NO	NO	NO	YES
Zooplankton samples (0-200 m):	NO	YES	YES	YES
Sea water pumped through the filters (total, l):				
Surface water		480		a: 5184/1089*** b: 5148
Intermediate water				
200 m		480		1029***
500 m		450		867***
750 m		480		700***
1000 m		480		834***
2000 m		480		945***
Bottom water		480		904***
Direct spectrometric analysis of surface sea water	NO	YES	NO	YES

***Filters were given to Japanese-Korean side, for radionuclide analysis

DATA LOG 3

Station 3				
Duration of station work: March 31 (19:40 GMT) - April 01 (08:25 GMT)				
Latitude 41°55′ N Longitude 134°20′ E Depth 3570 m				
	IAEA	JAPAN	KOREA	RUSSIA
Filtered surface water volume (l):	90-110	180	200	420
Filtered surface water pumped through the sorbents (l):	NO	a: 1145 b: 1300	1120	a: 480 b: 4380
Filtered bottom water volume (l):	90-110	160	160	445
Sediment samples (approximate wet weight, kg):				
- surface (3-5 cm)	0.5	0.7	0.5	0.5
- subsurface	4.0	5.0	2.0	2.0
Benthos samples:	NO	NO	NO	YES
Zooplankton samples (0-200 m):	NO	YES	YES	YES
Surface water pumped through the filters (total, l):		480		4860/1019***
Bottom water pumped through the filters (total, l):		480		935***
Direct spectrometric analysis of surface sea water	NO	YES	NO	YES

***Filters were given to Japanese-Korean side for radionuclide analysis

DATA LOG 4

Station 4

Duration of station work: April 01 (12:50 GMT) - April 02 (05:59 GMT)

Latitude 41°05′ N Longitude 134°20′ E Depth 3545 m

	IAEA	JAPAN	KOREA	RUSSIA
Filtered surface water volume (l):	90-110	180	200	420
Filtered surface water pumped through the sorbents (l):	NO	a: 1100 b: 1197	940	a: 617 b: 4555
Filtered bottom water volume (l):	90-110	160	160	455
Sediment samples (approximate wet weight, kg):				
- surface (3-5 cm)	0.5	0.7	0.5	0.5
- subsurface	4.0	7.0	-2.0	2.0
Benthos samples:	NO	NO	NO	YES
Zooplankton samples (0-200 m):	NO	YES	YES	YES
Surface water pumped through the filters (total, l):	480			5170/968***
Bottom water pumped through the filters (total, l):	480			946***
Direct spectrometric analysis of surface sea water	NO	YES	NO	YES

***Filters were given to Japanese-Korean side for radionuclide analysis

DATA LOG BG 2

Station BG 2 (BG - background)

Duration of
station work: April 02 (23:52 GMT) - April 04 (08:04 GMT)

Latitude 38°00'7 N Longitude 134°57'5 E Depth 2991 m

	IAEA	JAPAN	KOREA	RUSSIA
Filtered surface water volume (l):	90-110	180	200	420
Filtered surface water pumped through the sorbents (l):	NO	a: 1291 b: 1328	1250	a: 416 b: 4900
Filtered bottom water volume (l):	90-110	160	160	485
Sediment samples (approximate wet weight, kg):				
- surface (3-5 cm)	0.5	0.7	0.5	0.5
- subsurface	3.0	5.0	2.0	2.0
Benthos samples:	NO	NO	NO	YES
Zooplankton samples (0-200 m):	NO	YES	YES	YES
Surface water pumped through the filters (total, l):		500		5300/1024***
Bottom water pumped through the filters (total, l):		480		944***
Direct spectrometric analysis of surface sea water	NO	YES	NO	YES

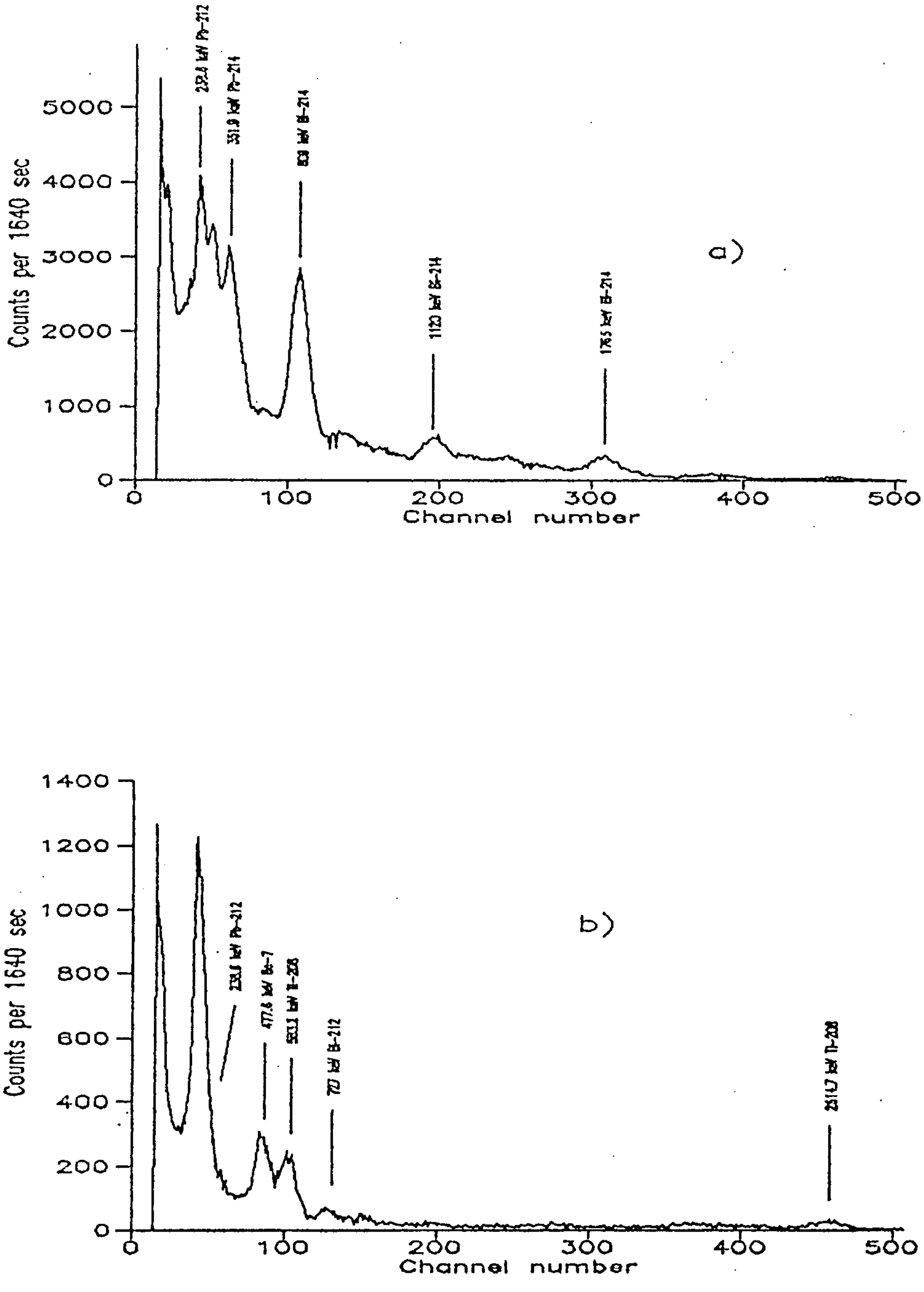
***Filters were given
to Japanese-Korean side
for radionuclide analysis

Annex 5

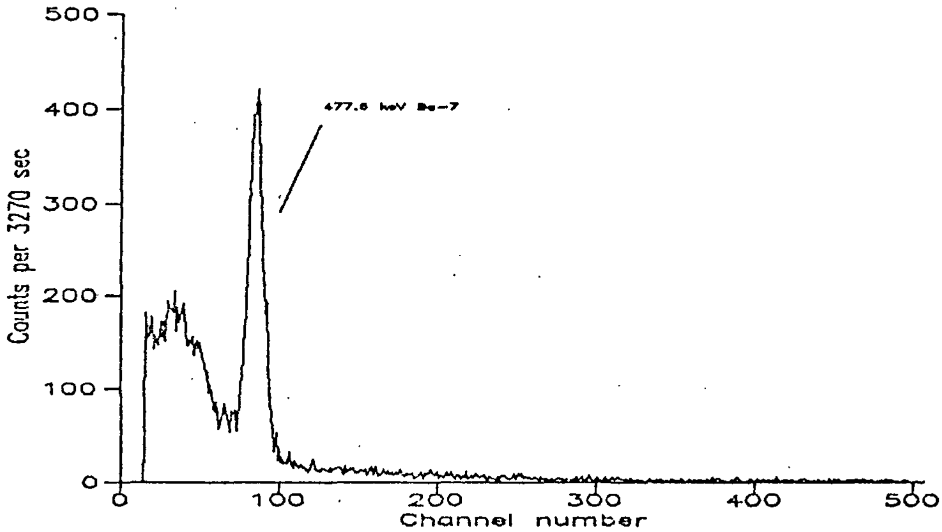
RADIONUCLIDE ANALYSIS REZULTS OF AEROSOLS SAMPLED ON BOARD OF R/V "OCEAN".

DATE OF SAMPLING (BEGINING)	COORDINATES		VOLUME M^3 E+4	TOTAL BETA-AKTIVITY, BQ/M^3 E-5	RADIONUCLIDE, BQ/M^3		
	LAT (N)	LON (E)			BE-7 E-5	PB-212 E-5	PB-214 E-2
18.03.94	41 00	134 54	9.7	11.1	265	125	212
19.03.94	P. NIIGATA		9.6	11.1	3	47	115
20.03.94	------		9.5	11.6	346	1052	590
21.03.94	P. NIIGATA		9.3	12.9	146	68	80
22.03.94	40 48	134 54	9.5	4.8	150	96	278
23.03.94	41 03	133 15	9.7	4.9	131	381	303
24.03.94	41 06	133 10	10.0	7.6	238	521	152
25.03.94	41 58	131 57	10.3	12.6	346	279	214
26.03.94	42 17	132 18	9.9	12.6	412	1118	401
27.03.94	41 53	133 12	10.0	23.5	284	613	257
28.03.94	41 40	133 46	9.9	10.6	213	334	190
29.03.94	41 40	133 46	10.1	13.1	3	495	246
30.03.94	41 39	133 45	9.9	23.3	303	289	245
31.03.94	41 53	134 21	9.2			151	187
1.04.94	41 03	134 20	9.2			620	166
2.04.94	38 10	134 56	9.0			352	191
3.04.94	38 03	135 03	9.1			227	192

REMARK: CS-137, CE-141, 144, RU-103,106, ZR-95, NB-95 ACTIVITIES WERE BELOW THE DETECTION LIMITS.



Gamma—spectra of aerosol sample at point N 2:
a) in 1 hour after sampled
b) in 10 hour after sampled

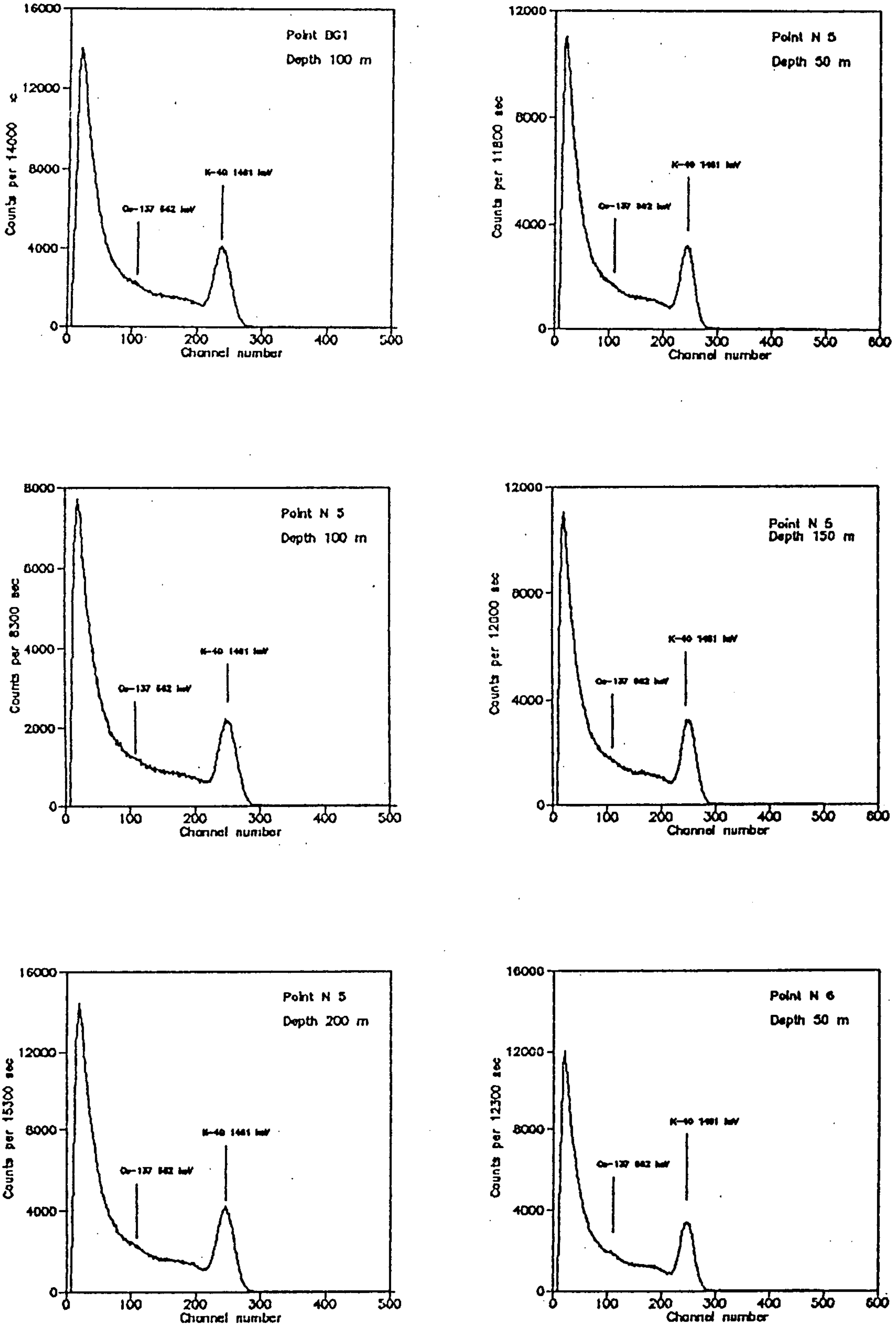


Gamma—spectrum of aerosol sample at point N 2
in 4 days after sampled

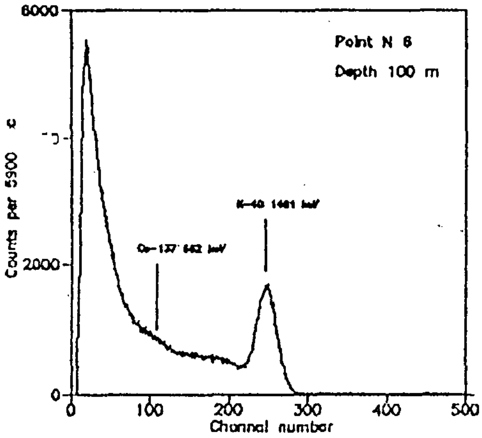
RESULTS FROM SPECTROMETRIC ANALYSIS OF SORBENTS FROM SEA WATER AT POINT N 2

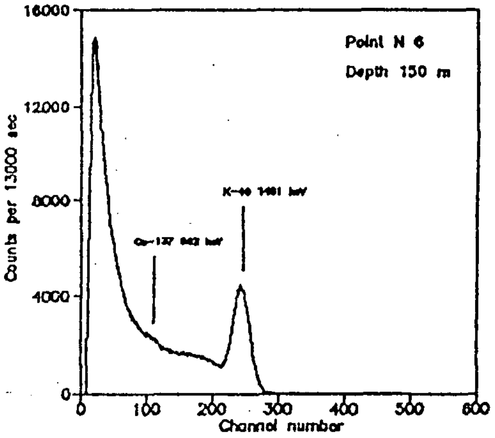
94/03/29-31

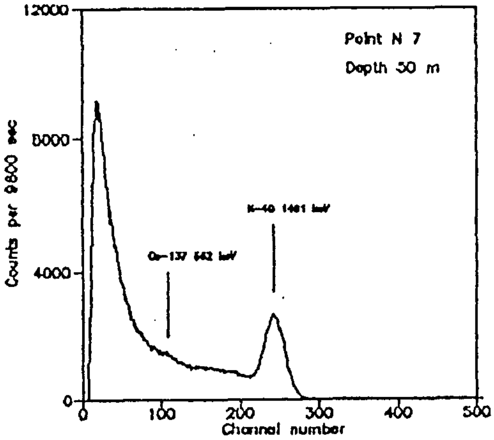
N	DEPTH, M	VOLUME, L	ACTIVITY CS-137, MBQ/L
1	0	546	4,2 ± 1,3
2	0	4838	3,8 ± 1,1
3	0	5148	3,8 ± 1,1
4	100	1267	3,7 ± 1,1
5	200	260	3,3 ± 1,1
6	500	140	< 3,6
7	750	75	< 4,0
8	1000	148	< 3,6
9	2000	264	< 2,6
10	BOTTOM	120	< 3,8

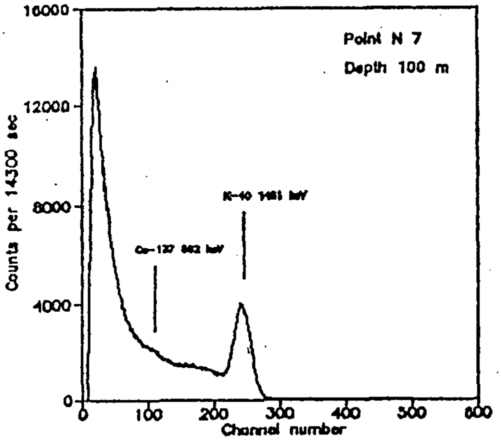


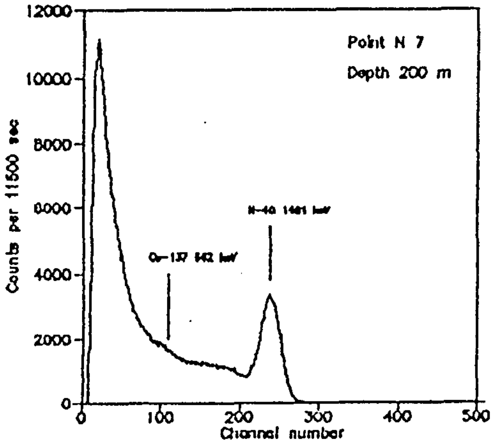
Gamma-spectra of sea water

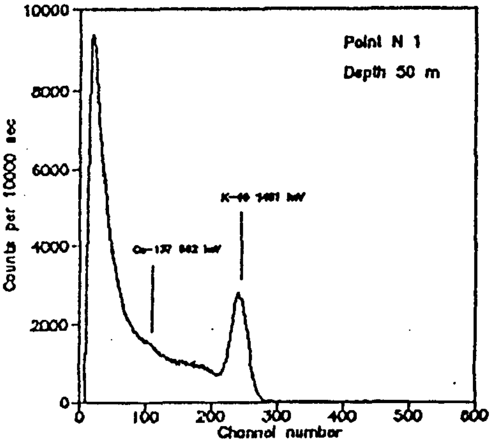

Point N 6
Depth 100 m
Counts per 5900 sec
Cs-137 662 keV
K-40 1461 keV
6000
2000
0
0
100
200
300
400
500
Channel number

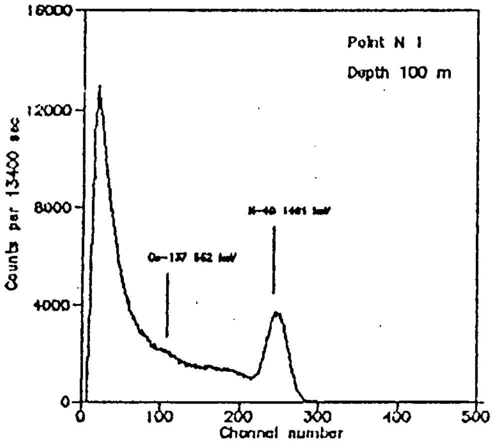

Point N 6
Depth 150 m
Counts per 13000 sec
Cs-137 662 keV
K-40 1461 keV
16000
12000
8000
4000
0
0
100
200
300
400
500
600
Channel number

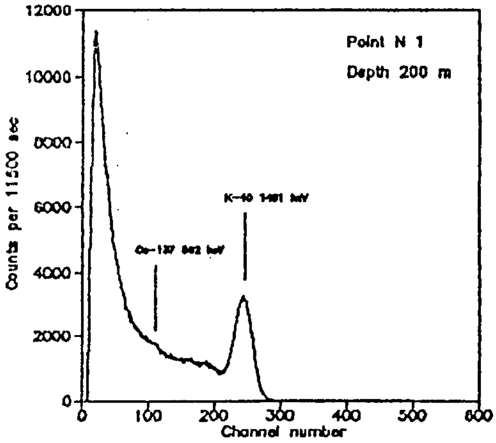

Point N 7
Depth 50 m
Counts per 9800 sec
Cs-137 662 keV
K-40 1461 keV
12000
8000
4000
0
0
100
200
300
400
500
Channel number

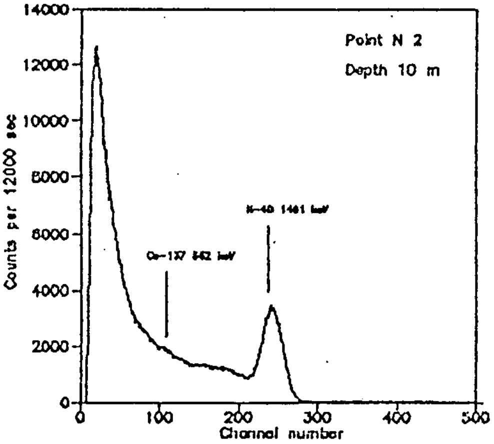

Point N 7
Depth 100 m
Counts per 14300 sec
Cs-137 662 keV
K-40 1461 keV
16000
12000
8000
4000
0
0
100
200
300
400
500
600
Channel number

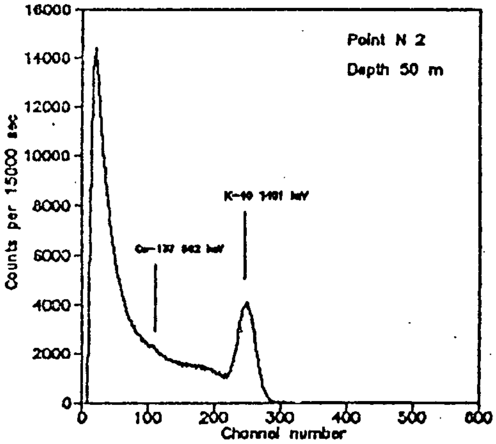

Point N 7
Depth 200 m
Counts per 11500 sec
Cs-137 662 keV
K-40 1461 keV
12000
10000
8000
6000
4000
2000
0
0
100
200
300
400
500
Channel number

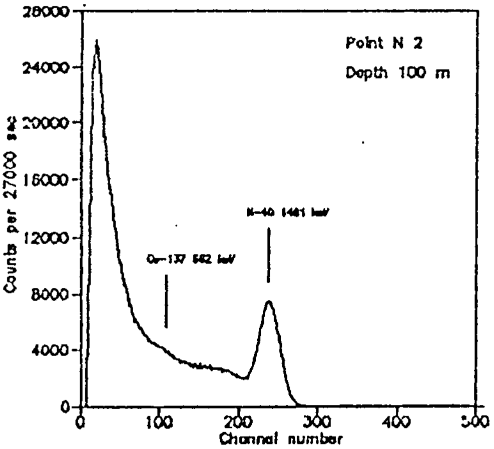

Point N 1
Depth 50 m
Counts per 10000 sec
Cs-137 662 keV
K-40 1461 keV
10000
8000
6000
4000
2000
0
0
100
200
300
400
500
600
Channel number

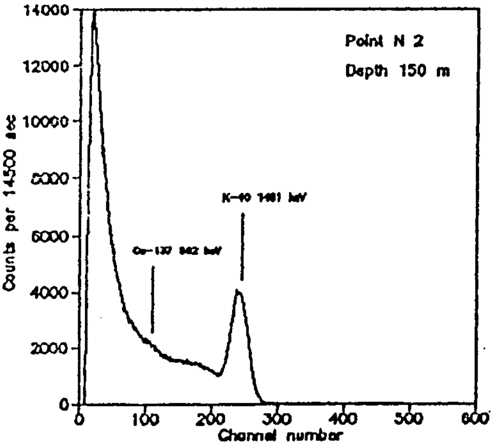

Point N 1
Depth 100 m
Cs-137 662 keV
K-40 1461 keV
Counts per 13400 sec
0
4000
8000
12000
16000
Channel number
0
100
200
300
400
500

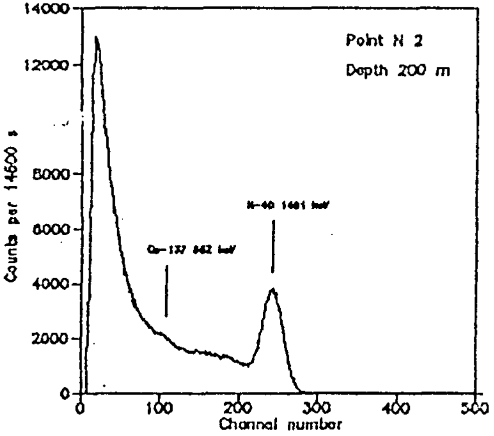

Point N 1
Depth 200 m
Cs-137 662 keV
K-40 1461 keV
Counts per 11500 sec
0
2000
4000
6000
8000
10000
12000
Channel number
0
100
200
300
400
500
600

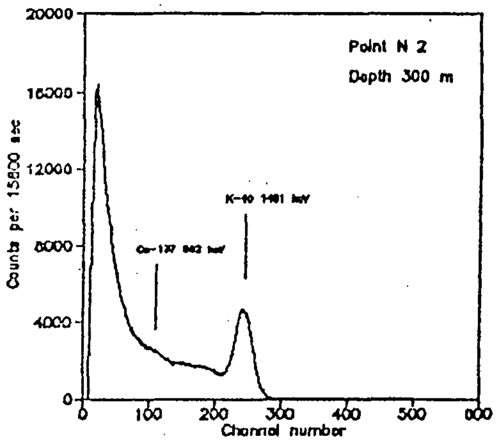

Point N 2
Depth 10 m
Cs-137 662 keV
K-40 1461 keV
Counts per 12000 sec
0
2000
4000
6000
8000
10000
12000
14000
Channel number
0
100
200
300
400
500

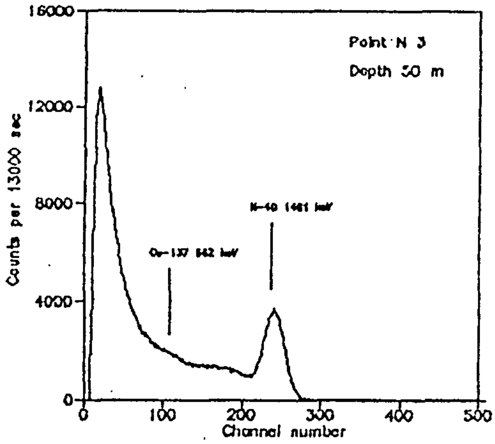

Point N 2
Depth 50 m
Cs-137 662 keV
K-40 1461 keV
Counts per 15000 sec
0
2000
4000
6000
8000
10000
12000
14000
16000
Channel number
0
100
200
300
400
500
600

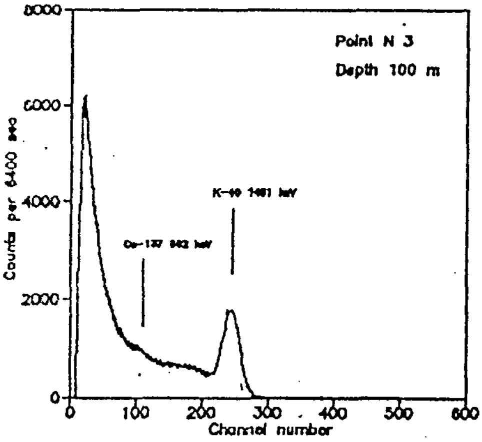

Point N 2
Depth 100 m
Cs-137 662 keV
K-40 1461 keV
Counts per 27000 sec
0
4000
8000
12000
16000
20000
24000
28000
Channel number
0
100
200
300
400
500

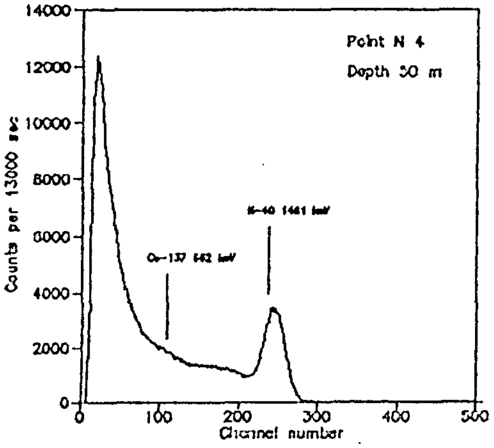

Point N 2
Depth 150 m
Cs-137 662 keV
K-40 1461 keV
Counts per 14500 sec
0
2000
4000
6000
8000
10000
12000
14000
Channel number
0
100
200
300
400
500
600

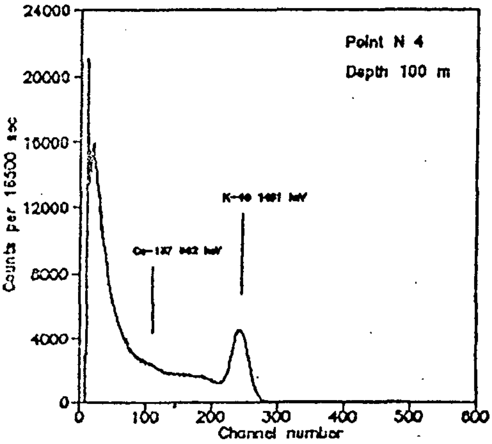

Point N 2
Depth 200 m
Counts per 14600 s
Channel number
Cs-137 662 keV
K-40 1461 keV
0
2000
4000
6000
8000
12000
14000
0
100
200
300
400
500

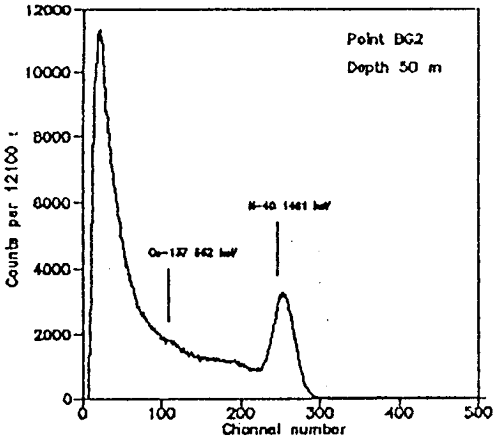

Point N 2
Depth 300 m
Counts per 15800 sec
Channel number
Cs-137 662 keV
K-40 1461 keV
0
4000
8000
12000
16000
20000
0
100
200
300
400
500
600

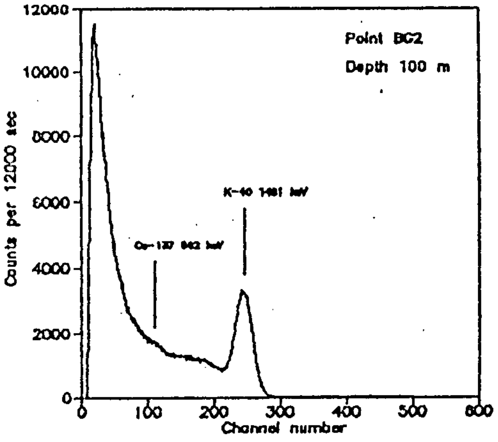

Point N 3
Depth 50 m
Counts per 13000 sec
Channel number
Cs-137 662 keV
K-40 1461 keV
0
4000
8000
12000
16000
0
100
200
300
400
500

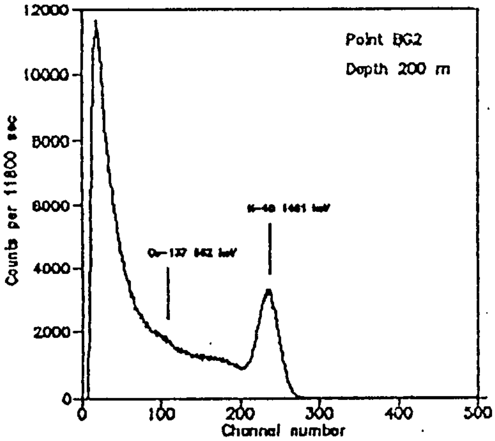

Point N 3
Depth 100 m
Counts per 6400 sec
Channel number
Cs-137 662 keV
K-40 1461 keV
0
2000
4000
6000
8000
0
100
200
300
400
500
600

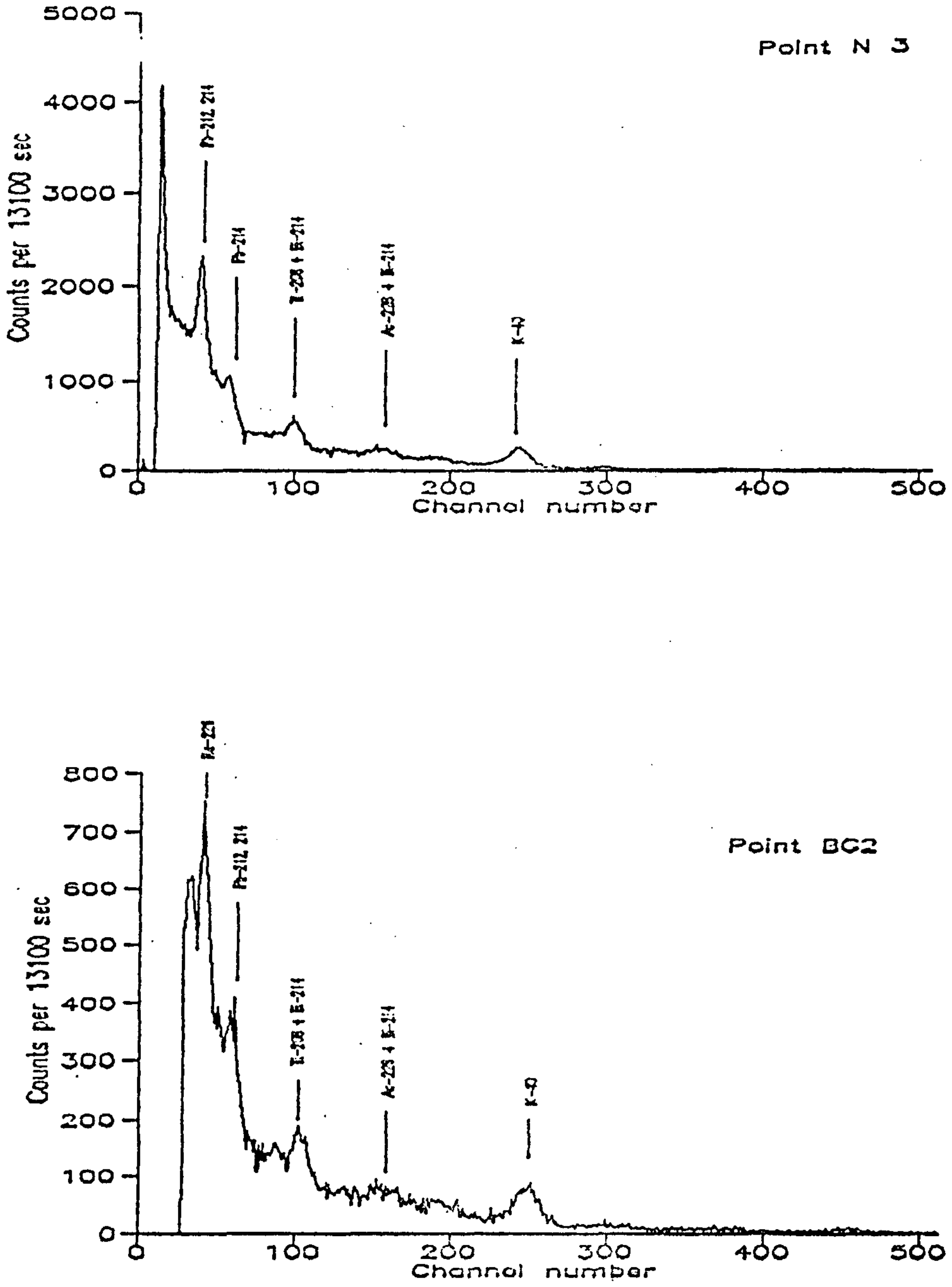

Point N 4
Depth 50 m
Counts per 13000 sec
Channel number
Cs-137 662 keV
K-40 1461 keV
0
2000
4000
6000
8000
10000
12000
14000
0
100
200
300
400
500


Point N 4
Depth 100 m
Counts per 16500 sec
Channel number
Cs-137 662 keV
K-40 1461 keV
0
4000
8000
12000
16000
20000
24000
0
100
200
300
400
500
600

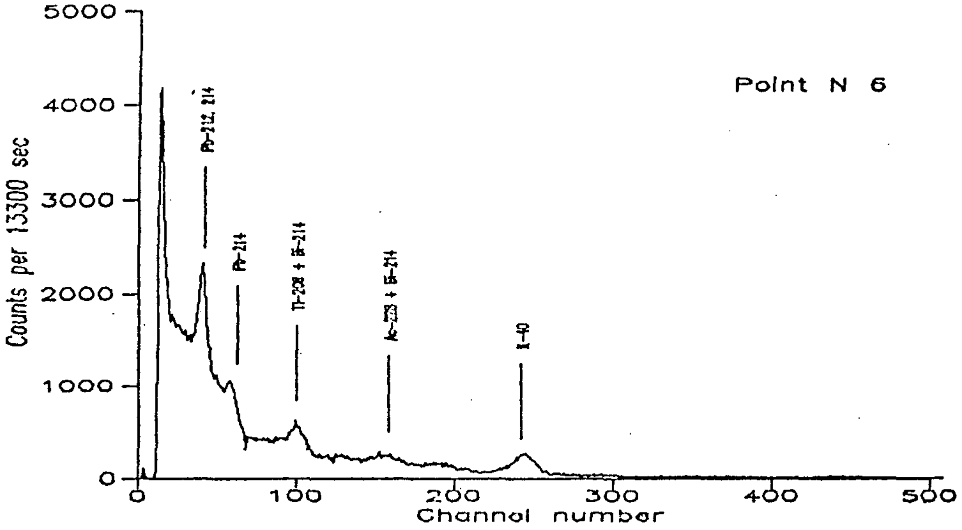

Point BG2
Depth 50 m
Cs-137 662 keV
K-40 1461 keV
Counts per 12100 s
0
2000
4000
6000
8000
10000
12000
0
100
200
300
400
500
Channel number

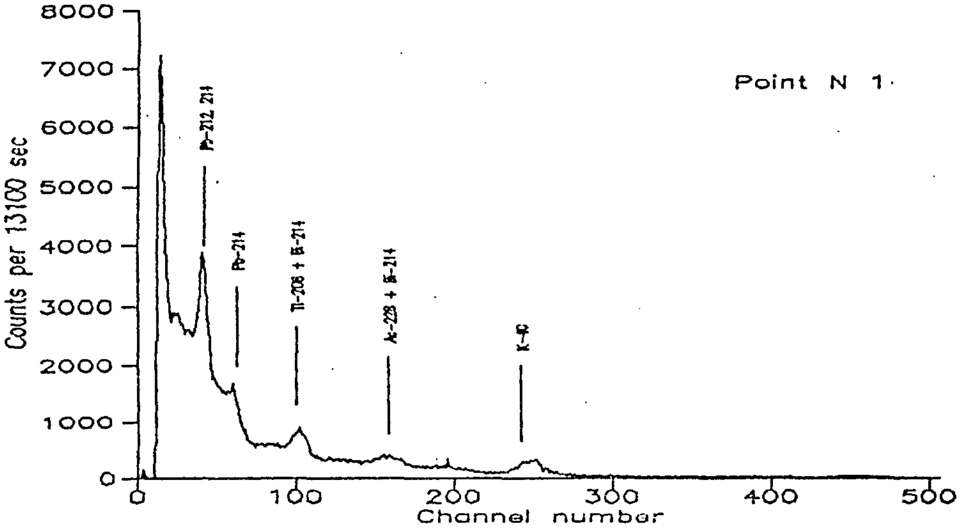

Point BG2
Depth 100 m
Cs-137 662 keV
K-40 1461 keV
Counts per 12000 sec
0
2000
4000
6000
8000
10000
12000
0
100
200
300
400
500
600
Channel number

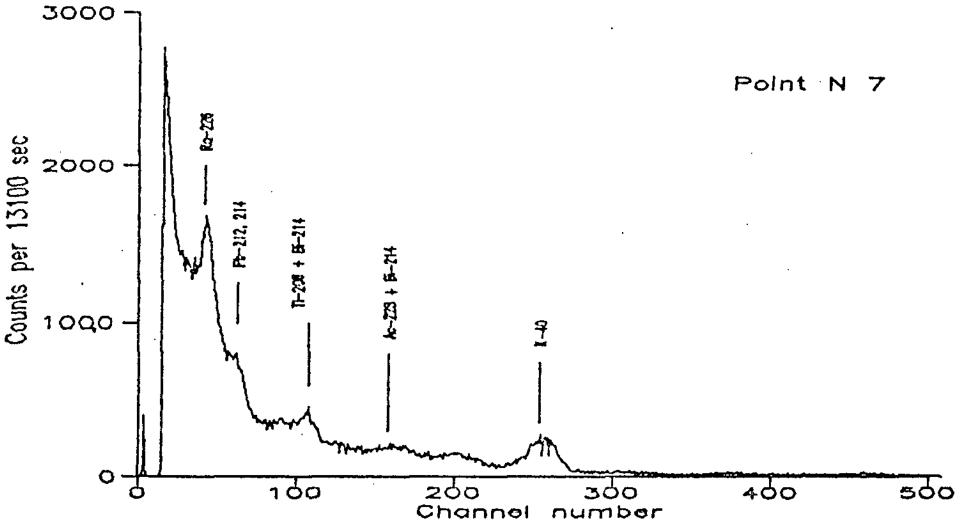

Point BG2
Depth 200 m
Cs-137 662 keV
K-40 1461 keV
Counts per 11800 sec
0
2000
4000
6000
8000
10000
12000
0
100
200
300
400
500
Channel number

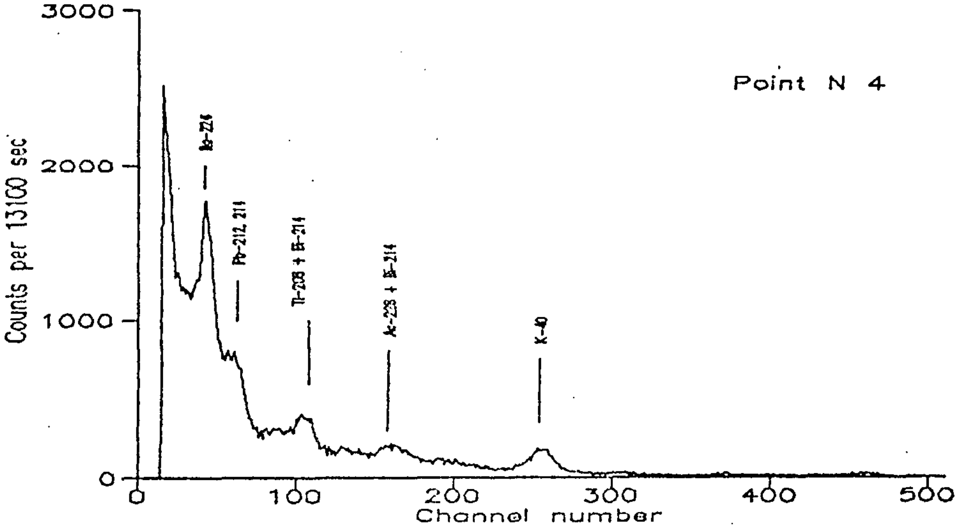


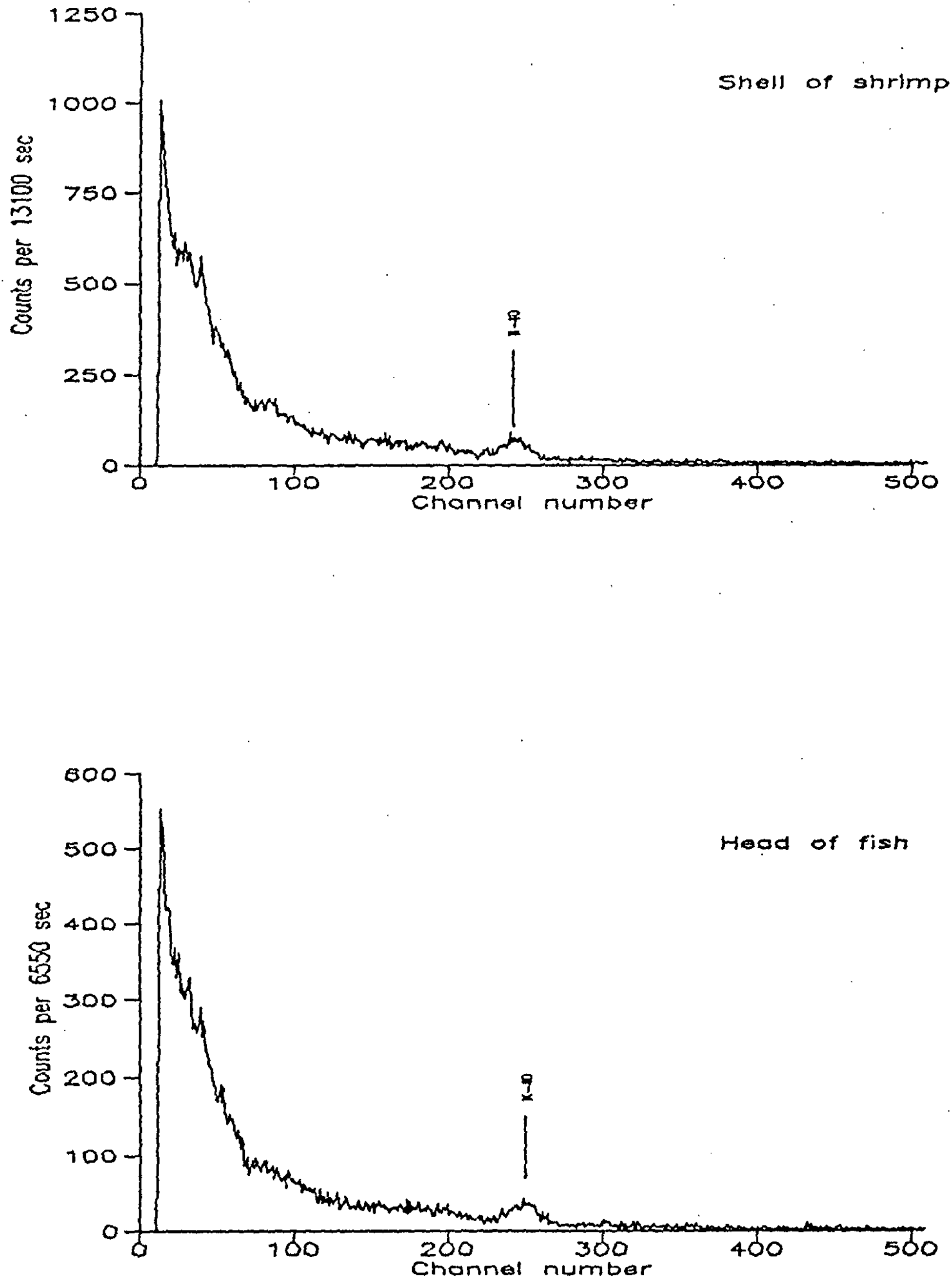
Gamma-spectra of surface sediment samples


Point N 6
Counts per 13300 sec
5000
4000
3000
2000
1000
0
Pb-212, 214
Pb-214
Tl-208 + Bi-214
Ac-228 + Bi-214
K-40
0
100
200
300
400
500
Channel number

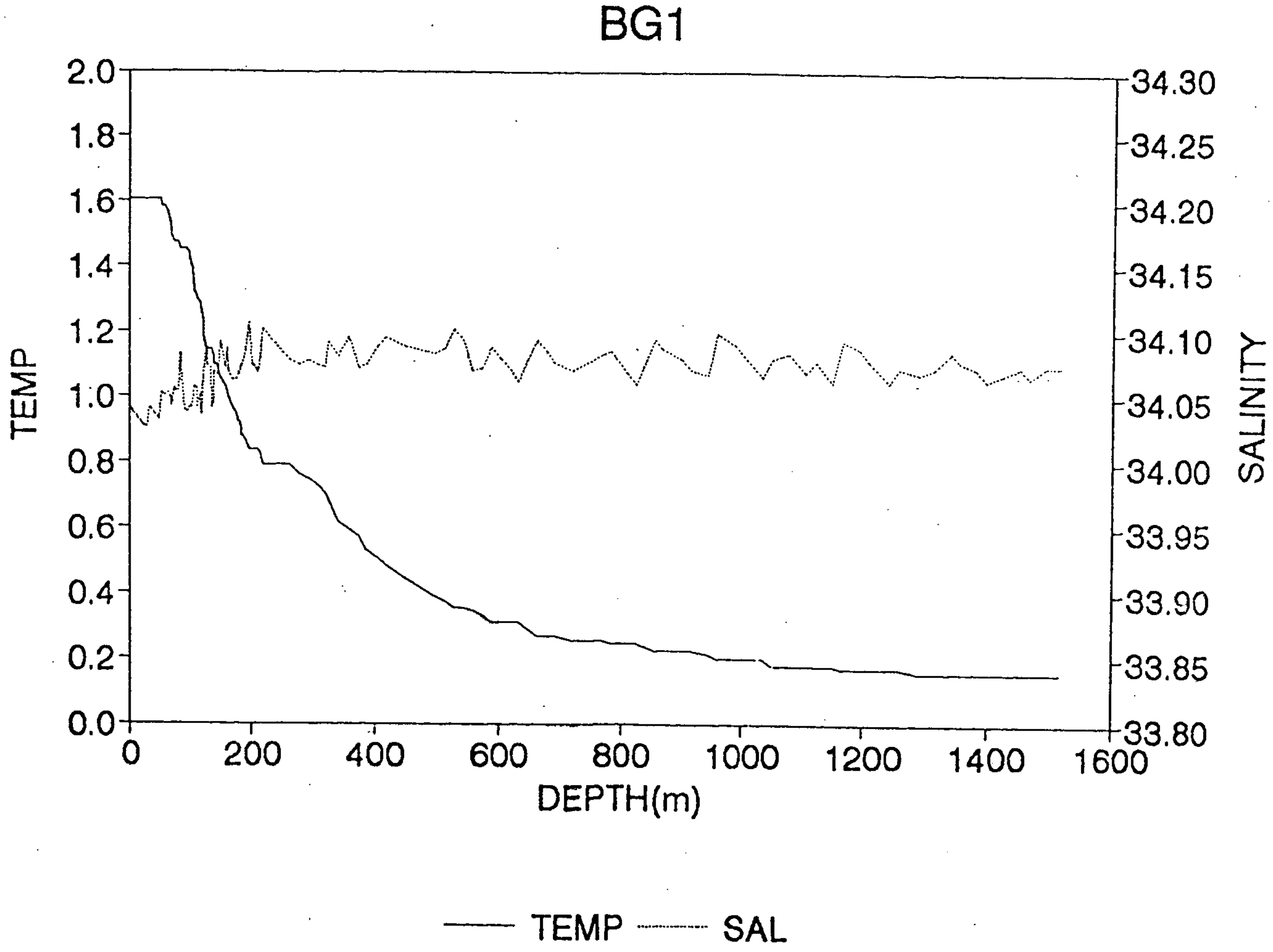

Point N 1
Counts per 13100 sec
8000
7000
6000
5000
4000
3000
2000
1000
0
Pb-212, 214
Pb-214
Tl-208 + Bi-214
Ac-228 + Bi-214
K-40
0
100
200
300
400
500
Channel number

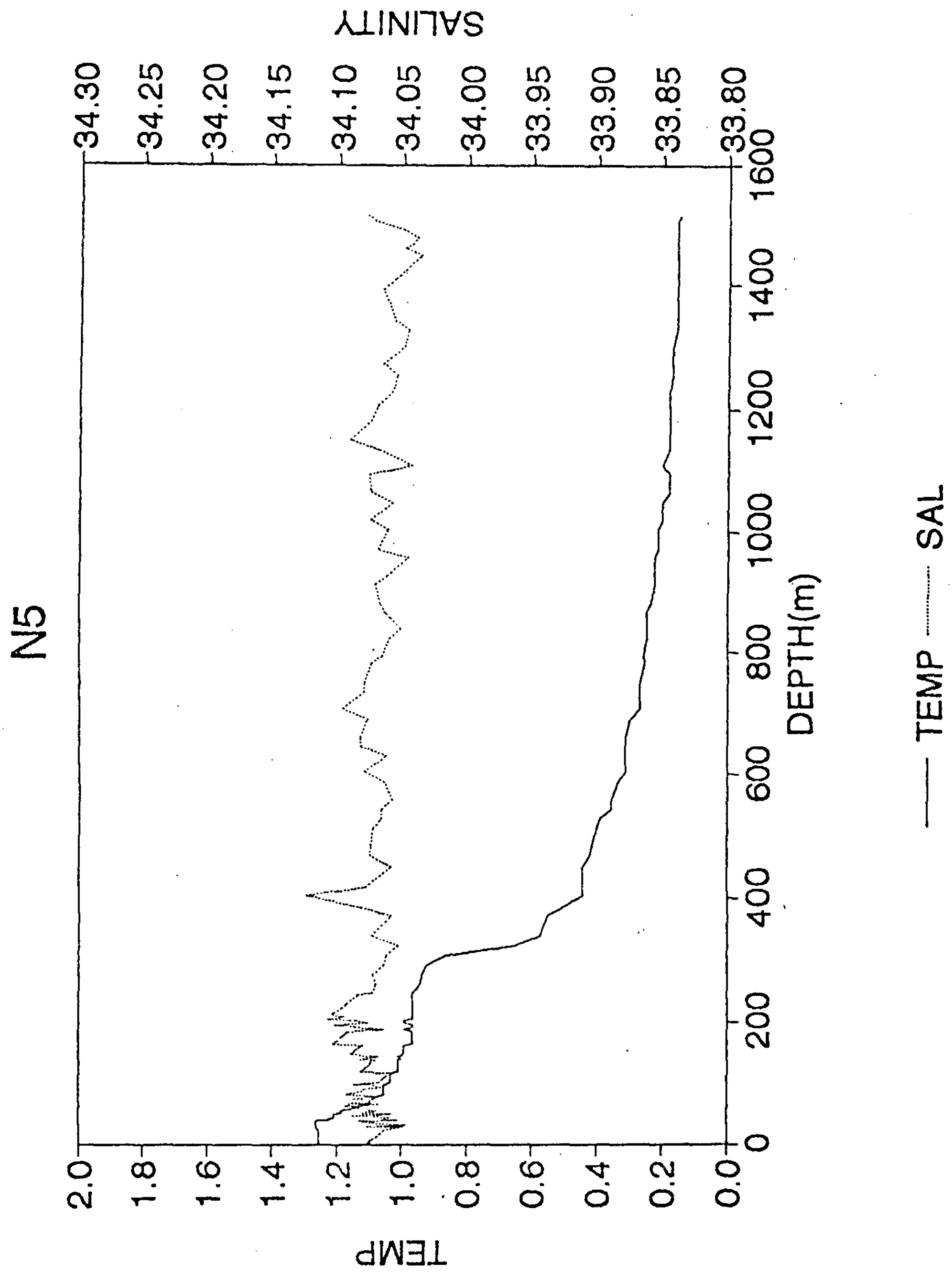

Point N 7
Counts per 13100 sec
3000
2000
1000
0
Ra-226
Pb-212, 214
Tl-208 + Bi-214
Ac-228 + Bi-214
K-40
0
100
200
300
400
500
Channel number

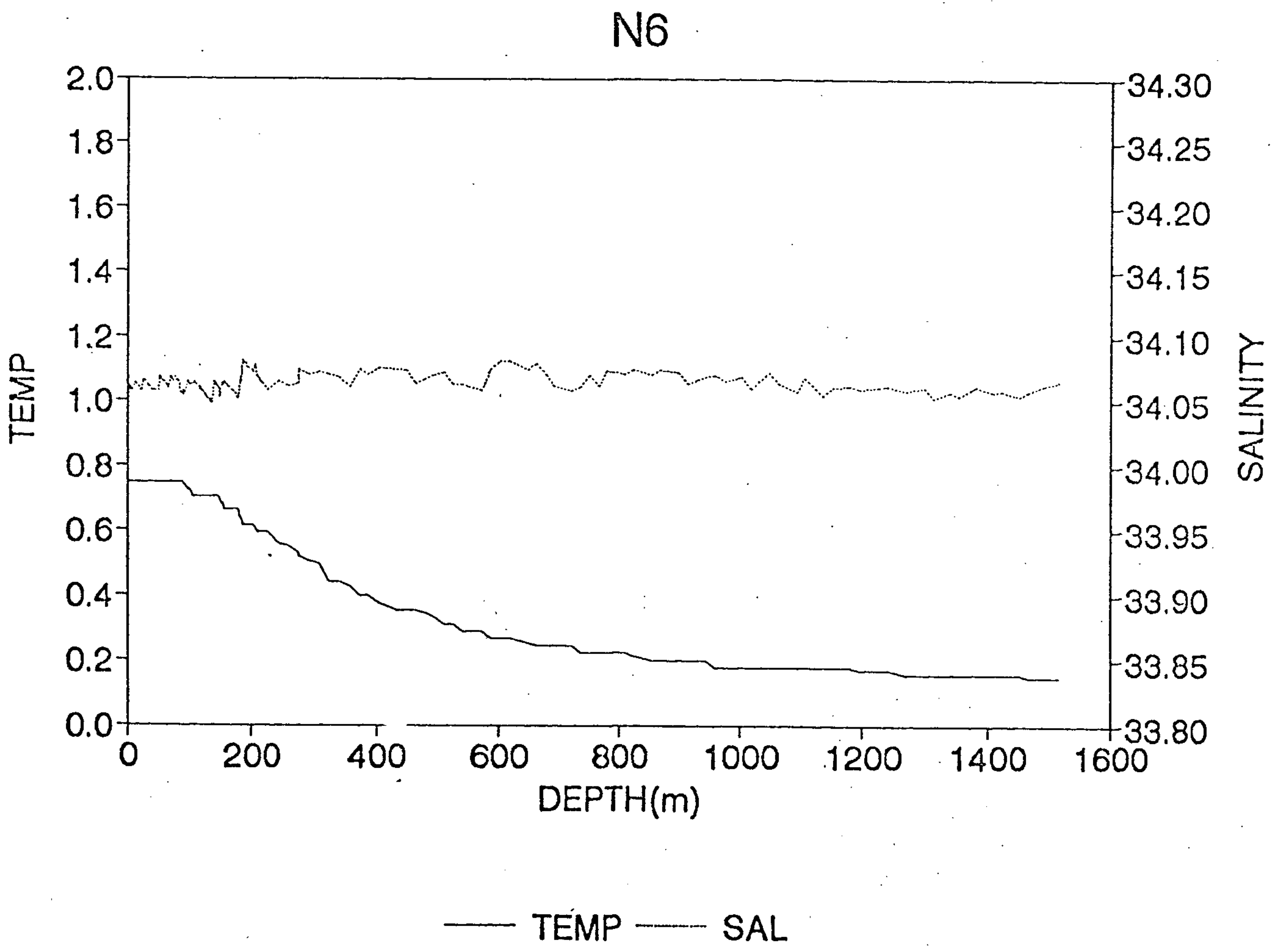

Point N 4
Counts per 13100 sec
3000
2000
1000
0
Ra-226
Pb-212, 214
Tl-208 + Bi-214
Ac-228 + Bi-214
K-40
0
100
200
300
400
500
Channel number



Gamma-spectra of biota samples


BG1
TEMP
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
SALINITY
34.30
34.25
34.20
34.15
34.10
34.05
34.00
33.95
33.90
33.85
33.80
DEPTH(m)
0
200
400
600
800
1000
1200
1400
1600
TEMP
SAL


N5
SALINITY
34.30
34.25
34.20
34.15
34.10
34.05
34.00
33.95
33.90
33.85
33.80
TEMP
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
DEPTH(m)
0
200
400
600
800
1000
1200
1400
1600
—— TEMP …… SAL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0.0
SALINITY
34.30
34.25
34.20
34.15
34.10
34.05
34.00
33.95
33.90
33.85
33.80
DEPTH(m)
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200
400
600
800
1000
1200
1400
1600
TEMP
SAL

N7

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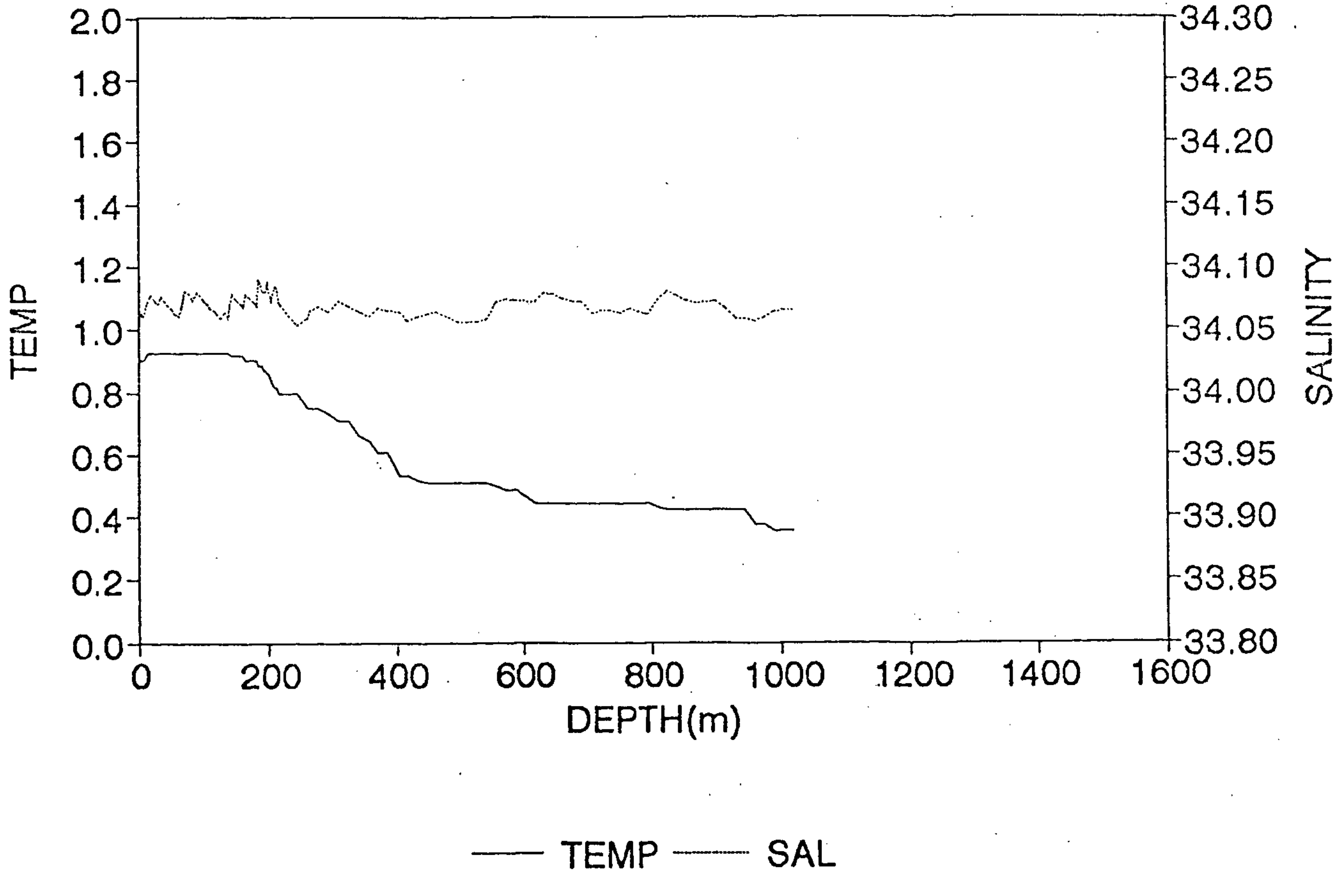

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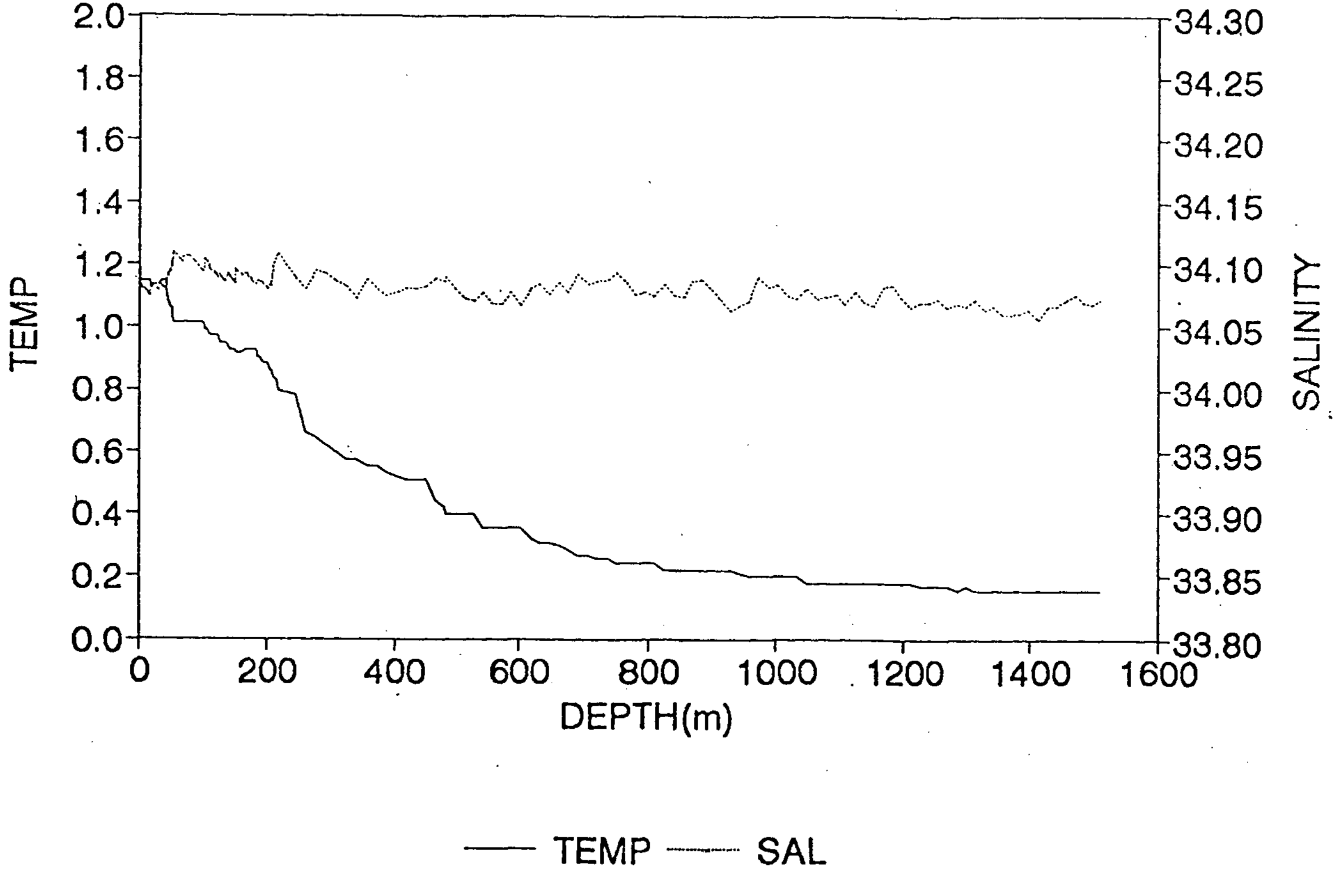

N2

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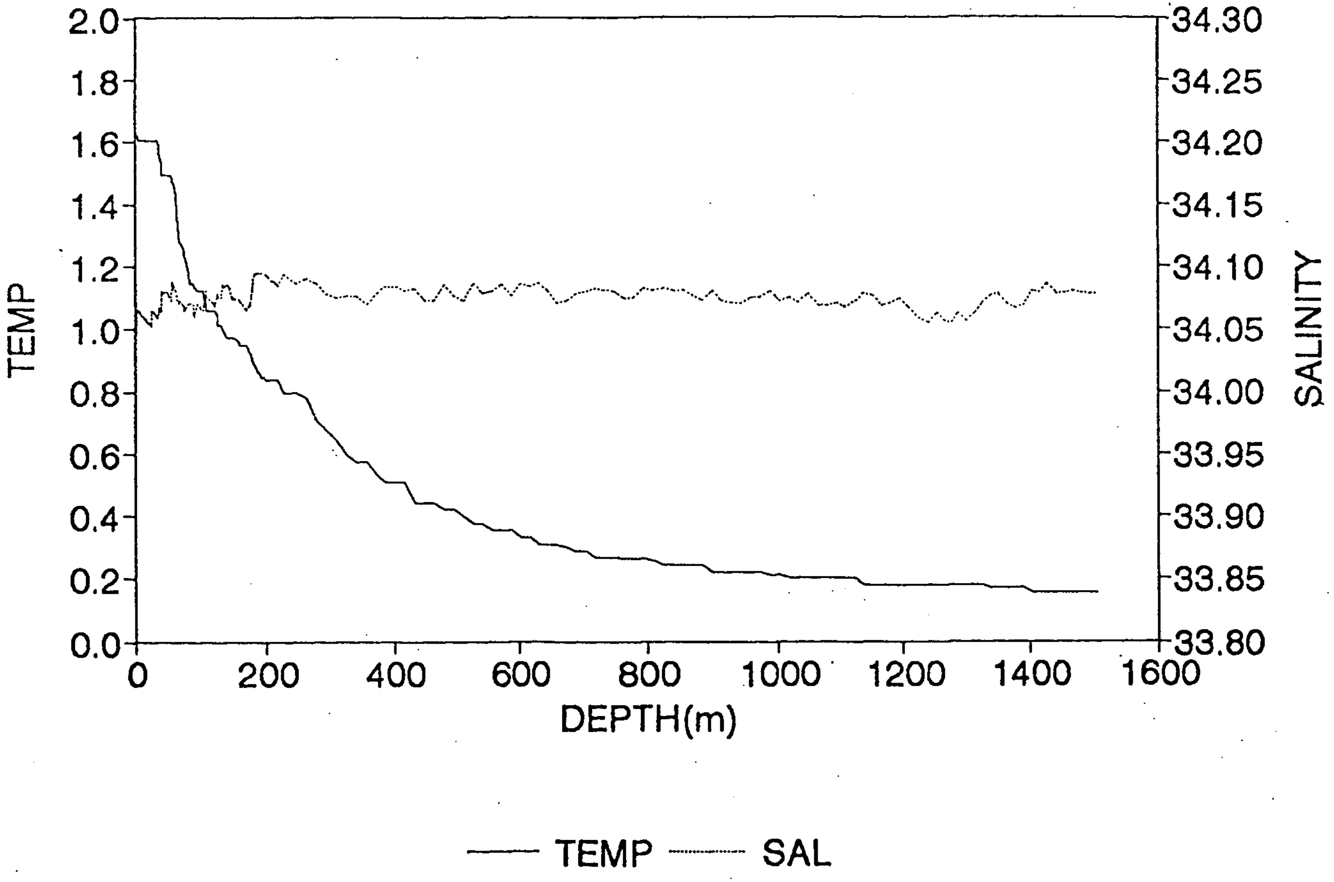

N2 R1

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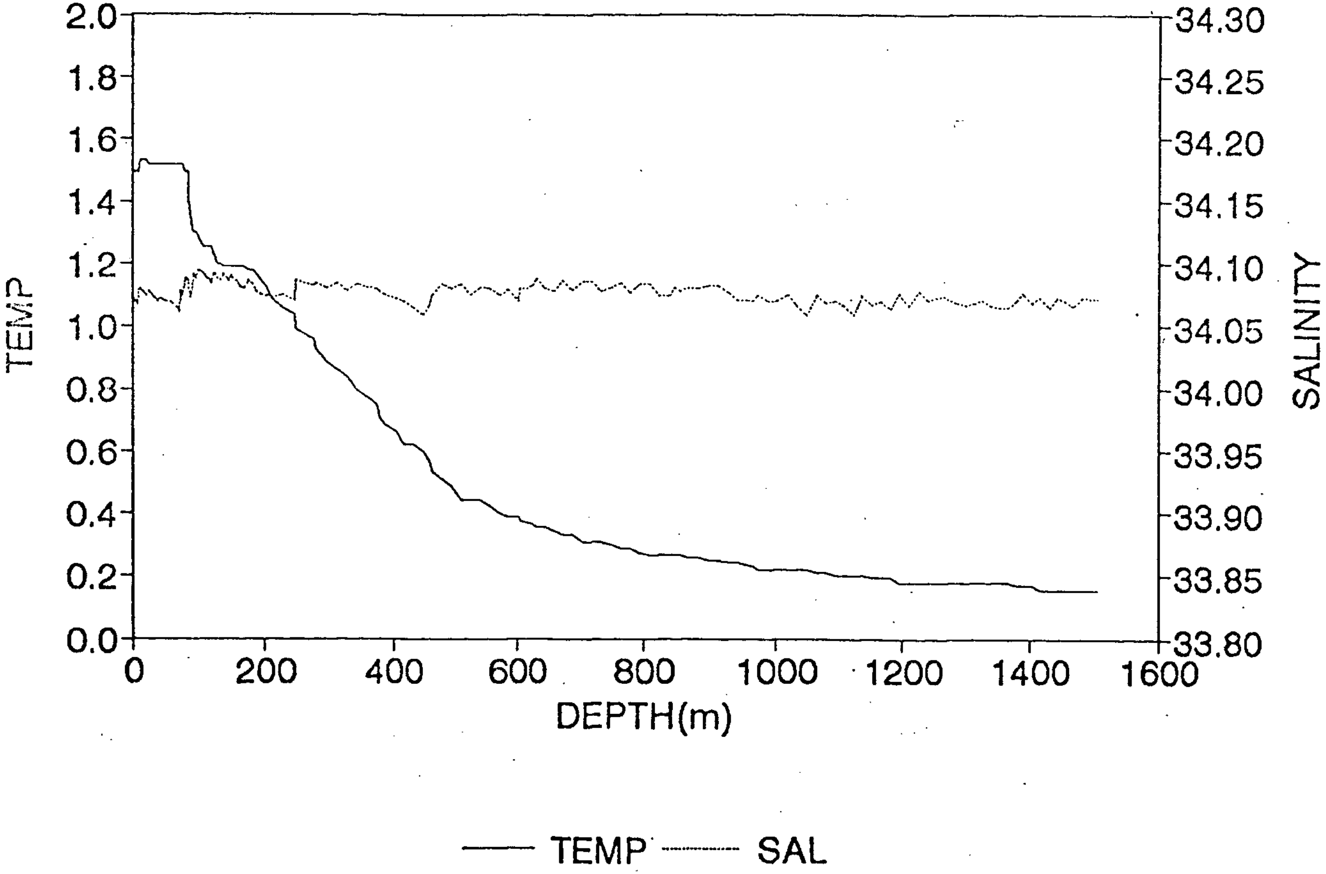

N2 R2

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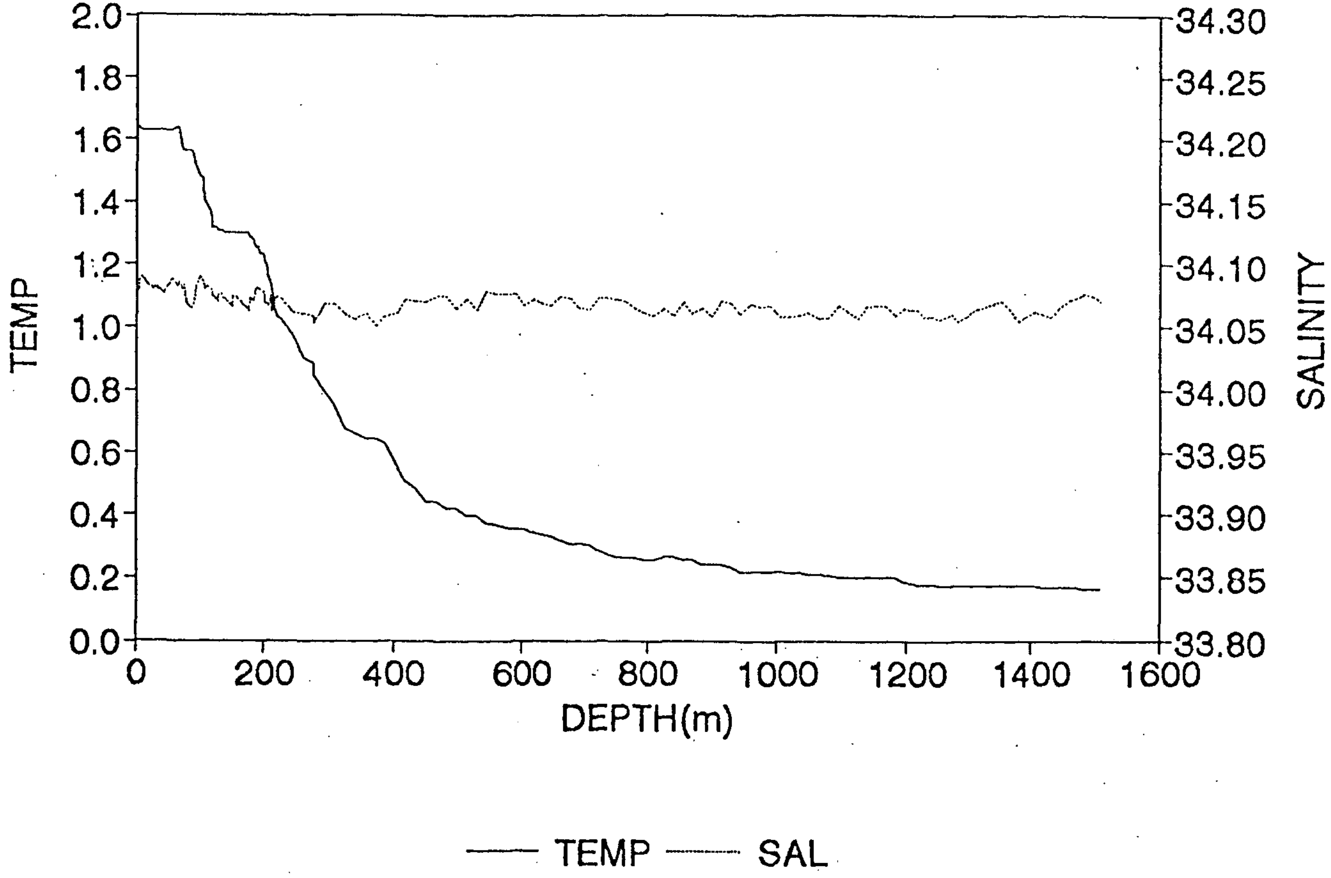

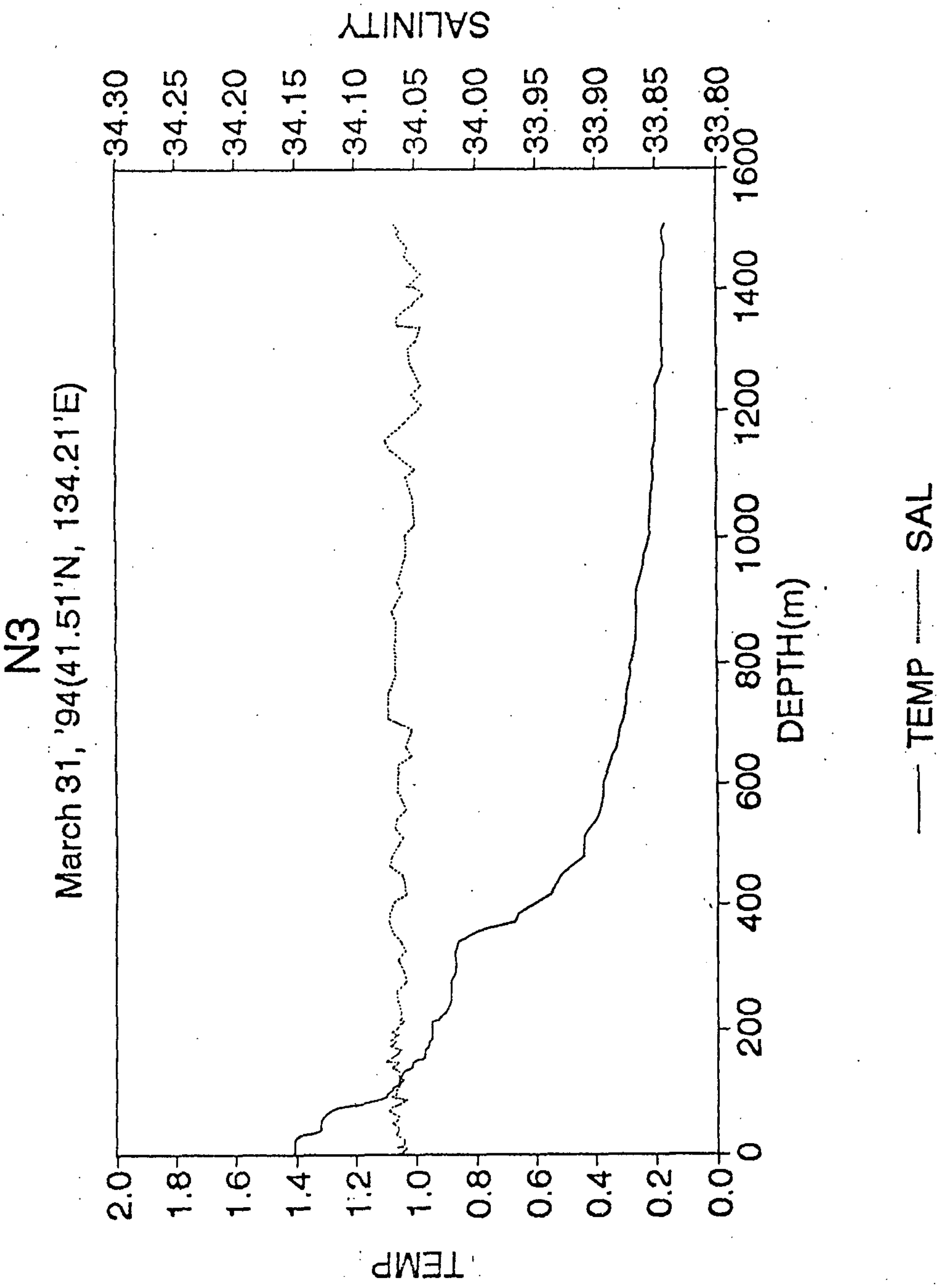

N4

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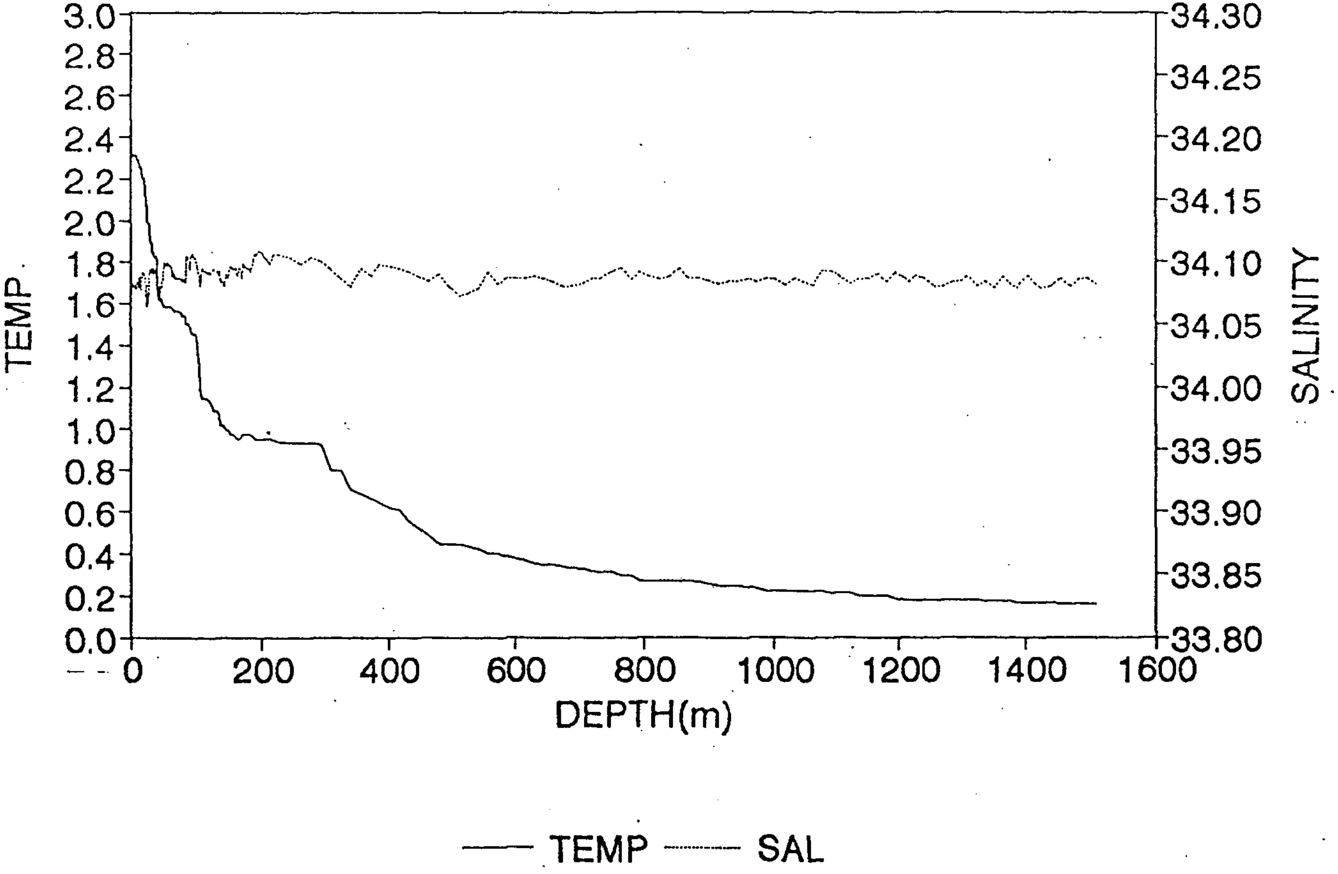

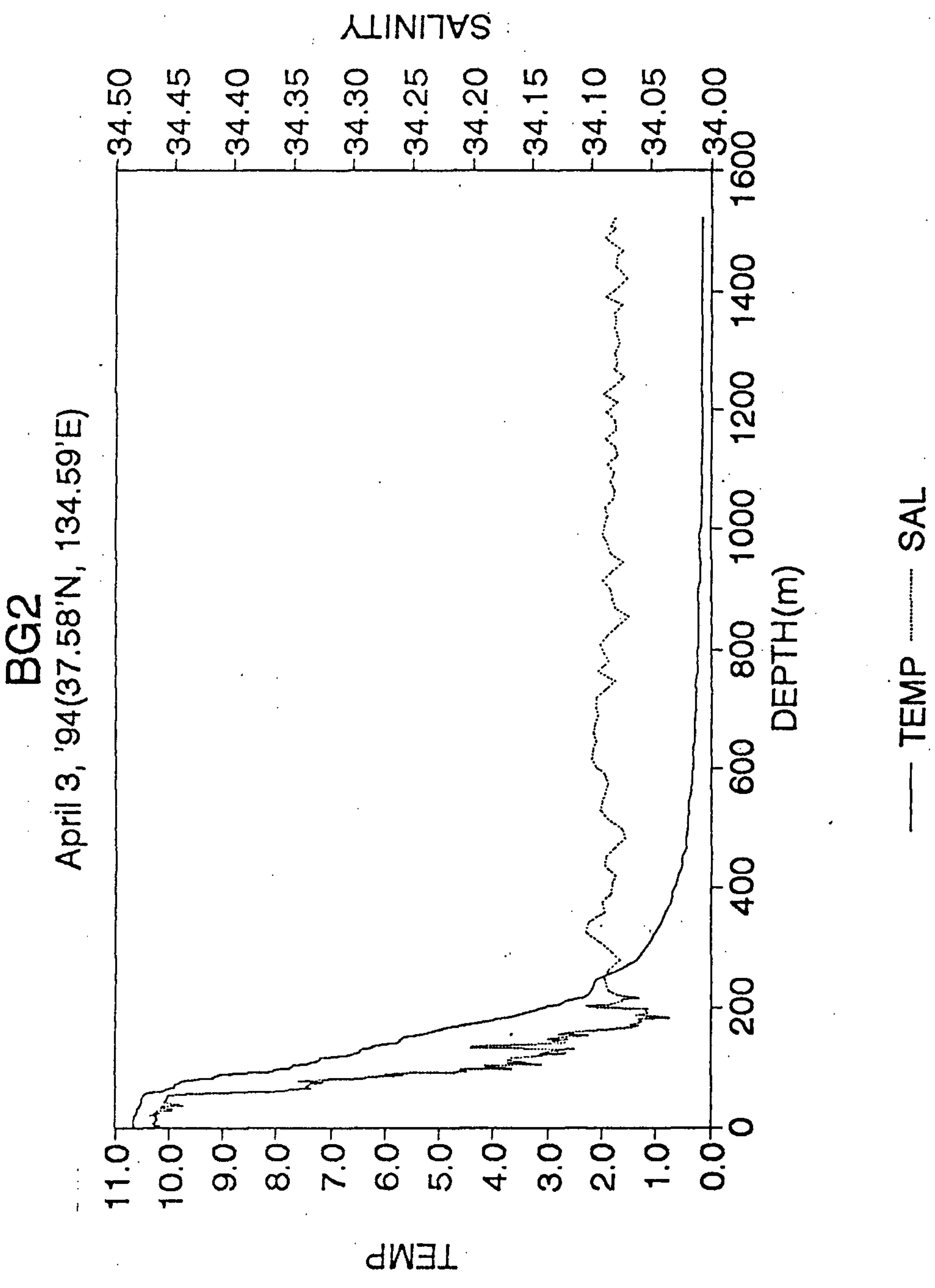

BG2

April 3, '94(37.58'N, 134.59'E)

N5

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 Probe T-7

 File. 03241527.DAT

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 LON  133°155 E



 DATE 94/03/24

 TIME 15:27:29


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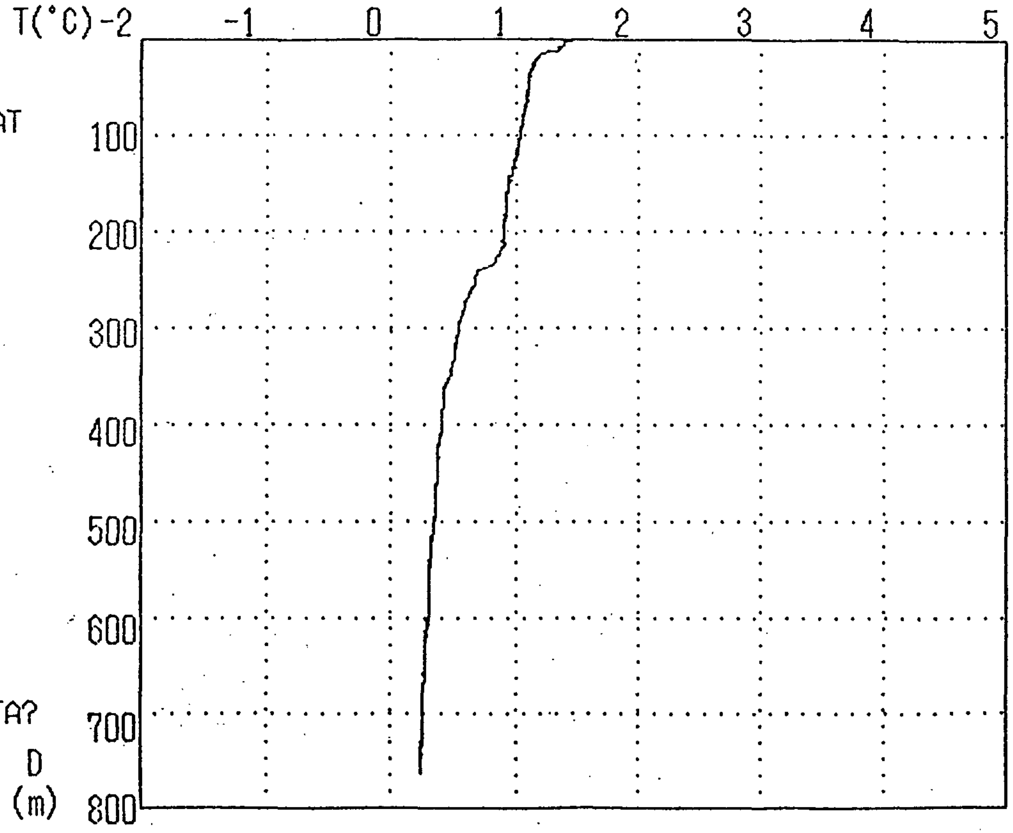
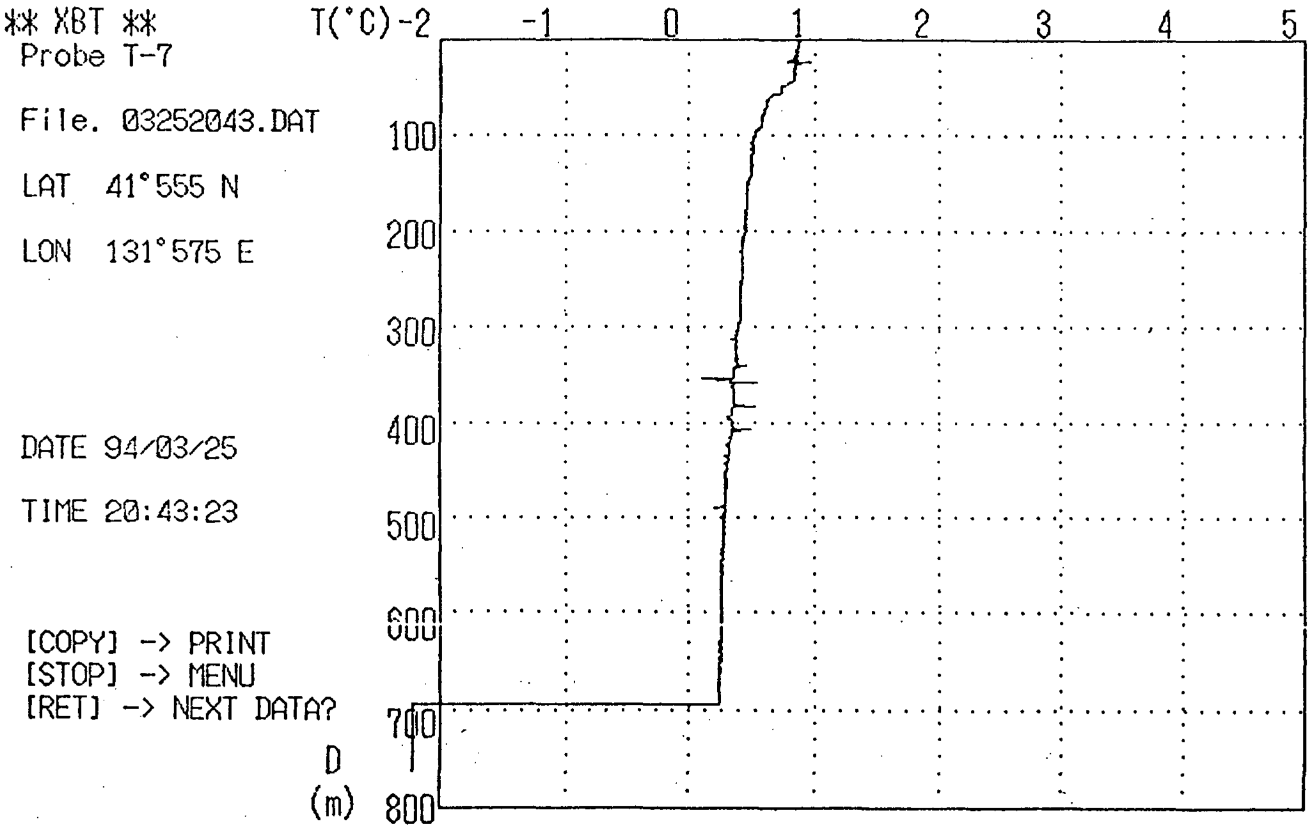


N6



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 DATE 94/03/25

 TIME 20:43:23


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N 7

** XBT **
Probe T-7

File. 03270816.DAT

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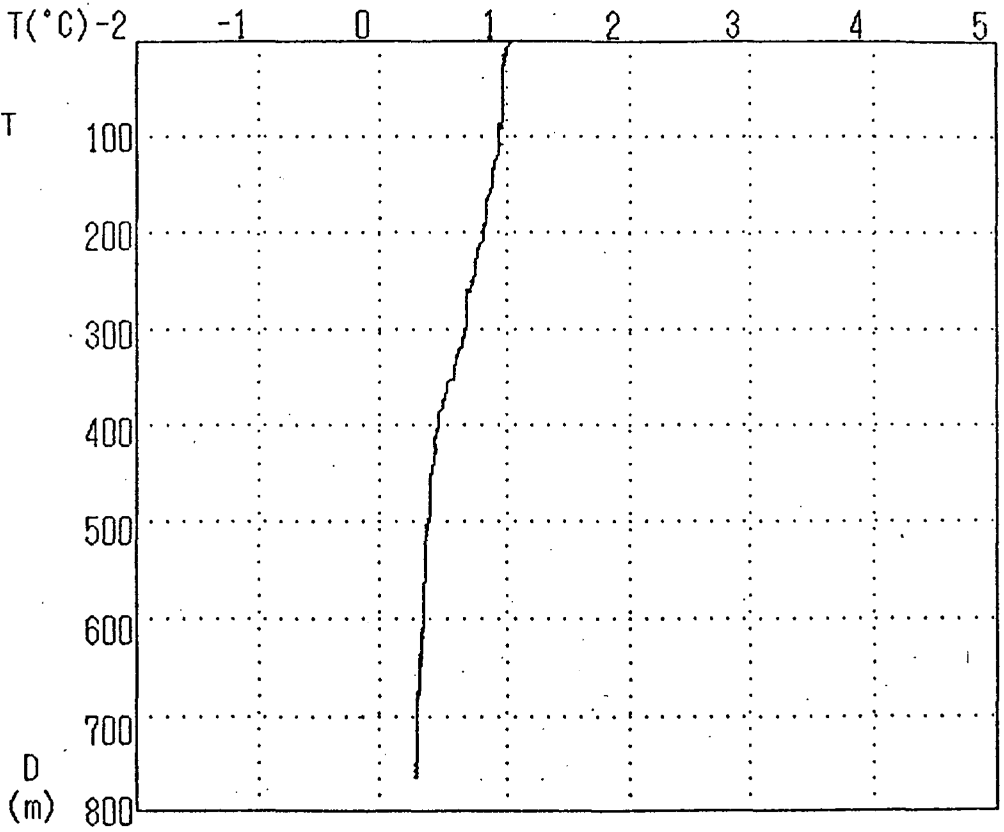
LON 132°182 E

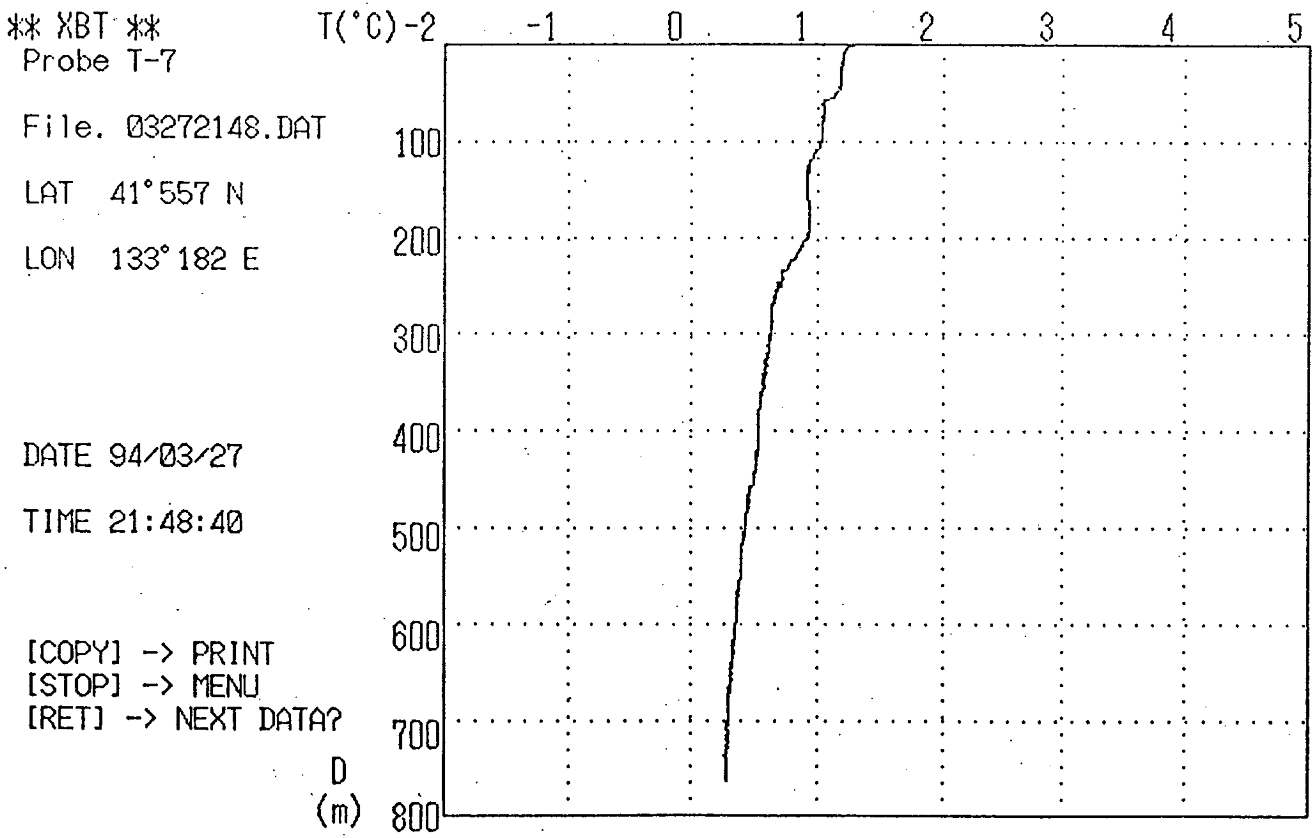
DATE 94/03/27

TIME 08:16:57



03272148.DAT PAGE 2

N 1



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 LAT  41°557 N

 LON  133°182 E



 DATE 94/03/27

 TIME 21:48:40


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 DATE 94/03/28

 TIME 20:08:07


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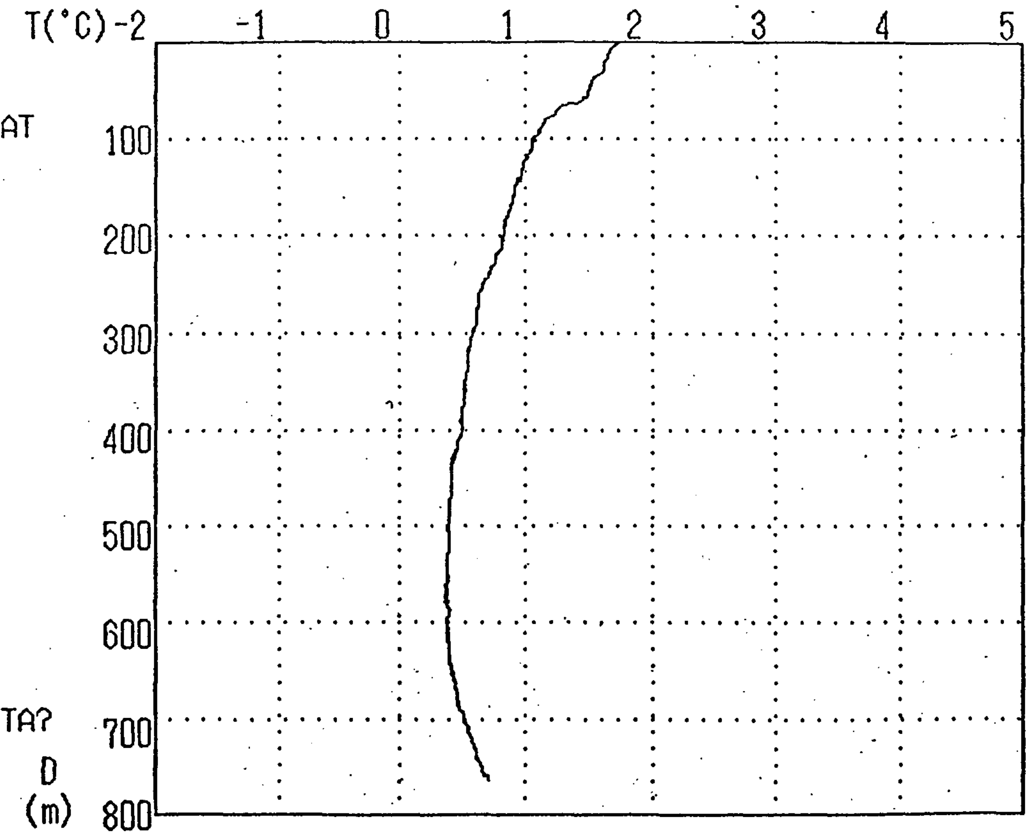

N3

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Probe T-7

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LON 134°190 E

DATE 94/04/01

TIME 18:14:06

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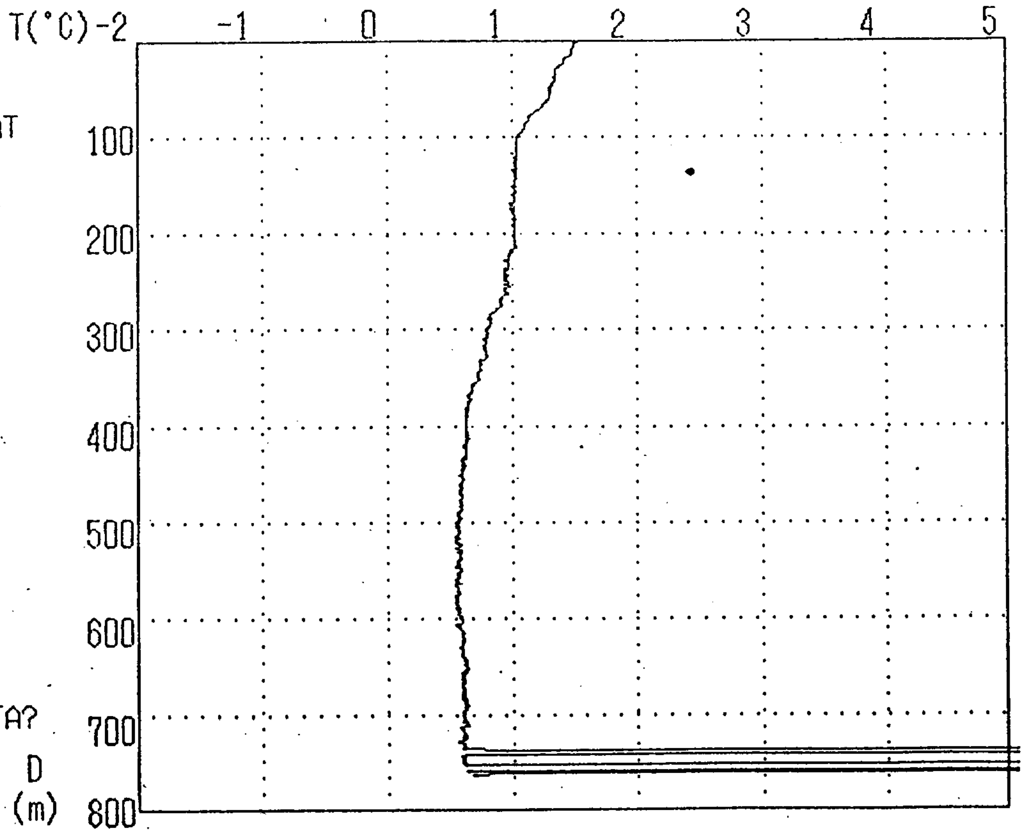

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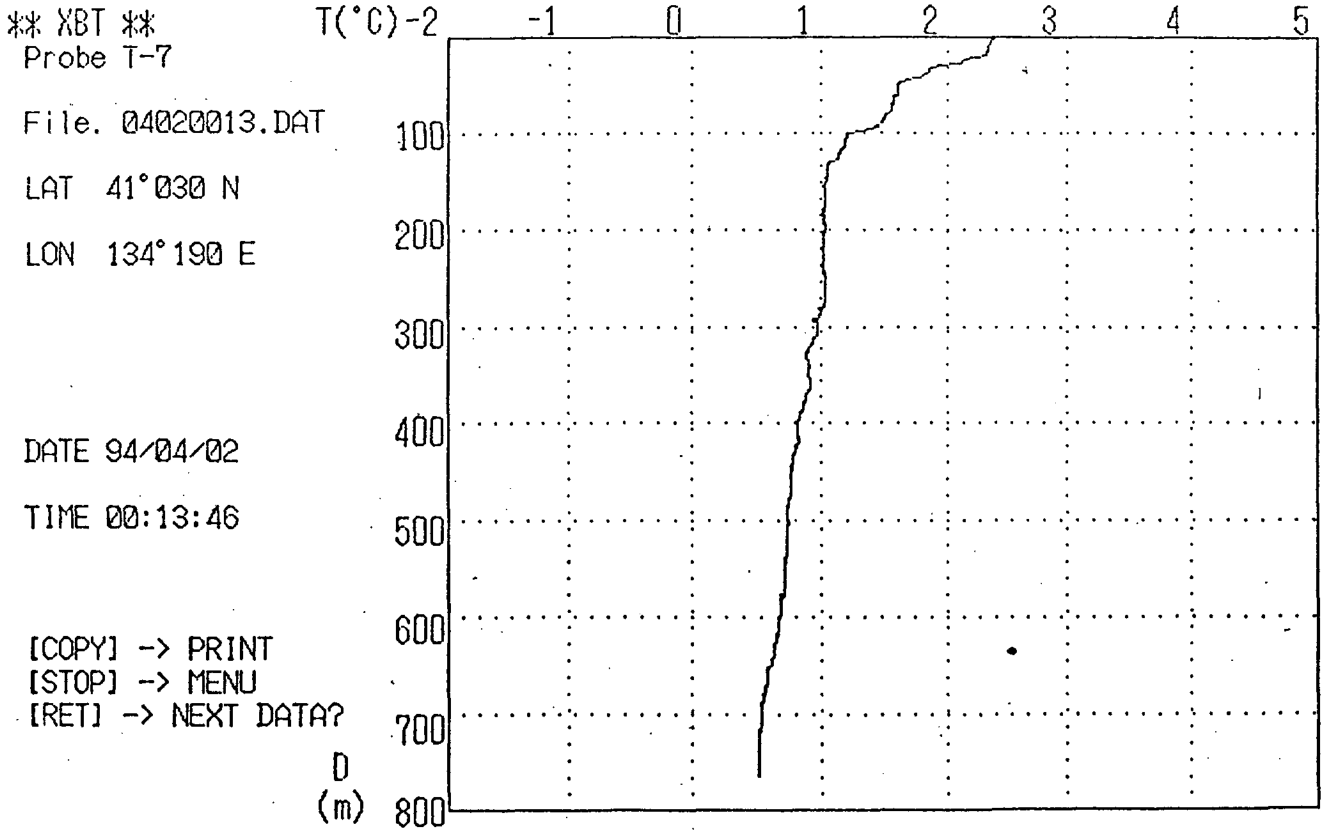

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LON 134°190 E

DATE 94/04/02

TIME 00:13:46

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04032108.DAT PAGE 2

BG2

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** XBT **
 Probe T-7

 File. 04032108.DAT

 LAT  37°583 N

 LON  134°594 E


 DATE 94/04/03

 TIME 21:08:41


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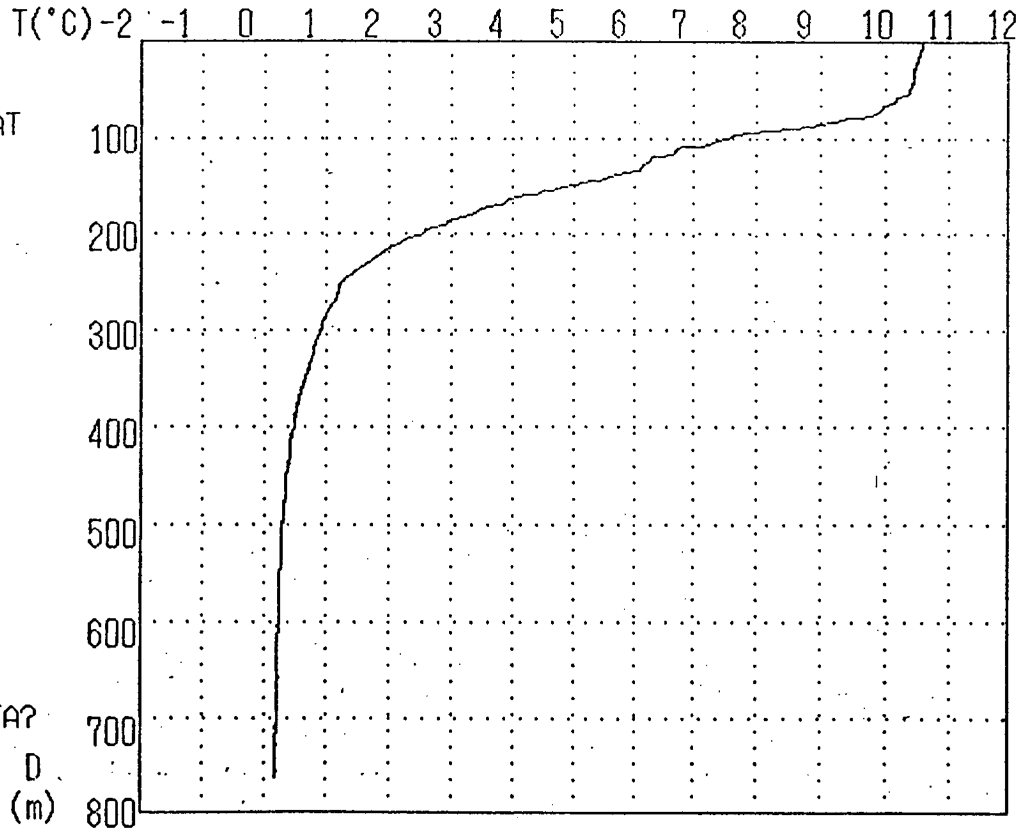

METEOROLOGICAL DATA

R/V "OCEAN" CRUISE N 56 EREI MARCH APRIL 1994

DATE	Time		Position		Temp.		Wind		Wave		Swell	
	GMT	Local	Lat	Lon	Air	Water	Dir.	Vel.	Dir.	H	Dir.	H
			Deg. Min.	Deg. Min.	Deg. *10	Deg. *10	Deg.	m/s *10	Deg.	m *10	Deg.	m *10
MARCH												
18	18	03	4148	13336	024	015	191	085	191	***	***	***
19	00	09	4052	13506	030	023	179	095	179	010	210	015
19	06	15	4003	13620	061	021	218	074	218	005	210	015
19	12	21	3912	13733	081	092	248	057	***	***	***	***
19	18	03	3818	13848	064	095	281	069	***	***	***	***
22	06	15	3827	13836	052	102	077	068	077	005	340	020
22	12	21	3918	13710	061	090	105	108	***	***	***	***
22	18	03	4010	13554	048	023	123	092	***	***	***	***
23	00	09	4047	13452	031	016	120	097	120	015	***	***
23	06	15	4049	13452	024	019	160	046	160	005	180	020
23	12	21	4049	13450	017	017	275	028	***	***	***	***
23	18	03	4056	13406	018	018	255	047	***	***	***	***
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25	06	15	4112	13307	005	012	310	088	310	015	020	025
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25	18	03	4148	13202	-026	007	340	134	***	***	***	***
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26	06	15	4149	13201	-006	011	320	078	320	015	010	020
26	12	21	4210	13212	008	007	241	073	***	***	***	***
26	18	03	4222	13218	014	008	265	092	***	***	***	***
27	00	09	4218	13218	014	009	200	089	200	010	000	000
27	06	15	4223	13219	020	010	200	072	200	010	000	000
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28	12	21	4137	13350	030	014	305	132	***	***	***	***
28	18	03	4138	13405	018	015	310	100	***	***	***	***

DATE	Time		Position		Temp.		Wind		Wave		Swell	
	GMT	Local	Lat	Lon	Air	Water	Dir.	Vel.	Dir.	H	Dir.	H
			Deg. Min.	Deg. Min.	Deg. *10	Deg. *10	Deg.	m/s *10	Deg.	m *10	Deg.	m *10
					MARCH							
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29	06	15	4140	13346	010	016	290	114	290	020	***	***
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31	06	15	4142	13352	023	020	205	058	205	005	310	015
31	12	21	4147	13350	024	018	210	061	***	***	***	***
31	18	03	4146	13350	033	016	200	081	***	***	***	***
					APRIL							
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01	06	15	4154	13419	026	013	202	097	202	015	***	***
01	12	21	4116	13418	044	018	197	099	***	***	***	***
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02	06	15	4109	13425	048	021	290	126	290	020	***	***
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03	00	09	3800	13500	094	102	325	113	325	020	***	***
03	06	15	3758	13506	078	106	320	061	320	005	340	025
03	12	21	3758	13458	081	105	190	009	***	***	***	***
03	18	03	3800	13500	084	102	180	048	***	***	***	***
04	00	09	3800	13500	095	105	160	046	160	005	360	020
04	06	15	3806	13459	101	104	170	063	170	005	360	025
04	12	21	3800	13352	096	089	181	084	***	***	***	***
04	18	03	3802	13206	102	100	219	065	***	***	***	***

Annex 8

Joint agreement on the onland radionuclide analysis

	Japan	Korea	Russia	IAEA
Sea water				
^{137}Cs	+++	+++	+++	+++
^{90}Sr	+++	+++	+++	+++
$^{239,\ 240}$Pu	+++	+++	++	+++
^{60}Co, ^{54}Mn	+++	++	++	+++
Other	++	++-	+	++
Bottom sediments				
^{137}Cs	+++	+++	+++	+++
^{90}Sr	+++	+++	+++	+++
$^{239,\ 240}$Pu	+++	+++	++	+++
^{60}Co, ^{54}Mn	+++	++	++	+++
Other	+	+	+	++
Biota				
^{137}Cs	+++	++	+	+
^{90}Sr	++	++	+	+
$^{239,\ 240}$Pu	++	++	+	+
^{60}Co, ^{54}Mn	+++	++	+	+
Other	+	+	+	+
Suspended matter		++	++	

+++ radionuclide that will be analysed in all samples;

++ radionuclide that will be analysed in a limited number of samples;

\+ radionuclide that will probably not be analysed.

Taking into consideration that the concentrations of some radionuclides in the study area are very low, the participating parties will undertake necessary efforts to provide as low detection limits as required to determine background activities of the above mentioned radionuclides caused by their global fallout. During the onland analysis it is recommended to take into account the minimum activity levels of ^{137}Cs and ^{90}Sr about 0.5-1.5 mBq/l for seawater, 0.5-1.5 Bq/kg for bottom sediments and biota, 3 uBq/l of ^{239,240}Pu for seawater and 10 mBq/kg of ^{239,240}Pu for bottom sediments and biota.

2.3. 육상 실험실 정밀조사보고서

Investigation of Environmental Radioactivity in Waste Dumping Areas of the Far Eastern Sea Areas

Results from the First Korean Korean-Japanese-Russian Joint Expedition 1994

July 1995

CONTENTS

Summary

This report describes the results obtained by analysis of marine samples collected during the 1994 Japanese-Korean-Russian joint expedition to the Far Eastern sea areas.

7 sampling stations within the areas at which radioactive waste was dumped by the former USSR and the Russian Federation were investigated together with 2 additional background stations.

The principal aim was to measure the levels of anthropogenic radionuclides in the study area in order to facilitate the assessment of the present consequences of the radioactive waste disposals.

The results show that the radionuclide concentrations in seawater and seabed sediment samples from the study area are not significantly different from those found in the western North Pacific. Although the study is at an early stage, analysis of isotopic activity ratios and estimates of radionuclide inventories indicate the absence of any significant anthropogenic contamination other than global fallout in the study area.

Introduction

The White Book (1993) revealed that large quantities of radioactive waste, which included liquid and solid waste, have been dumped in the Far Eastern sea areas by the former USSR and Russia (Table-1). In the past, lesser quantities of solid radioactive waste were also dumped in the Far Eastern sea areas by Japan and Korea.

In order to survey any marine radioactive contamination in the Far Eastern sea areas, the first Japanese-Korean-Russian joint expedition (From Vladivostock, Russia 18.March 1994 to Tonghae, Korea 6.April 1994) was conducted at the areas of the Russian radioactive waste dumping, namely at areas No.1, No.2, No.5, No.6 and No.9 shown in Fig-1.

The expedition was carried out using the Russian research vessel "Ocean", and 37 scientists from Japan, Korea, Russia and IAEA participated. The list of participants is shown in Annex-1.

The observations were carried out at 7 sampling stations in the study area and at 2 additional locations outside this region, the latter to reflect background conditions.

The first background station (BG1) was set up in the sea area within 200 nautical mile from the Russian coast in order to test the sampling apparatus.

The second background station (BG2) was situated SSE of the survey area.

The expedition cruise chart, including sampling stations and corresponding water depths, is shown in Fig-1, and radioactive waste dumping history in the Far Eastern sea areas is summarized in Table-1.

Seawater (surface water, bottom water), sediment and plankton samples were collected at each sampling station. At area No.9 (station N2), where the largest inventory of the radioactive wastes was dumped, intermediate waters were collected at depths of 200m, 500m, 750m, 1000m and 2000m in addition to surface and bottom waters.

In-situ radioactive measurements of surface waters and sediments were carried out using a Ge semiconductor detector and a NaI detector at each sampling point.

Japanese, Korean and Russian groups pumped large volumes of surface water through radionuclide preconcentration systems in order to collect the radionuclides in seawater, and then measured the adsorbed radionuclides by gamma spectrometry.

As a result of the *in-situ* gamma spectrometry, no anthropogenic radionuclides were detected from surface water and sediment samples.

The measurements of the adsorbents showed ^{137}Cs concentrations of 2-5 mBq L^{-1} in surface waters. No other anthropogenic radionuclides were detected.

The IAEA returned a representative set of samples to its Marine Environment Laboratory in Monaco and carried out independent radiochemical analysis there.

This report gives the detailed results of radiochemical analysis by each side's laboratories. The results were compared with past marine environment radioactivity monitoring data reported for the Far Eastern sea areas.

1. Sampling and handling procedures

1.1 Hydrocasts

According to the programme of the joint expedition, seawater samples were collected from surface and near-bottom layers at each station, and at station K2 also intermediate waters from 200m, 500m, 750m, 1000m and 2000m depths. Due to a lack of instrumentation for determining the distance between the water sampler and the sea bottom accurately, waters of about 100 m above the bottom was dosignated as bottom water.

Due to ship drift by wind and ocean currents during the sampling operations, all groups adopted a 5-mile radius around the sampling point as a working area for each station. If the ship drifted outside this area, the process of sampling was stopped, and the ship returned to the initial sampling point to continue sampling.

At each station, CTD (conductivity, water temperature and depth) casts were carried out down to 1500m depth using a CTD from the bowside deck.

At each station except the first, background one, XBT (water temperature and depth) measurements were performed down to 700-800m depth, using a XBT system from the stern deck.

Regular meteorological observations were carried out at 00:00, 06:00, 12:00 and 18:00 GMT by the "Ocean" crew.

1.2 Water sampling and handling

a) Surface water

Surface water for subsequent distribution among the four parties (Japan, Korea, Russia and IAEA) was collected at the stern side deck by immersing a vibrating pump below the sea surface.

Water was pumped through a filtration unit for the separation of suspended particulate matter. The filtration unit consisted of a fabric filter(FPP-15-1,5) and a paper filter("blue tape"). The pore size of the combined filter was about 1 μm, and the flow rate was about 12 L min^{-1}.

After distributing the filtered water, the filters were removed from the filtration unit, placed in plastic containers and distributed for future radionuclide analysis in shore laboratories.

One group performed preconcentration of radionuclides in filtered water on board.

For the water sample storage on board and for transportation to shore laboratories, 20 L plastic containers (Cubitainers) were used. To avoid sorption of radionuclides onto the container's surface during storage, 40 mL of concentrated HCl was added to each container.

In addition to the above mentioned operations, Japanese, Korean and Russian scientists undertook pumping of large volumes of surface waters by means of submersible pumps. The seawater was passed through special units for radionuclide sorption.

At some stations Russian scientists collected subsurface waters of 100 m depth, and then filtered and passed the water through sorbents to determine radiocaesium.

Japanese scientists also performed *in-situ* measurements. Surface waters were pumped into a large plastic container (300 L) and an immersed HPGe detector was used for the direct spectrometric analysis.

b) Intermediate and bottom waters

Intermediate and bottom waters were collected by means of a large volume water sampler. About 250-300 L of seawater was collected on each cast. Three successful casts were performed at each station, with the following distribution of intermediate and bottom waters:

IAEA : 120 L, Japan ; 160 L, Republic of Korea ; 160 L,
Russia; the remaining, up to 450 L

Intermediate and bottom water samples were pumped through a filtration unit according to the same procedure as for surface waters.

Filtered water was pumped into two plastic tanks (500L each). Each tank was filled with one half of the sample volume after each cast to ensure sample homogeneity for further water distribution. As for the surface water, one group undertook on-board preconcentration of radionuclides.

Japanese, Korean and IAEA scientists used 20 L plastic containers for sample storage and the same sample treatment procedure as for surface water. The samples of suspended matter were packed into plastic containers and distributed according to the joint agreement for radionuclide analysis in shore laboratories.

1.3 Seabed sediment sampling and handling

Seabed sediment samples were collected at each station using a modified Petersen grab sampler with a surface area of about 0.25 m^2 and a sampling depth of about 10-15 cm ("Ocean-0,25").

The sediment sample was divided into two parts ; the top layer (surface to ~3cm depth), and the remaining subsurface layer. Each surface layer sample was well mixed in a plastic tray, placed in plastic cans and distributed. The subsurface sample was well mixed in a stainless steel tray and then placed in 5 L plastic bottles and distributed.

The approximate wet weights of surface and subsurface sediment samples are given in Table-2.

Russian scientists divided their samples into two parts. The first was packed into a plastic container for transportation to shore laboratories. The second was dried and measured on board by gamma spectrometry by Japanese and Russian groups.

The sediment remaining after distribution was used for benthos sampling.

2. Methods of on board preconcentration of radionuclides in seawater

2.1 Japan

Surface seawater was pumped up at a flow rate of about 2-3 L min^{-1} into a radionuclide collection system, which consisted of a combination of one filter column (0.45 μm pore size) to collect suspended radionuclides and two columns with acrylic fiber, impregnated with KCFC (Potassium hexacobalt ferrate, $K_2[CoFe(CN)_6]$), to collect dissolved radionuclides.

Surface seawater was also pumped up at a flow rate of about 2-3 L min^{-1} directly into a radionuclide collection system which was composed of a combination of one filter column (0.45 μm pore size) and two columns with acrylic fiber, impregnated with MnO_2.

2.2 Korea

Surface water of 1000 to 5000 L total volume was pumped at a flow rate of about 2 L min^{-1} into a Cs sorbent system consisting of three consecutive filters, the first to collect suspended particulate matter (>0.45~1 μm) and the following two containing Cs-adsorbents, namely cartridge filters impregnated with $Cu_2Fe(CN)_6$.

2.3 Russia

Russian scientists performed preconcentration procedures for Cs, Sr and Pu radionuclides in seawater.

2.3.1 Plutonium

a) The filtered seawater sample was acidified to pH 2 by adding concentrated HCl during mixing, followed by addition of ^{242}Pu tracer and 200 g of sodium sulfite per 100 L of water. The sample was mixed periodically for 12 hours: then $FeCl_3$ solution was added (1 g Fe^{3+} per 100 L sample), and the sample was mixed again periodically for 2-3 hours.

During mixing, a solution of sodium hydroxide was added in steps up to pH 8.5-9.5. The sample was left standing for 12-24 hours to yield a completely clear supernate. The supernate was then decanted and the precipitate filtered.

b) Preconcentration of plutonium was carried out by precipitation at pH 3-4 with zirconium phosphate from 100 L of seawater acidified by HCl. The supernate was decanted, and the precipitate filtered, dried and stored until analysis on land.

2.3.2 Strontium

Samples of deep water were collected with a large-volume sampler and the surface water with a hose connected to a pump. A 11-12 L plastic bottle was filled with filtered water (filter pore size 1 μm). A 0.5 L subsample was taken from this bottle and transferred to a small glass or plastic bottle for stable strontium determination. The water volume in the larger bottle was adjusted to 10 L and then 120 g of Na_2CO_3 was added. The bottle was shaked (15-20 min) until dissolution of the Na_2CO_3 and then was left standing for 24 hours.

After preparing the precipitate, the supernate was decanted carefully and the precipitate filtered in a Buchner funnel, then washed with 20 cm^3 of deionized water. The filtered precipitate was then packed into plastic bags.

2.3.3 Caesium

a) Surface water was pumped using a submersible pump: first through the filtration unit (1 μm pore size) and then through the fiber sorbent impregnated with $Cu_2Fe(CN)_6$ (flow rate about 10 L min^{-1}).

b) A large tank was filled with filtered deep water then water was pumped through the fiber sorbent impregnated with $Cu_2Fe(CN)_6$ (flow rate about 1.5-2.0 L min^{-1}).

2.3.4 Co, Cs, Ce and Sr

Preconcentration of Co and Cs was carried out on potassium ferrocyanide, and Ce and Sr on sodium carbonate from the same sample (100 L). Determination of carrier yield is performed by atomic absorption spectrometry on land.

3. Methods of radionuclide analysis

3.1 Japan

3.1.1 Gamma emitters

(1) Sample preparation

a) Seawater

2 g of ammonium phosphododecamolybdate (AMP)/5 L water was added to seawater(36～58 L) and mixed to adsorb caesium. After settling, the AMP was taken out by filtration (Precipitation A). The pH of the filtrate was adjusted to 8.2 using aqueous ammonia.

10 g of MnO_2 powder/5 L was added and mixed for two hours. After settling, the MnO_2 was removed by filtration (Precipitation B).

After both precipitates(A, B) were dried, they were mixed thoroughly in a polystyrene counting container (55mmH, 48mmφ) for counting by gamma spectrometry.

b) Seabed sediment

The fresh sediments were dried at 105 ℃ and then reduced to a fine powder in a mechanical grinder, homogenized and then divided. One part of the powder sample was placed in a polystyrene counting container (55 mmH, 48mmφ) for gamma spectrometry. Another part was used for radiochemical analysis.

C) Adsorbent

The analytical samples were the prefilter and two kinds of adsorbent through which 1-5 m^3 of surface water had been passed.

The prefilters were dried at 110℃ in an oven, followed by ashing at 450℃ for 12 hours in an electric furnace. The ashed sample was transferred to a plastic container (60mmφ) and subjected to gamma spectrometry.

The adsorbents (acrylic fiber) with cobalt potassium ferrocyanate (for adsorbing Cs) and manganese dioxide (for adsorbing Co) were dried (110℃, 8 hours), and then ashed (450℃, 12 hours) for gamma spectrometry.

(2) Measurements

The water and sediment samples were counted on a Ge semiconductor detector for 70,000～90,000 sec. The adsorbent samples were measured for 300,000～400,000 sec.

3.1.2 Strontium-90

(1) Sample preparation

a) Seawater

The sample (40 L) was heated to more than 90 ℃, and then sodium hydroxide solution was added. Magnesium hydroxide was precipitated and filtered. After the filtrate was acidified by HCl, Yttrium(Y^{3+}) carrier was added and the solution was left standing for more than two weeks.

Yttrium-90 (^{90}Y) which attained radioequilibrium with strontium-90 (^{90}Sr) in the solution was coprecipitated with magnesium hydroxide by adding sodium hydroxide solution. The precipitate was filtered and dissolved in HCl. Yttrium was separated by HDEHP (di-2-ethylhexyl phosphate) extraction and purified by a cation exchange method. Yttrium oxalate was precipitated and filtered and dried, and then it was prepared for counting.

b) Seabed sediment

Dried sediment of 50g(upper layer) or 300g(lower layer) was leached by hot HCl twice. The solution was filtered and then diluted to 5 L with water. After removing CO_2 gas by heating the solution, it was neutralized using aqueous ammonia. The precipitate (Al etc.) was filtered. Magnesium chloride solution was added to it and heated. After adding sodium hydroxide, the precipitate (Mn etc.) was separated by filtration. After the filtrate was acidified by HCl, Y^{3+} carrier was added and the solution was left standing for more than two weeks. ^{90}Y which attained radioequilibrium with ^{90}Sr in the solution was coprecipitated with magnesium hydroxide by adding sodium hydroxide solution.

The precipitate was filtered and dissolved in HCl. Yttrium was separated by HDEHP extraction and purified by a cation exchange method. Yttrium oxalate was precipitated and filtered and dried and then prepared for counting.

(2) Measurements

The measurements of sample and background were carried out alternately for 70,000～80,000 sec. using low-background gas-flow counters.

3.1.3 Plutonium

(1) Sample preparation

a) Seawater

The samples for Pu analysis comprised dissolved and particulate fractions. The particulate Pu is defined as Pu in suspended matter, which was obtained by large-volume filtration of seawater (720 to 1150 L). The analysis of dissolved Pu was applied to surface and bottom waters (N1-N7, BG1, BG2) and to intermediate waters (N2; 200m, 500m, 750m, 1000m and 2000m). For particulate Pu, suspended matter was analyzed from surface and bottom waters of each station.

Dissolved Pu ;

The acidified seawater samples (74～91 L) were weighed and transferred to a polyethylene vessel. Iron carrier (Fe^{3+}) was added and mixed well. A known amount of ^{242}Pu chemical yield tracer was added to the samples and mixed well.

After more than an hour, aqueous ammonia was added to form ferric hydroxide, which coprecipitates Pu. The precipitate was separated by decanting and centrifuging the solution.

The precipitate was dissolved in 9M HNO_3 and dried on a hot plate. After the filtration, the solution containing the Pu fraction was passed through an anion-exchange column and washed by 9M HNO_3 and 10M HCl solutions successively.

The Pu fraction was eluted with ammonium iodide-HCl solution. The eluate was then dried. The residue was decomposed using HNO_3 and $HClO_4$ and evaporated to dryness. The Pu fraction was dissolved in 1.8M H_2SO_4, the pH of the solution adjusted to 2.1 with aqueous ammonia and then it was electrodeposited onto a stainless steel disc (1 inch in diameter).

Particulate Pu :

The filter sample was ashed in a furnace at 450℃. The weight of the ash samples ranged from 3.9g to 6.5g. The ash sample was dissolved in conc.HNO_3 on a hot plate followed by addition of yield tracer (^{242}Pu). After the removal of the residue by filtration, the solution was evaporated to dryness. The residue was dissolved in a mixture of 9M

HNO_3 and H_2O_2. The purification and electrodeposition of Pu followed the same procedures as for dissolved Pu.

b) Seabed sediment

50g of dried sediment was weighed and burned in a furnace at 450℃. A known amount of ^{242}Pu chemical yield tracer was added and the sample leached by HNO_3 on a hot plate. After the filtration, the solution, including Pu, was evaporated to near dryness. Then 9M HNO_3 and a little H_2O_2 were added and the sample heated on a hot plate. The purification and electrodeposition of Pu was the same for dissolved Pu.

(2) Measurements

The counting of Pu was carried out by alpha spectrometers, using silicon surface barrier detectors. The counting time was greater than 200,000 sec.

3.2 Korea

3.2.1 Gamma emitters

(1) Seawater

The acidified seawater samples(>100 L) were consecutively processed for Pu, Cs and Sr. After adding ^{242}Pu, stable Cs, ^{85}Sr and stable Sr to the acidified seawater, iron or manganese oxide coprecipitation was effected to isolate Pu, and AMP (ammonium phosphododecamolybdate) coprecipitation was carried out to isolate Cs, and finally oxalate coprecipitation was performed to isolate Sr. The recovered AMP was dissolved in NaOH solution and heated in order to decompose the AMP, followed by re-coprecipitation of Cs with AMP (1 g) and then dissolution of the AMP with NaOH solution for subsequent gamma spectrometry.

(2) Cs sorbent

Sorbents were dried and reduced to ash at 500 ℃ for subsequent gamma spectrometric analyses using a HPGe detector.

(3) Seabed sediment

Seabed sediment samples were dried at 105 ℃ and pulverized for subsequent gamma spectrometry.

3.2.2 Strontium-90

(1) Seawater

^{90}Sr was separated from seawater samples as strontium oxalate. The oxalates were separated by centrifugation and then dissolved in boiling conc. HNO_3. ^{90}Sr was separated from Ca by the precipitation of $Sr(NO_3)_2$

treated with fuming HNO_3. Stable Y was added. The solution was left more than 20 days for establishment of radioequilibrium between ^{90}Sr and ^{90}Y. Y was separated from Sr by hydroxide precipitation and was purified using cation-exchange resin (Dowex 50X8, 100-200 mesh, H^+ form) and ^{90}Y was counted by a low background proportional counter. Sr recovery was determined by ^{85}Sr gamma counting (Wong et al., 1994).

(2) Seabed sediment

The sediments were dried and pulverized. ^{242}Pu, ^{85}Sr, and stable Sr were added to the samples followed by acid digestion. Pu radionuclides were separated by iron hydroxide coprecipitation, and the remaining solution was subjected to oxalate precipitation for Sr isolation.

3.2.3 Plutonium

(1) Seawater

Manganese oxide coprecipitates were digested in 8M nitric acid. The digested samples were purified by anion exchange resin, followed by electrodeposition of Pu on stainless steel discs. $^{239,240}Pu$ activity was determined by alpha-spectrometry.

(2) Seabed sediment

Iron hydroxide precipitate was treated as described in 3.2.3.(1) for seawater.

(3) Suspended particulate matter on the filters

Filters were dried and ashed at 500℃. ^{242}Pu was added to the ashed sample, followed by acid digestion. Iron co-precipitate was treated as described in 3.2.3.(1) for seawater.

3.3 Russia

3.3.1 Gamma emitters

(1) Seawater

Gamma emitting radionuclides (^{60}Co, ^{137}Cs and others) which were coprecipitated aboard from 100 L of seawater were measured by gamma spectrometry using a Ge detector.

(2) Sorbents

Sorbents were dried and reduced to ashes at 400-450℃. Then the radionuclides in the ashes were measured by gamma spectrometry using a Ge detector.

(3) Seabed sediment

Sediment samples were dried and reduced to a powder. Then the radionuclides in the powder were measured by gamma spectrometry using a

Ge detector.

3.3.2 Strontium-90

(1) Seawater

^{90}Sr were collected from seawater samples by a precipitation method. Then the ^{90}Y produced from ^{90}Sr was measured with a low background beta-ray detector.

(2) Seabed sediment

After drying and reducing to a powder, ^{90}Sr was extracted from the sediment powder into an acid solution. Strontium was collected by a precipitation method, and then the ^{90}Y produced from ^{90}Sr was measured with a low background beta-ray detector.

3.3.3 Plutonium

(1) Seawater

Plutonium was collected from seawater by a coprecipitation method using iron. Then the plutonium was purified by an ion exchange resin column method. After the electrodeposition of plutonium on a stainless steel disc, it was measured by alpha spectrometry using a silicon semi-conductor detector.

(2) Seabed sediment

Sediment was dried and reduced to a powder. Plutonium was extracted from the powder to an acid solution, and then purified by an ion exchange resin column method. After the electrodeposition of plutonium on a stainless steel disc, it was measured by alpha spectrometry using a silicon semi-conductor detector.

3.4 IAEA

3.4.1 Gamma emitters

(1) Seawater

The acidified seawater samples of about 100 liters each were transferred to 120 litre precipitation tanks and treated radiochemically by sequential extraction of actinides, caesium and strontium. After sample mixing, addition of yield determinants (^{85}Sr, ^{242}Pu, stable Cs) and chemical carriers (stable Sr and Cs) and additional mixing, the actinides were co-precipitated with MnO_2 at pH 8-9. After settling and removal of the precipitate, AMP (ammonium phosphododecamolybdate) was added during mixing at pH 1.5 to adsorb caesium. The recovered AMP was dissolved in NaOH followed by repeated centrifugations. After boiling to remove NH_3, caesium was again adsorbed on AMP at pH 1.5 and after settling and centrifugation the AMP was dissolved in 2-3 mL NaOH and then transferred to plastic counting tubes to a final volume of 4.5 mL. Analysis was done on a well-type HPGe detector with 2-5 days counting time, giving detection limits of 0.1-0.2 mBq kg^{-1} for ^{137}Cs. The chemical recovery of caesium was determined by ICP-MS, giving typical recoveries of about 70 %.

(2) Seabed sediment

The fresh sediments were sieved through a 1 mm mesh sieve and then freeze-dried. The dry samples were then ground to a fine powder in a porcelain mortar, homogenized and compressed into 200 mL metal cans, sealed and stored for >2 weeks and then counted on a HPGe detector (35 % rel. efficiency) for a minimum of 5 days. The detection limit for ^{137}Cs (661keV, ^{137m}Ba) was typically 0.2-0.4 Bq kg^{-1}.

3.4.2 Strontium-90

(1) Seawater

After the AMP sorption of caesium, strontium was precipitated as oxalate at pH 3-4, followed by centrifugation and dry ashing at 550℃. Strontium was separated from calcium by precipitation as $Sr(NO_3)_2$ in conc. HNO_3. After further purification, the chemical recovery was determined by gamma-spectrometric counting of ^{85}Sr. After letting ^{90}Y build up in the solution (>14 days), known amounts of stable yttrium were added and the yttrium was separated from strontium by hydroxide precipitation. After further purification, the yttrium was precipitated as yttrium oxalate and filtered onto a pre-weighed membrane filter and the chemical recovery of yttrium determined gravimetrically. The ^{90}Y concentration was determined by counting in a low background beta-counter for 24-48 h and, with chemical recoveries of 23±11 %, the resulting detection limits were 0.04-0.3 mBq kg^{-1}.

(2) Seabed sediment

For each analysis, between 25 and 100g of dry ground sediment was ashed at 550℃ for about 24 h. After adding ^{85}Sr yield determinant and stable strontium and purification by $Fe(OH)_3$ co-precipitation, the strontium was precipitated as oxalate from the supernate. The remaining procedure for isolating strontium and yttrium and for the counting of ^{90}Sr and ^{90}Y were the same as for water, described previously. The ^{90}Y samples were counted for 24-36 h and, with total chemical recoveries of 36±18 %, the resulting detection limits were 0.03-0.3 Bq kg^{-1}.

3.4.3 Plutonium

(1) Seawater

The dried MnO_2 precipitate was dissolved in 8M $HNO_3+H_2O_2$ and after digestion and oxidation, plutonium was separated and purified by anion-exchange column extraction. Elution of plutonium was carried out in reduced conditions followed by electrodeposition onto stainless steel discs and analysis by alpha-spectrometry using surface barrier detectors. The counting times ranged from 10 to 14 days and, with typical chemical recoveries of 50-60 %, the resulting detection limits were 0.3-0.5 μBq kg^{-1} for ^{238}Pu and ^{239,240}Pu.

(2) Seabed sediment

For each analysis up to 25 g of dry ground sediment were mixed with oxalic acid and ashed at 550℃ for about 24 h. After adding the ^{242}Pu yield determinant, the sediments were leached repeatedly with 8M HNO_3 followed by $Fe(OH)_3$ precipitation. Plutonium was then extracted, electroplated and counted as described previously for plutonium in water. The counting times ranged from 10 to 14 days and, with typical recoveries of 60-70 %, the resulting detection limits were 1-3 mBq kg^{-1} for ^{238}Pu and ^{239,240}Pu.

4. Analytical Results

The concentrations of gamma-emitting nuclides, strontium-90 and plutonium isotopes in seawater and sediment samples are shown in Table-3(a) and 3(b) (median and range of concentrations obtained from the joint analysis) and Annex 2-5 (individual laboratory results).

The interpretation and discussion of the results in the following are based on the median values.

In Table-3(c), we summarize the results of laboratory measurements of filter and adsorbent samples, and of on-board measurements of adsorbent samples.

The radionuclide activity ratios in seawater and sediment samples are shown in Table-4(a) and 4(b) respectively.

4.1 Seawater

4.1.1 Gamma emitters

(1) Coprecipitation method

The only anthropogenic gamma emitter which was detected in seawater samples was ^{137}Cs: the activities of other radionuclides such as ^{60}Co were below the detection limits.

The ^{137}Cs concentrations detected in surface waters of the dumping area ranged from 2.8 to 3.6 mBq kg^{-1} with an average of 3.1 mBq kg^{-1}.

The ^{137}Cs concentrations detected in the bottom waters ranged from 0.6 to 2.0 mBq kg^{-1} with an average of 1.2 mBq kg^{-1}.

The ^{137}Cs concentrations detected in surface waters at stations BG1 and BG2 ranged from 3.0 to 3.2 mBq kg^{-1}, namely the same as for the dumping area.

The ^{137}Cs concentrations detected in bottom waters at stations BG1 and BG2 ranged from 1.1 to 1.4 mBq kg^{-1}, which also corresponds well with those for the dumping area.

The ^{137}Cs concentrations in surface waters were generally higher than those in bottom waters. The vertical profile of ^{137}Cs at station N2 is shown in Fig-2. The ^{137}Cs concentrations in the water column decreased gradually with increasing depth.

(2) Adsorbent method

On board measurement:

Of the anthropogenic gamma emitters, only ^{137}Cs was detected. The concentrations of dissolved ^{137}Cs in surface waters of the dumping area ranged from 3.0 to 4.7 mBq L^{-1} with an average of 4.0 mBq L^{-1}.

The concentration of dissolved ^{137}Cs in surface waters at stations BG1 and BG2 ranged from 2.9 to 3.5 mBq L^{-1}, which is the same order of magnitude as at the dumping area.

Laboratory measurement;

The concentrations of dissolved ^{137}Cs in surface waters of the dumping area ranged from 1.62 to 5.5 mBq L^{-1} with an average of 3.5 mBq L^{-1}.

The concentrations of dissolved ^{137}Cs in surface waters at stations BG1 and BG2 ranged from 3.1 to 4.0 mBq L^{-1} with an average of 3.6 mBq L^{-1}, which are the same order of magnitude as at the dumping area.

The results obtained by the on board measurements agree reasonably well with the laboratory measurements of the adsorbents, considering the rather large counting errors. The adsorbent method results are in general in good agreement with the more precise coprecipitation method results.

(3) Particulate ^{137}Cs

Particulate ^{137}Cs in surface waters was detected at stations N1, N2, N3, N4 and BG2 where concentrations ranged from 0.013 to 0.04 mBq L^{-1}

The percentage of the particulate ^{137}Cs to the total was in the range 0.33 to 0.99 %.

4.1.2 Strontium-90

The ^{90}Sr concentrations detected in surface waters of the dumping area ranged from 1.6 to 2.0 mBq kg^{-1} with an average of 1.8 mBq kg^{-1}, and the concentrations in bottom waters were in the range from 0.4 to 1.2 mBq kg^{-1} with an average of 0.7 mBq kg^{-1}.

The ^{90}Sr concentrations detected in surface waters of the background stations BG1 and BG2 ranged from 1.8 to 1.9 mBq kg^{-1}, whereas the values in bottom waters ranged from 0.4 to 0.7 mBq kg^{-1} which agree well with the data from the dumping area.

The ^{90}Sr concentrations in surface waters were higher than those in bottom waters at each station. The vertical profile of ^{90}Sr at station N2 is shown in Fig-2. The vertical profile of ^{90}Sr showed a surface maximum and then a gradual decrease with depth.

4.1.3 Plutonium

The concentrations of dissolved ^{239,240}Pu detected in surface waters of the dumping area ranged from 8 to 25 μBq kg^{-1} with an average of 19μBq kg^{-1}, whereas the values in bottom waters were in the range of 15 to 29 μBq kg^{-1} with an average of 24μBq kg^{-1}.

For the background area, the concentrations of dissolved ^{239,240}Pu detected in surface waters ranged from 8 to 21 μBq kg^{-1}, whereas the values in bottom waters ranged from 21 to 23 μBq kg^{-1}, which do not differ significantly from those found at the dumping areas.

The concentrations of dissolved ^{239,240}Pu detected in surface waters were lower than those in bottom waters at all stations. The vertical profile of ^{239,240}Pu at station N2 is shown in Fig-2, showing a surface minimum, mid-depth maximum and then a gradual decrease with depth.

The concentrations of particulate ^{239,240}Pu detected in surface waters at the 9 stations ranged from 0.17 to 0.87 μBq kg^{-1} with an average of 0.36μBq kg^{-1}, whereas the values for bottom waters ranged from 0.25 to 1.67 μBq kg^{-1} with an average of 0.64μBq kg^{-1}. The fraction of particulate ^{239,240}Pu to the total was in the range of 0.8 to 8%. The concentration of ^{238}Pu in dissolved and particulate samples was less than the detection limits. (The unit was converted per volume into per weight.)

4.1.4 Activity ratios

The median and range of radionuclide activity ratios, ^{137}Cs/^{90}Sr, ^{239,240}Pu/^{90}Sr and ^{239,240}Pu/^{137}Cs obtained from the analysis of water are shown in Table-4(a).

The mean of the median values for surface water were; 1.7±0.4 (1S.D.), 0.010±0.004, and 0.006±0.002 for ^{137}Cs/^{90}Sr, ^{239,240}Pu/^{90}Sr and ^{239,240}Pu/^{137}Cs respectively.

The corresponding mean of the medians for bottom water were, 1.8±0.4(1 S.D.), 0.05±0.02 and 0.025±0.009.

There was no significant difference between activity ratios in the dumping area and those at the background stations.

The results show that for the non-particle reactive radionuclides in the water, ^{90}Sr and ^{137}Cs, the activity ratio ^{137}Cs/^{90}Sr is rather constant with water depth. However, for plutonium, which is very particle reactive, preferential sinking of particles containing plutonium will give higher ^{239,240}Pu/^{90}Sr and ^{239,240}Pu/^{137}Cs activity ratios at deep waters comparing with the surface.

The activity ratios given in the literature for nuclear weapon test global fallout (UNSCEAR, 1993) are; ^{137}Cs/^{90}Sr:1.6, ^{239,240}Pu/^{90}Sr:0.018, ^{239,240}Pu/^{137}Cs:0.011.

4.2 Seabed sediment

4.2.1 Gamma emitters

Of the anthropogenic gamma emitters, only ^{137}Cs was detected in sediment samples. The ^{137}Cs concentrations in the upper layer of sediments (0-3cm) in the dumping area ranged from <0.4 to 2.8 Bq kg^{-1} dry weight.

The ^{137}Cs concentrations detected in the lower layer of sediments (>3cm) in the dumping area, ranged from <0.2 to 2.3 Bq kg^{-1} dry weight.

For the background stations, the ^{137}Cs concentrations detected in the upper layer of sediments ranged from <0.7 to 1.0 Bq kg^{-1} dry weight, whereas the concentration detected in the lower layer of sediments was <0.3-2.8 Bq kg^{-1} dry weight, which are the same order of magnitude as at the dumping area.

The ^{137}Cs concentrations in the upper layer of sediments were higher than in the lower layer. The highest ^{137}Cs concentration in the sediment samples was observed at station N7.

4.2.2 Strontium-90

The concentrations of ^{90}Sr, both in surface and subsurface layers, were generally very low and close to or below the detection limits. The concentrations ranged from <0.04 to 0.2 Bq kg^{-1} dry weight.

4.2.3 Plutonium

^{239,240}Pu in the upper layer of sediments was detected in all stations of the dumping area. The ^{239,240}Pu concentrations ranged from 0.01 to 1.0 Bq kg^{-1} dry weight with an average of 0.23 Bq kg^{-1} dry weight.

^{239,240}Pu in the lower layer of sediments was observed in all stations of the dumping area. The ^{239,240}Pu concentrations ranged from 0.004 to 0.76 Bq kg^{-1} dry weight with an average of 0.12 Bq kg^{-1} dry weight.

For the background stations, ^{239,240}Pu concentrations detected in the upper layer of sediments at the stations BG1 and BG2 ranged from 0.014 to 0.14 Bq kg^{-1} dry weight, whereas the values detected in the lower layer of sediments ranged from 0.014 to 0.037 Bq kg^{-1}, which are the same order of magnitude as at the dumping area.

The ^{239,240}Pu concentrations in the upper layer of sediments were generally higher than in the lower layer. The highest ^{239,240}Pu concentration in the sediment samples, which is about one order of magnitude greater than those at other stations, was observed at station N7.

The ^{238}Pu in the upper layer of sediments was detected at stations N5 and N7 in the dumping area, concentrations ranging from 0.004 to 0.022 Bq kg^{-1} dry weight, whereas a ^{238}Pu concentration of 0.013 Bq kg^{-1} dry weight was observed in the lower layer of sediments at station N7. The activity ratios of ^{238}Pu to ^{239,240}Pu in the sediment samples ranged from 0.017 to 0.038 (Table-4(b)).

5. Analytical quality assurance

In order to check the analytical performance, i.e. accuracy and reproducibility, for each sample batch analyzed by radiochemical means, all participating laboratories were provided with an IAEA reference material, IAEA-135 sediment, with given recommended radionuclide concentrations. This reference material was processed in an identical manner alongside the samples. However, for the water analysis, no reference material is currently available.

In addition, as agreed by all parties, an intercomparison exercise was organized by the IAEA-MEL. A separate bulk sediment sample was taken from station N2 (about 5 kg dry weight) which was processed at IAEA-MEL following established procedures for processing/preparation of intercomparison and reference materials. After analysis of several sample aliquots at IAEA-MEL, it was found that the levels of ^{137}Cs and ^{90}Sr were below the detection limits, and therefore it was decided that the intercomparison should be based on natural radionuclides and values for ^{90}Sr, ^{137}Cs and ^{239,240}Pu could be reported on a voluntary basis as information values. The results are shown in Table-5. For the natural radionuclides, the analytical quality is acceptable, showing deviations from the median values of less than 10 %. For ^{239,240}Pu, where the levels are very low, the larger deviation is a consequence of larger counting errors.

6. Discussion

6.1 Seawater

6.1.1 Gamma emitters

Of the anthropogenic gamma emitters, only ^{137}Cs was detected in seawater samples of the dumping area. The analytical results are summarized in Table-6, where the present data are compared with the past data from observations in the northwest sea areas of the Japanese Islands and the North Pacific (Nagaya and Nakamura, 1987, 1993; Miyake et al., 1987; Hirose et al., 1992; Aoyama and Hirose, 1995 ; Hydrographic Department, Maritime Safety Agency, 1982-1992)

The ^{137}Cs concentrations in waters of the dumping areas are of the same order of magnitude as those observed in non-dumping areas of the northwest sea areas of the Japanese Islands and the North Pacific.

The vertical profile of ^{137}Cs at station N2, which showed a surface maximum and gradual decrease with depth, is similar to that observed in non-dumping areas of the northwest sea areas of the Japanese Islands (Aoyama and Hirose, 1995). However, it slightly differs from that observed in the North Pacific, which has a subsurface maximum and rather rapid decrease with depth (Nagaya and Nakamura, 1987, 1993; Miyake et al., 1987).

The distribution of ^{137}Cs in the northwest sea areas of the Japanese Islands may be controlled by physical processes such as vertical mixing, diffusion, advection and convection, because of the low affinity of ^{137}Cs onto particulate matter. The particulate ^{137}Cs was less than 0.99 % of the total.

6.1.2 Strontium-90

The analytical results of ^{90}Sr in seawater samples of the dumping area are summarized in Table-6, where the present data are compared with the past data from observations in the northwest sea areas of the Japanese Islands and the North Pacific (Vakulovskyet et al., 1978; Nagaya and Nakamura, 1987, 1993; Hydrographic Department, Maritime Safety Agency, 1982-1992).

The ^{90}Sr concentrations in waters of the dumping areas are of the same order of magnitude as those observed in non-dumping areas of the northwest sea areas of the Japanese Islands and the North Pacific.

The vertical profile of ^{90}Sr at station N2, which showed a surface maximum and gradual decrease with depth, is similar to that observed in non-dumping areas of the northwest sea areas of the Japanese Islands. The pattern of the vertical distribution of ^{90}Sr is similar to that of ^{137}Cs.

6.1.3 Plutonium

The analytical results of ^{239,240}Pu in seawater samples of the dumping area are summarized in Table-6, where the present data are compared with the past data from observations in the northwest sea areas of the Japanese Islands and the North Pacific(Nagaya and Nakamura, 1987, 1993; Miyake et al., 1987; Hirose et al., 1992; Hydrographic Department, Maritime Safety Agency, 1982-1992).

The ^{239,240}Pu concentrations in waters of the dumping areas are of the same order of magnitude as those observed in non-dumping areas of the northwest sea areas of the Japanese Islands and the North Pacific.

However, the ^{239,240}Pu concentrations in surface waters of the north central part of the northwest sea areas of the Japanese Islands were slightly higher than recent values observed in the North Pacific (Hirose et al., 1992).

The vertical profile of ^{239,240}Pu at station N2, which showed a surface minimum, mid-depth maximum and gradual decrease in deep waters, is similar to that observed in non-dumping areas of the northwest sea areas of the Japanese Islands and the North Pacific(Nagaya and Nakamura, 1987, 1993; Miyake et al., 1987). However, the profile slightly differs from that observed in the North Pacific,- which has a rather large maximum at near 700 m depth. The vertical distribution of ^{239,240}Pu in the study areas may be controlled by oceanographical processes (convective mixing) and biogeochemical processes such as scavenging in the euphotic zone due to the high affinity of Pu onto particulate matter (Hirose et al., 1992) and by resolubilization at depth. In fact, the particulate ^{239,240}Pu was in the range of 0.9 to 8.1 % of the total.

6.1.4 Inventory

The observed vertical profiles of ^{90}Sr, ^{137}Cs and ^{239,240}Pu at station N2 (see Fig-2) may be used to estimate fallout deposition by calculating the water column inventories. A polynomial fit was applied to the profiles derived from the median concentrations (Table-3(a)), which gave acceptable correlations, R^2=0.97, 0.91 and 0.87 for ^{90}Sr, ^{137}Cs and ^{239,240}Pu respectively. Each water column inventory was then calculated by integrating the best fit equation over the depth range 0-3500m. The following inventories were obtained: 3.0 kBq m^{-2} for ^{90}Sr, 5.8 kBq m^{-2} for ^{137}Cs and 0.10 kBq m^{-2} for ^{239,240}Pu. These inventories are in good agreement with estimates for ^{90}Sr and ^{137}Cs based on global fallout data. However, to be able to compare these inventories with the deposition densities given in the literature, the sediment inventories should also be considered. Although, for deep sea sediments the addition is only marginal (see chapter 6.2.4). UNSCEAR (1993) estimates integrated deposition densities of 2.3-3.2 kBq m^{-2}, 3.7-5.2 kBq m^{-2} and 0.04-0.06 kBq m^{-2} for ^{90}Sr, ^{137}Cs, and ^{239,240}Pu for latitudes 30°-50°N. Estimates from fallout data in Japan (Hirose et al. 1987) give similar values; 1.4-2.8 kBq m^{-2}, 3.6-7.2 kBq m^{-2} and 0.04-0.09 kBq m^{-2} for ^{90}Sr, ^{137}Cs and ^{239,240}Pu, respectively. The estimated inventory for ^{239,240}Pu in this work shows a surplus compared to global fallout estimates. However, this is consistent with the previous literature in that, as for the Atlantic and Pacific Oceans in general, measured inventories are higher (by at least 50 %) than those expected from fallout delivery ; e.g., Nagaya and Nakamura (1984) found a mean deposit of 0.11±0.04 kBq m^{-2} of ^{239,240}Pu at 5 stations in the central North Pacific.

6.2 Seabed sediment

6.2.1 Gamma emitters

Of the anthropogenic gamma emitters, only ^{137}Cs was detected in sediment samples of the dumping area. The analytical results are summarized in Table-6 and compared with the past data from observations in the northwest sea areas of the Japanese Islands (Nagaya and Nakamura, 1987, 1993; Hydrographic Department, Maritime Safety Agency, 1982-1992; National Research Institute of Fisheries Sciences, Fisheries Agency, 1982-1992).

The ^{137}Cs concentrations in sediments of the dumping areas are of the same order of magnitude as that observed in non-dumping areas of the northwest sea areas of the Japanese Islands and the North Pacific.

The highest ^{137}Cs concentration in sediment samples (2.8 Bq kg^{-1}dry weight) was observed at station N7. Although the causes are unknown, it may be related to the topography of the sea bottom because station N7 is near to the continental coast and shallow (1500m depth) compared with the other stations (3000-3500m depth)

6.2.2 Strontium-90

The analytical results for ^{90}Sr in the seabed sediment samples of the dumping area are summarized in Table-6, where the present data are compared with the past data from observations in the northwest sea areas of the Japanese Islands and the North Pacific (Nagaya and Nakamura, 1987, 1993; Hydrographic Department, Maritime Safety Agency, 1982-1992).

The ^{90}Sr concentrations in sediments of the dumping areas are generally very low and of the same order of magnitude as those observed in non-dumping areas of the northwest sea areas of the Japanese Islands and the North Pacific.

6.2.3 Plutonium

The analytical results for ^{239,240}Pu in the sediment samples of the dumping area are summarized in Table-6, where the present data are compared with the past data from observations in the northwest sea areas of the Japanese Islands and the North Pacific (Nagaya and Nakamura, 1987, 1993; Yamamoto et al., 1990 ; Hydrographic Department, Maritime Safety Agency, 1982-1992).

The ^{239,240}Pu concentrations in sediments of the dumping areas are of the same order of magnitude as those observed in non-dumping areas of the northwest sea areas of the Japanese Islands and the North Pacific. The highest ^{239,240}Pu concentration in the sediment samples (1.0 Bq kg^{-1}dry weight) was observed at station N7. As discussed earlier, it may be due to the topography of the sea bottom.

The $^{238}Pu/^{239,240}Pu$ activity ratios in the environmental samples provide a useful tool to determine the source of plutonium. ^{238}Pu was detected in sediment at several stations including station N7. The $^{238}Pu/^{239,240}Pu$ activity ratios in these sediment samples were in the range of 0.017 to 0.038, which is in agreement with that in global fallout, 0.026. The $^{238}Pu/^{239,240}Pu$ ratios in upper and lower layer sediments at station N7, in which the highest Pu concentrations were observed, were 0.026 and 0.017 respectively. This finding strongly suggests that plutonium in sediments of the dumping areas has originated from global fallout.

6.2.4 Inventory

The observed radionuclide concentration in upper and lower layer sediments may be used to derive an estimate of the sediment inventories if we make a simplistic assumption that the sum of the radionuclide activities per unit area in the two layers equals the total sediment inventory. For the calculation the depth intervals 0-3 cm and 3-10 cm were assumed. The following inventories were obtained: ^{90}Sr: 0.01-0.06 kBq m^{-2}, ^{137}Cs: 0.05-0.4 kBq m^{-2} and $^{239,240}Pu$: 0.001-0.12 kBq m^{-2}. For ^{90}Sr and ^{137}Cs the inventories are only marginal compared to the water column inventories. For $^{239,240}Pu$, the sediment inventories for all stations except station N7 showed values of 0.001-0.015 kBq m^{-2}, which is significantly lower than that found in the water column but, for station N7, a higher $^{239,240}Pu$ sediment inventory of 0.12 kBq m^{-2} was obtained. The surplus may be related to the topography of the sea floor because the station N7 is near to the continental coast and is much shallower (1500m depth) than the other station (3000-3500m depth).

7. Conclusion

The results of analysis of the marine samples obtained from the joint expedition show that the concentrations of ^{90}Sr, ^{137}Cs and $^{239,240}Pu$ in seawater and sediment samples from the study area are not significantly different from those found in the western North Pacific. Although the study is at an early stage, analysis of isotopic activity ratios ($^{137}Cs/^{90}Sr$, $^{239,240}Pu/^{90}Sr$, $^{239,240}Pu/^{137}Cs$ and $^{238}Pu/^{239,240}Pu$) and radionuclide inventories estimated from vertical profiles and sediment data indicate the absence of any significant anthropogenic contamination other than global fallout in the study area.

8. Tables and Figures

Tables

Figures

Table-1 Summary of the radioactive waste dumping inventory in the Far-Eastern sea areas

Russia

Dumping Area No.	Sampling Station	Type of waste	Activity (TBq)
1	N1, N2, N3, N4, N5	Liquid	0.05
2	N4, N5	Liquid	0.03
3		Liquid	0.004
4		Liquid	0.007
5	N7	Liquid	4.3
6	N6	Liquid Solid	18.1 32.2
7		Liquid	13.0
8		Solid	111
9	N2	Liquid Solid	401 82.5
10		Liquid Solid	19.8 26.7

Japan

Dumping Site	Type of waste	Activity (TBq)
Middle Pacific Ocean region	Solid	15.1

Korea

Dumping Site	Type of waste	Surface dose rate (mR/h)
South-western sea area of the ullung island	Solid	0.1～46

Table-2 Distributed sample quantities

Sampling Station (Latitude, Longitude)	Distribution	Filtered Seawater(L)							Sediment(kg-wet)	
		Surface Water	Bottom Water	Intermediate Water					Upper Layer (0～3cm)	Lower Layer (>3cm)
				200m	500m	750m	1000m	2000m		
N.1 (41°.55′ N 133° 15′ E)	Japan Korea Russia IAEA	180 200 420 90-110	180 160 450 90-110						0.7 0.5 0.5 0.5	5.0 2.0 2.0 3.0
N.2 (41°.40′ N 133° 51′ E)	Japan Korea Russia IAEA	180 200 420 90-110	160 160 430 90-110	160 160 480 90-110	160 160 350 90-110	100 100 300 90-110	160 160 368 90-110	160 160 464 90-110	0.7 0.5 0.5 0.5+10	5.0 2.0 2.0 5.0
N.3 (41°.55′ N 134° 20′ E)	Japan Korea Russia IAEA	180 200 420 90-110	160 160 445 90-110						0.7 0.5 0.5 0.5	5.0 2.0 2.0 4.0
N.4 (41°.05′ N 134° 20′ E)	Japan Korea Russia IAEA	180 200 420 90-110	160 160 455 90-110						0.7 0.5 0.5 0.5	7.0 2.0 2.0 4.0
N.5 (41°.05′ N 133° 15′ E)	Japan Korea Russia IAEA	180 200 420 90-110	150 160 320 90						1 1 0.3 0.5	2 2 2.0 2.0
N.6 (41°.55′ N 132° 00′ E)	Japan Korea Russia IAEA	180 200 420 90-110	160 140 420 90-110						0.7 0.5 0.5 0.5	5.0 2.0 2.0 5.0
N.7 (42°.19′ N 132° 19′ E)	Japan Korea Russia IAEA	180 200 420 90-110	180 160 485 90-110						0.7 0.5 0.5 0.5	5.0 2.0 2.0 5.0
B.G.1 (40°.47′ N 134° 52′ E)	Japan Korea Russia IAEA	180 200 420 90-110	160 140 400 90-110						0.7 1 2.0 1	1.0 3 2.5 2
B.G.2 (38°.00′ N 134° 57′ E)	Japan Korea Russia IAEA	180 200 420 90-110	180 200 420 90-110						0.7 0.5 0.5 0.5	5.0 2.0 2.0 3.0

Table-3(a) Analysis of seawater (median and range of concentrations)

Sampling Station	Sampling Horizon	Sampling Date	^{90}Sr (mBq kg^{-1})	^{137}Cs (mBq kg^{-1})	^{239,240}Pu (μBq kg^{-1})
N1	Surface	1994-03-28	1.7 (1.3-2.7)	3.2 (2.6-4.2)	24 (16-25)
	Bottom	"	0.4 (0.3-0.8)	1.1 (<1.3-3.9)	26 (24-28)
N2	Surface	1994-03-29	1.9 (1.6-2.5)	3.3 (2.2-4.5)	17 (5-17)
	200m	1994-03-30	2.0 (1.0-2.1)	3.6 (2.6-4.9)	18 (4-20)
	500m	1994-03-29	1.7 (1.0-2.0)	2.9 (2.0-3.5)	27 (21-35)
	750m	1994-03-31	1.3 (1.0-1.4)	3.1 (2.3-3.3)	37 (9-40)
	1000m	1994-03-29	1.2 (0.6-1.3)	2.0 (1.9-3.4)	33 (32-38)
	2000m	1994-03-31	0.5 (0.4-0.7)	0.81 (<1.4-1.8)	24 (12-30)
	Bottom	1994-03-30	0.4 (0.2-0.6)	0.75 (<0.8-1.4)	23 (18-27)
N3	Surface	1994-04-01	1.9 (1.6-2.5)	3.6 (2.4-4.5)	18 (9-20)
	Bottom	"	0.7 (0.5-1.2)	1.1 (<1.3-2.0)	22 (14-30)
N4	Surface	1994-04-02	1.8 (1.7-2.4)	3.0 (2.6-4.3)	8 (4-16)
	Bottom	"	0.7 (0.5-1.1)	1.1 (<1.3)	15 (13-30)
N5	Surface	1994-03-24	2.0 (0.8-2.6)	2.8 (2.3-4.2)	21 (20-21)
	Bottom	1994-03-25	1.2 (0.7-1.3)	1.6 (<1.3-1.9)	28 (25-29)
N6	Surface	1994-03-26	1.6 (0.9-1.7)	3.2 (2.4-3.8)	25 (22-26)
	Bottom	"	0.4 (<0.14-1.1)	0.6 (<1.3)	29 (19-32)
N7	Surface	1994-03-27	1.6 (1.1-2.0)	2.8 (2.3-3.7)	22 (21-26)
	Bottom	"	0.9 (0.3-1.4)	2.0 (1.6-2.9)	28 (26-29)
BG1	Surface	1994-03-23	1.9 (1.2-2.1)	3.2 (2.7-4.5)	21 (12-21)
	Bottom	"	0.4 (0.3-0.7)	1.1 (<1.4-2.2)	21 (17-27)
BG2	Surface	1994-04-03	1.8 (1.7-2.4)	3.0 (2.6-4.0)	8 (7-9)
	Bottom	"	0.7 (<0.4-0.9)	1.4 (<1.5-2.2)	23 (17-29)

Note: 1. The median used in this report implies an average of analytical values except maximum and minimum ones, determined by five laboratories.
2. The median and range of values are based on the joint data set(Annex-2, 3, 4, 5).
3. Bottom water was designated the water 100m above the bottom.

Table-3(b) Analysis of seabed sediment (median and range of concentrations)

Sampling Station	Sampling Layer	Sampling Date	^{90}Sr (Bq kg^{-1})	^{137}Cs (Bq kg^{-1})	^{239,240}Pu (Bq kg^{-1})	^{238}Pu (Bq kg^{-1})
N1	0-3 cm	1994-03-27	- (<0.04-0.2)	1.5 (<0.5-3.4)	0.05 (0.042-0.150)	- (<0.006)
	>3 cm	"	- (<0.3)	- (<0.2-2.6)	0.006 (<0.006-0.010)	- (<0.008)
N2	0-3 cm	1994-03-28	- (<0.14)	- (<0.4-1.9)	0.036 (0.035-0.063)	- (<0.016)
	>3 cm	"	- (<0.2)	- (<0.4-1.5)	0.009 (0.009-0.025)	- (<0.007)
N3	0-3 cm	1994-04-01	- (<0.1-0.8)	1.0 (<1.4-2.0)	0.12 (0.084-0.150)	- (<0.010)
	>3 cm	"	- (<0.2)	- (<1.7)	0.009 (0.007-0.012)	- (<0.013)
N4	0-3 cm	1994-04-01	- (<0.1-0.8)	- (<1.4)	0.011 (0.010-0.060)	- (<0.009)
	>3 cm	"	- (<0.2)	- (<1.8)	0.004 (<0.005-0.008)	- (<0.004)
N5	0-3 cm	1994-03-24	0.1 (0.05-0.3)	1.2 (<1.3-1.3)	0.12 (0.056-0.340)	0.004 (<0.001-0.013)
	>3 cm	"	- (<0.2)	- (<1.9)	0.040 (0.038-0.058)	- (<0.007)
N6	0-3 cm	1994-03-25	0.2 (0.05-0.2)	2.1 (<1.1-3.4)	0.24 (0.078-0.400)	- (<0.019)
	>3 cm	"	- (<0.14)	- (<1.6)	0.038 (0.035-0.038)	- (<0.006)
N7	0-3 cm	1994-03-27	0.2 (0.1-0.2)	2.8 (2.3-3.1)	1.03 (0.840-1.200)	0.022 (<0.001-0.036)
	>3 cm	"	- (<0.3)	2.3 (1.5-3.0)	0.76 (0.753-0.790)	0.013 (<0.001-0.014)
BG1	0-3 cm	1994-03-23	- (<0.3)	- (<0.7-2.8)	0.014 (0.009-0.065)	- (<0.010)
	>3 cm	"	- (<0.2)	- (<0.3-2.8)	0.014 (0.010-0.025)	- (<0.011)
BG2	0-3 cm	1994-04-03	- (<0.14-0.16)	1.0 (0.7-1.5)	0.14 (0.112-0.230)	- (<0.018)
	>3 cm	"	- (<0.3)	- (<1.9)	0.037 (0.007-0.066)	- (<0.014)

Note: 1. The median and range of values are based on the joint data set (Annex-2, 3, 4, 5).
2. The median is not given when less than 3 quantitative data is available.
3. The concentrations are given per dry weight.

Table-3(C) Analysis of surface water by adsorbent method (range of concentrations)

Sampling Station	Pre-Filter (Suspended ^{137}Cs) (mBq L^{-1})	Adsorbent (Dissolved ^{137}Cs) (mBq L^{-1})	On Board Measurement (Dissolved ^{137}Cs) (mBq L^{-1})
N1	<0.010-0.03	3.0-4.1	4.2-4.7
N2	<0.01-0.013	3.5-4.4	3.3-4.1
N3	0.013-<0.02	2.56-4.6	3.9-4.3
N4	<0.01-0.020	1.62-4.1	3.7-4.4
N5	<0.012	2.10-4.4	3.8-4.7
N6	<0.014	2.71-3.8	3.0-3.6
N7	<0.02	2.49-5.5	3.9-4.1
BG1	<0.014	3.5-3.75	2.9-3.5
BG2	<0.018-0.04	3.1-4.0	3.0-3.5

Note:The range of values are based on the joint data set(Annex-2, 3, 4).

Table-4(a) Radionuclide activity ratios in seawater (median and range of ratios)

Sampling Station	Sampling Horizon	Sampling Date	^{137}Cs/^{90}Sr	^{239,240}Pu/^{90}Sr	^{239,240}Pu/^{137}Cs
N1	Surface	1994-03-28	1.6 (1.2-3.2)	0.014 (0.009-0.015)	0.009 (0.005-0.009)
	Bottom	"	2.3 (1-9.8)	0.059 (0.031-0.108)	- (>0.02-0.044)
N2	Surface	1994-03-29	1.5 (1.2-2.8)	0.007 (0.003-0.009)	0.005 (0.002-0.006)
	200m	1994-03-30	1.7 (1.3-4.9)	0.009 (0.003-0.010)	0.005 (0.001-0.007)
	500m	1994-03-29	1.8 (1.5-3.1)	0.019 (0.014-0.020)	0.010 (0.009-0.014)
	750m	1994-03-31	2.4 (2.2-2.5)	- (0.032-0.038)	- (0.013-0.016)
	1000m	1994-03-29	2.2 (1.6-5.7)	0.030 (0.027-0.038)	0.017 (0.016-0.019)
	2000m	1994-03-31	1.7 (0.9-<3.6)	0.036 (0.031-0.058)	- (<0.009-0.046)
	Bottom	1994-03-30	2.2 (<2.9-7.0)	0.069 (0.032-0.079)	- (>0.028-0.044)
N3	Surface	1994-04-01	1.8 (1.5-2.1)	0.009 (0.005-0.012)	0.006 (0.002-0.008)
	Bottom	"	1.6 (<2.6)	0.030 (0.028-0.048)	- (>0.011-0.029)
N4	Surface	1994-04-02	1.5 (1.3-2.0)	0.003 (0.002-0.009)	0.003 (0.001-0.006)
	Bottom	"	1.2 (1.1-<2.6)	0.026 (0.021-0.046)	- (>0.010-0.028)
N5	Surface	1994-03-24	1.4 (1.3-5.2)	0.010 (0.010-0.012)	0.008 (0.007-0.009)
	Bottom	1994-03-25	1.5 (<1.1-2.2)	0.027 (0.024-0.034)	0.017 (0.016-0.018)
N6	Surface	1994-03-26	2.6 (1.4-3.7)	0.016 (0.014-0.020)	0.007 (0.007-0.010)
	Bottom	"	- (<5.2)	0.081 (<0.024-0.128)	- (>0.025-0.046)
N7	Surface	1994-03-27	1.8 (1.4-3.4)	0.014 (0.014-0.014)	0.010 (0.008-0.010)
	Bottom	"	2.3 (1.1-9.7)	0.026 (0.021-0.031)	0.013 (0.011-0.019)
BG1	Surface	1994-03-23	1.7 (1.4-3.8)	0.010 (0.007-0.011)	0.007 (0.003-0.008)
	Bottom	"	2.0 (1.1-7.3)	0.052 (0.042-0.059)	- (>0.012-0.038)
BG2	Surface	1994-04-03	1.4 (1.3-2.4)	0.004 (0.004-0.005)	0.003 (0.002-0.004)
	Bottom	"	1.6 (0.8->4)	0.045 (0.026->0.073)	- (>0.011-0.032)

Note: 1. The median and range of values are based on the joint data set(Annex-2, 3, 4, 5)
2. The median is not given when less than 3 quantitative data is available.
3. Bottom water was designated the water 100m above the bottom.

Table-4(b) Radionuclide activity ratios in seabed sediment (median and range of ratios)

Sampling Station	Sampling Layer	Sampling Date	$^{137}Cs/^{90}Sr$	$^{239,240}Pu/^{90}Sr$	$^{238}Pu/^{239,240}Pu$
N1	0-3 cm	1994-03-27	-	- (0.2->1.1)	- (<0.04)
	>3 cm	"	-	- (>0.04)	- (<0.25)
N2	0-3 cm	1994-03-28	-	- (>0.1)	- (<0.25)
	>3 cm	"	-	- (>0.04)	- (<0.75)
N3	0-3 cm	1994-04-01	-	- (0.2->0.7)	- (<0.07)
	>3 cm	"	-	- (>0.05)	- (<1.1)
N4	0-3 cm	1994-04-01	-	- (0.07->0.68)	- (<0.85)
	>3 cm	"	-	- (>0.03)	- (<0.37)
N5	0-3 cm	1994-03-24	10 (9-18)	1.4 (0.2-2.8)	0.038 (<0.03-0.04)
	>3 cm	"	-	- (>0.2)	- (<0.12)
N6	0-3 cm	1994-03-25	-	1.4 (1.2->1.8)	- (<0.24)
	>3 cm	"	-	- (>0.3)	- (<0.17)
N7	0-3 cm	1994-03-27	15 (10-24)	4.9 (4.2-9.2)	0.026 (<0.002-0.03)
	>3 cm	"	- (>8-100)	- (>3)	0.017 (<0.002-0.02)
BG1	0-3 cm	1994-03-23	-	- (>0.03)	- (<0.67)
	>3 cm	"	-	- (>0.04)	- (<0.79)
BG2	0-3 cm	1994-04-03	-	- (>0.8)	- (<0.12)
	>3 cm	"	-	- (>0.05)	- (<0.38)

Note: 1. The median and range of values are based on the joint data set(Annex-2, 3, 4, 5)
2. The median is not given when less than 3 quantitative data is available.

Table-5 Analytical results of intercomparison
(Sediment from station N2)

Radionuclide concentration (Bq kg^{-1} dwt)

Lab No.	^{40}K	^{137}Cs	^{208}Tl	^{228}Ac	^{226}Ra	^{239,240}Pu
1	1120 ± 5	< 0.5	137 ± 2	139 ± 1	88 ± 1	0.010 ± 0.002
2	1080 ± 28	< 1.3	-	123 ± 6	82 ± 5	-
3	1262 ± 12	< 0.4	160 ± 3	157 ± 3	74 ± 2	-
4	1200 ± 20	< 1.9	131 ± 2	140 ± 3	78 ± 2	0.018 ± 0.004
5	1176 ± 14	< 1.1	131 ± 2	140 ± 3	85 ± 1	-
6	-	-	-	-	-	0.007 ± 0.001
7	1163 ± 15	-	132 ± 2	143 ± 3	76 ± 2	0.009 ± 0.002
Median	1170	-	132	140	80	0.010

Table-6 Comparison with the past marine environmental radioactivity monitoring data around Japan

Here we compare the analytical results obtained in the joint expedition with the past survey data around Japan. These past data are selected from the marine environmental radioactivity surveys carried out mainly by the Maritime Safety Agency and the Fishery Agency between 1982 and 1992 (exclusive of inland bays). (Hydrographic Department, Maritime Safety Agency, 1982-1992; National Research Institute of Fisheries Sciences, Fisheries Agency, 1982-1992)

Seawater

		^{90}Sr (mBq L^{-1})	^{137}Cs (mBq L^{-1})	$^{239+240}$Pu (μBq L^{-1})
The Joint Expedition	N1～N7	0.4-2.0 * (ND-2.7)**	0.6-3.6 (ND-5.5)	8-29 (3.5-39.8)
Past data (during the past about 10 years)	Far Eastern sea areas around Japan	ND-10	ND-21	ND-109

Notes:

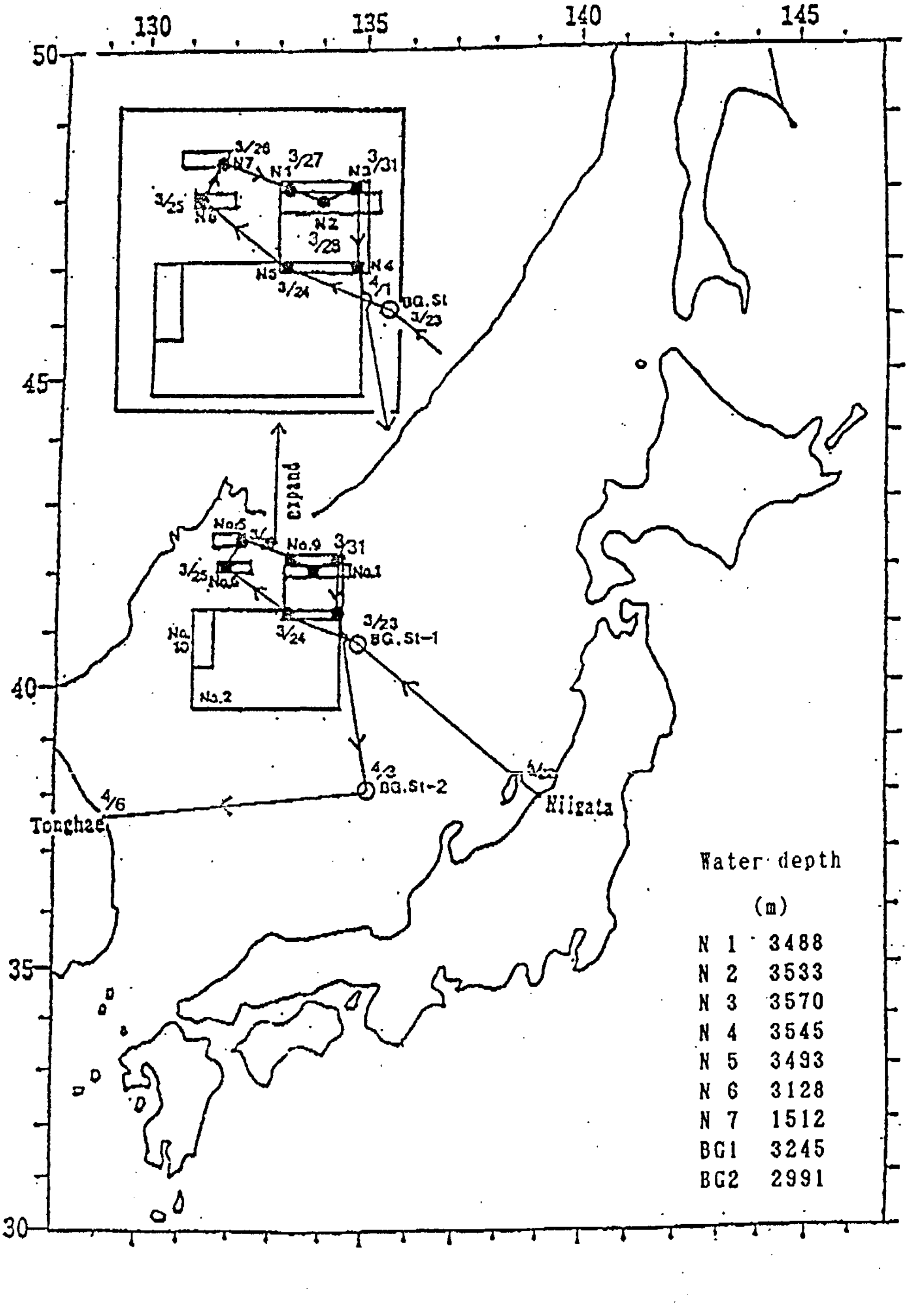
1. ND (Not detected) indicates that the net count is less than three times the counting error.
2. * Range of median concentrations in surface, intermediate and bottom water.
3. ** Overall range of reported concentrations in surface, intermediate and bottom water (Japan, Korea, Russia, IAEA).

Sediment (Bq kg^{-1} dry)

		^{90}Sr	^{137}Cs	$^{239+240}$Pu
The Joint Expedition	N1～N7	ND(<0.04)-0.2 * (ND-0.85)**	ND(<0.2)-2.8 (ND-3.4)	0.004-1.0 (ND-1.2)
Past data (during the past about 10 years)	Far Eastern sea areas around Japan	ND-1.1	ND-35	ND-2.3

Notes:

1. ND (Not detected) indicates that the net count is less than three times the counting error.
2. * Range of median concentrations in upper and lower layer sediments.
3. ** Overall range of reported concentrations in upper and lower layer sediments (Japan, Korea, Russia, IAEA).



Water depth (m)

N 1	3488
N 2	3533
N 3	3570
N 4	3545
N 5	3493
N 6	3128
N 7	1512
BG1	3245
BG2	2991

Fig-1 Cruising Chart

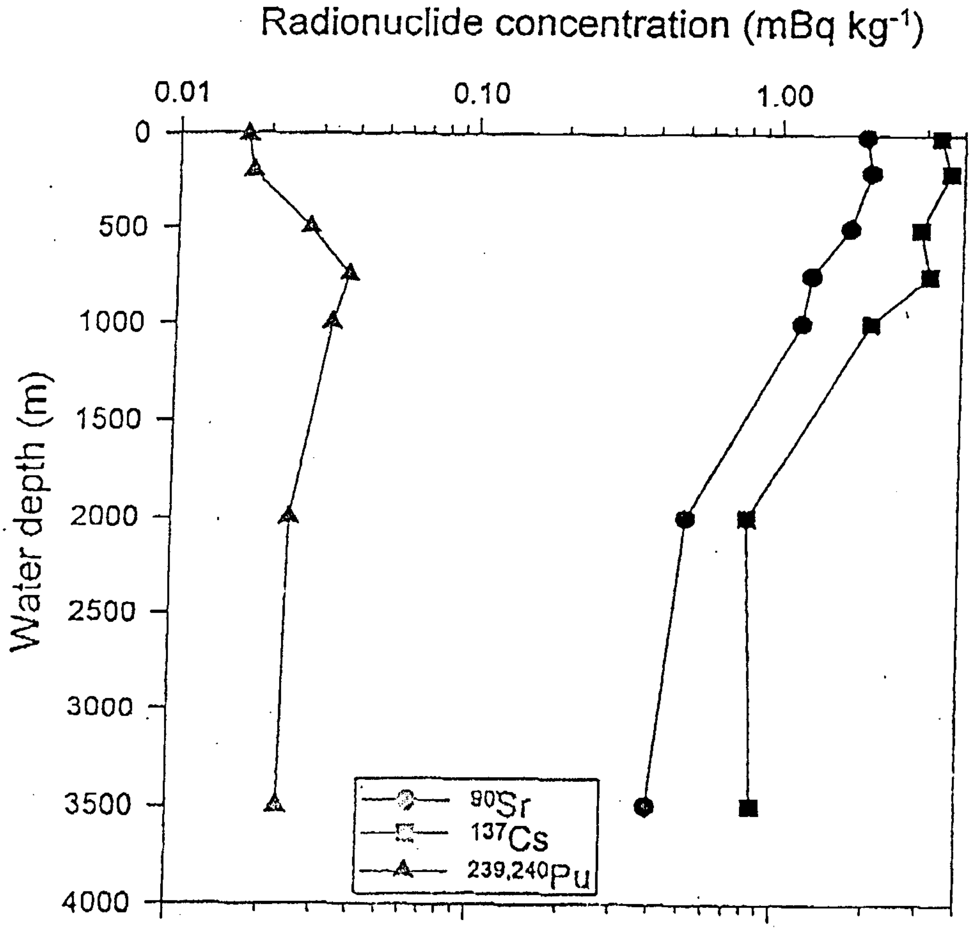


Fig-2. Concentration of ^{90}Sr, ^{137}Cs and ^{239,240}Pu in seawater at station N2 (based on the median values)

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10. Annexes

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RUSSIAN FEDERATION

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Name	Affiliation	Position
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Analytical Results of Seawater (Japan)

Sampling Station	Sampling Depth	Sampling Date	^{137}Cs (mBq/L)	^{90}Sr (mBq/L)	$^{239+240}$Pu (μBq/L) Dissolved	$^{239+240}$Pu (μBq/L) Suspended matter
N 1	Surface	1994. 3. 28	3.5 ±0.6	1.7 ±0.04	16 ± 3	0.87±0.17
	Bottom		ND(<1.3)	0.26±0.02	28 ± 3	0.25±0.06
N 2	Surface	1994. 3. 29	2.2 ±0.6	1.8 ±0.04	4.6 ± 1.1	–
	200 m	1994. 3. 30	2.9 ±0.6	1.3 ±0.03	3.9 ± 1.0	–
	500 m	1994. 3. 29	2.0 ±0.5	1.1 ±0.03	21 ± 2	–
	750 m	1994. 3. 31	–	–	8.6 ± 1.6	–
	1,000 m	1994. 3. 29	1.9 ±0.5	0.86±0.03	33 ± 3	–
	2,000 m	1994. 3. 31	ND(<1.4)	0.39±0.02	12 ± 2	–
	Bottom	1994. 3. 30	ND(<0.83)	0.29±0.02	23 ± 3	–
N 3	Surface	1994. 4. 1	3.8 ±0.7	1.8 ±0.04	9.0 ± 1.4	0.26±0.06
	Bottom		ND(<1.3)	0.50±0.02	14 ± 2	ND(<0.20)
N 4	Surface	1994. 4. 2	3.0 ±0.6	1.7 ±0.04	3.5 ± 0.9	ND(<0.20)
	Bottom		ND(<1.3)	0.51±0.03	13 ± 2	0.26±0.06
N 5	Surface	1994. 3. 24	2.3 ±0.4	1.7 ±0.04	20 ± 3	–
	Bottom	1994. 3. 25	1.6 ±0.5	0.73±0.03	25 ± 4	–
N 6	Surface	1994. 3. 26	3.8 ±0.6	1.6 ±0.04	26 ± 3	0.53±0.10
	Bottom		ND(<1.3)	0.25±0.02	32 ± 4	ND(<0.20)
N 7	Surface	1994. 3. 27	2.3 ±0.6	1.6 ±0.04	22 ± 3	–
	Bottom		2.0 ±0.5	0.85±0.03	26 ± 3	–
B G 1	Surface	1994. 3. 23	3.5 ±0.6	1.7 ±0.04	12 ± 2	–
	Bottom		ND(<1.4)	0.33±0.02	17 ± 3	–
B G 2	Surface	1994. 4. 3	2.6 ±0.4	1.8 ±0.04	9.3 ± 1.4	0.20±0.05
	Bottom		ND(<1.5)	0.38±0.02	17 ± 2	ND(<0.06)

Note: The errors denote ±1σ counting error.

Analytical Results of Seabed Sediment (Japan)

Sampling Station	Sampling Layer	Sampling Date	^{137}Cs (Bq/kg-dry)	^{90}Sr (Bq/kg-dry)	^{238}Pu (Bq/kg-dry)	$^{239+240}$Pu (Bq/kg-dry)
N 1	0～3cm	1994. 3. 27	ND(<1.2)	ND(<0.044)	ND(<0.006)	0.050 ±0.004
	>3cm		ND(<1.7)	ND(<0.006)	ND(<0.008)	ND(<0.006)
N 2	0～3cm	1994. 3. 28	ND(<1.0)	0.048±0.014	ND(<0.016)	0.063 ±0.008
	>3cm		ND(<1.7)	ND(<0.006)	ND(<0.007)	0.0092±0.0021
N 3	0～3cm	1994. 4. 1	1.0 ±0.3	0.068±0.013	ND(<0.010)	0.15 ±0.01
	>3cm		ND(<1.7)	ND(<0.007)	ND(<0.013)	0.012 ±0.004
N 4	0～3cm	1994. 4. 1	ND(<1.2)	ND(<0.037)	ND(<0.009)	0.011 ±0.003
	>3cm		ND(<1.9)	ND(<0.007)	ND(<0.004)	ND(<0.005)
N 5	0～3cm	1994. 3. 24	1.2 ±0.3	0.12 ±0.02	0.013 ±0.004	0.34 ±0.02
	>3cm		ND(<1.9)	ND(<0.007)	ND(<0.007)	0.058 ±0.006
N 6	0～3cm	1994. 3. 25	ND(<1.1)	0.054±0.014	ND(<0.019)	0.078 ±0.010
	>3cm		ND(<1.6)	ND(<0.007)	ND(<0.006)	0.035 ±0.004
N 7	0～3cm	1994. 3. 27	2.5 ±0.3	0.24 ±0.02	0.036 ±0.005	1.2 ±0.04
	>3cm		2.5 ±0.4	0.024±0.003	0.013 ±0.003	0.79 ±0.03
BG 1	0～3cm	1994. 3. 23	ND(<1.2)	ND(<0.041)	ND(<0.010)	0.015 ±0.003
	>3cm		ND(<1.7)	ND(<0.006)	ND(<0.011)	0.014 ±0.004
BG 2	0～3cm	1994. 4. 3	1.3 ±0.3	0.073±0.013	ND(<0.018)	0.15 ±0.01
	>3cm		ND(<1.9)	ND(<0.006)	ND(<0.014)	0.037 ±0.005

Note: The errors denote ±1σ counting error.

Analitical Results of Surface Water by Adsorbent Method (Japan)

Sampling Station	Sampling Date	Filtered volume of surface water (L)	^{137}Cs (mBq/L)		
			Pre-filter (Suspended matter)	Adsorbent (Dissolved)	Adsorbent (On board measurement)
N 1	1994. 3.27～3.28	1464	ND(<0.010)	3.0 ±0.05	4.7 ±0.9
N 2	1994. 3.28～3.31	5121	0.013 ±0.0008	3.5 ±0.03	3.3 ±0.5
N 3	1994. 3.31～4. 1	1300	0.013 ±0.004	3.9 ±0.06	3.9 ±1.2
N 4	1994. 4. 1～4. 2	1197	0.020 ±0.005	3.2 ±0.05	4.4 ±0.6
N 5	1994. 3.23～3.25	1140	ND(<0.012)	3.4 ±0.04	4.7 ±1.4
N 6	1994. 3.25～3.26	1182	ND(<0.014)	3.3 ±0.07	3.6 ±1.3
N 7	1994. 3.26～3.27	705	ND(<0.020)	3.1 ±0.07	4.1 ±0.8
BG 1	1994. 3.22～3.23	1018	ND(<0.014)	3.5 ±0.05	3.5 ±1.3
BG 2	1994. 4. 2～4. 4	1328	ND(<0.018)	3.1 ±0.04	3.5 ±0.9

Note: The errors denote ±1σ counting error.

Annex-3(a)

Analytical Results of Seawater (Korea)

Sampling Station	Sampling Horizon	Sampling Date	Dissolved Fraction		
			^{137}Cs(mBq kg^{-1})	^{90}Sr(mBq kg^{-1})	^{239,240}Pu(μBq kg^{-1})
N1	Surface	Mar. 28, 1994	2.56±0.15	1.71±0.14	23.8±1.9
	Bottom		0.53±0.05	0.40±0.10	23.6±4.1
N2	Surface	Mar. 29, 1994	3.33±0.12	2.52±0.42	16.7±1.3
	200m	Mar. 30, 1994	3.72±0.26	2.04±0.22	17.5±1.6
	500m	Mar. 29, 1994	2.89±0.25	1.95±0.21	27.3±1.8
	750m	Mar. 31, 1994	3.13±0.31	1.25±0.18	39.8±5.1
	1000m	Mar. 29, 1994	2.01±0.27	1.19±0.20	32.1±1.8
	2000m	Mar. 31, 1994	0.63±0.25*	0.68±0.18	24.5±1.7
	Bottom	Mar. 30, 1994	0.61±0.15	0.55±0.13	17.5±2.7
N3	Surface	Apr. 1, 1994	2.78±0.16	1.89±0.21	17.7±1.4
	Bottom		1.08±0.10	0.73±0.07	22.1±3.2
N4	Surface	Apr. 2, 1994	3.02±0.17	2.40±0.31	7.8±1.3
	Bottom		0.88±0.13	0.71±0.22	14.9±1.8
N5	Surface	Mar. 24, 1994	3.11±0.14	2.08±0.15	21.2±1.7
	Bottom	Mar. 25, 1994	1.59±0.09	1.22±0.09	28.7±4.7
N6	Surface	Mar. 26, 1994	3.11±0.26	1.09±0.27	22.3±2.7
	Bottom		0.63±0.15	0.78±0.36*	18.9±2.5
N7	Surface	Mar. 27, 1994	2.71±0.16	1.84±0.09	26.0±2.0
	Bottom		1.57±0.15	1.38±0.14	29.4±1.3
BG1	Surface	Mar. 23, 1994	2.70±0.18	1.90±0.08	20.9±2.3
	Bottom		0.55±0.05	0.49±0.08	20.7±1.4
BG2	Surface	Apr. 3, 1994	2.97±0.13	1.79±0.26	6.5±1.4
	Bottom		0.72±0.13	0.89±0.24	23.3±2.6

Note: 1. Bottom water was designated the water 100m above the bottom.

2. The mark* indicates the net count is less than three times the counting error.

3. MDA: 0.14 mBq kg^{-1} for Sr-90 and 3.94 μBq kg^{-1} for Pu-239, 240.

Analytical Results of Seabed Sediment (Korea)

Sampling	Sampling	Sampling	Radionuclide Concentrations Per Unit Dry Weight			
Station	Depth	Date	^{137}Cs(Bq kg^{-1})	^{90}Sr(Bq kg^{-1})	^{239,240}Pu(mBq kg^{-1})	^{238}Pu(mBq kg^{-1})
N1	0-3cm	Mar. 27, 1994	1.49±0.57	0.19±0.06	42±2	-
	>3cm		<MDA	<MDA	6±1	-
N2	0-3cm	Mar. 28, 1994	<MDA	0.37±0.17*	36±2	1.75±0.53
	>3cm		<MDA	0.30±0.16*	25±2	0.86±0.53*
N3	0-3cm	Apr. 1, 1994	<MDA	<MDA	92±5	-
	>3cm		<MDA	<MDA	9±1	-
N4	0-3cm	Apr. 1, 1994	<MDA	0.27±0.16*	11±3	-
	>3cm		<MDA	<MDA	4±1	-
N5	0-3cm	Mar. 24, 1994	<MDA	0.29±0.06	56±3	-
	>3cm		<MDA	<MDA	38±3	-
N6	0-3cm	Mar. 25, 1994	1.86±0.48	0.22±0.08	249±22	-
	>3cm		<MDA	<MDA	38±2	-
N7	0-3cm	Mar. 27, 1994	2.76±0.01	0.18±0.04	856±39	-
	>3cm		1.52±0.01	0.15±0.03	753±23	-
BG1	0-3cm	Mar. 23, 1994	<MDA	0.17±0.07*	13±1	-
	>3cm		<MDA	<MDA	25±6	-
BG2	0-3cm	Apr. 3, 1994	0.97±0.13	0.63±0.29*	112±8	2.98±2.16*
	>3cm		<MDA	0.22±0.13*	7±2	-

Note: 1. The mark* indicates the net count is less than three times the counting error.

2. MDA: 1.44 Bq kg^{-1} for Cs-137, 0.14 Bq kg^{-1} for Sr-90, 2.09mBq kg^{-1} for Pu-239, 240 and 1.48 mBq kg^{-1} for Pu-238.

Analytical Results of Surface Water by Adsorbent Method (Korea)

^{137}Cs concentration determined using cartridge filter impregnated with ($K_4Fe(CN)_6$)(uncorrected for salt)

Sampling Station	Depth (m)	Sampling date	^{137}Cs (mBq L^{-1})
BG1	0	Mar. 23, 1994	3.75 ± 0.01
N3	0	Apr. 1, 1994	2.56 ± 0.01
N4	0	Apr. 2, 1994	1.62 ± 0.01
N5	0	Mar. 24, 1994	2.10 ± 0.01
N6	0	Mar. 26, 1994	2.71 ± 0.16
N7	0	Mar. 27, 1994	2.49 ± 0.01

Analytical Results of Suspended Particulate Matter (Korea)

Concentration of $^{239,240}Pu$ in suspended particulate matter

Sampling Station	Depth (m)	Sampling date	$^{239,240}Pu$ (μBq L^{-1})
N2	0	Mar. 29, 1994	0.17 ± 0.03
	200	Apr. 30, 1994	0.48 ± 0.06
	500	Apr. 29, 1994	1.00 ± 0.15
	750	Mar. 31, 1994	0.68 ± 0.08
	1000	Mar. 29, 1994	0.67 ± 0.07
	2000	Mar. 31, 1994	0.53 ± 0.10
	Bottom	Mar. 31, 1994	0.43 ± 0.09

N5	0	Mar. 24, 1994	0.26 ± 0.05
N5	Bottom	Mar. 25, 1994	0.46 ± 0.08
N7	0	Mar. 27, 1994	0.21 ± 0.06
N7	Bottom	Mar. 27, 1994	0.77 ± 0.12
BG1-1	Near Bottom	Mar. 23, 1994	1.67 ± 0.15

Annex-4(a)

Analytical Results of Seawater (Russia)

Concentrations of man-made radionuclides in seawater
(dissolved parts)、 Bq/m^3

Sampling Station	Horizon	^{137}Cs		^{90}Sr	
		Lab. 1	Lab. 2	Lab. 1	Lab. 2
N1	Surface	3.2±0.1	4.2±0.4	2.7±0.4	1.3±0.2
	Bottom	1.3±0.3	3.9±0.4	0.4±0.1	0.4±0.1
N2	Surface	3.8±0.2	4.5±0.4	2.1±0.3	1.6±0.2
	200m	3.6±0.4	4.9±0.6	2.1±0.3	1.0±0.2
	500m	3.5±0.4	3.1±0.4	1.7±0.3	1.0±0.1
	750m	3.3±0.7	3.1±0.6	1.3±0.3	1.4±0.1
	1000m	2.9±0.4	3.4±0.3	1.2±0.2	0.6±0.1
	2000m	1.0±0.2	1.8±0.6	0.45±0.13	0.6±0.2
	Bottom	1.1±0.3	1.4±0.2	0.4±0.1	0.2±0.1
N3	Surface	3.6±0.2	4.5±0.4	1.9±0.3	2.5±0.2
	Bottom	<1.0	2.0±0.4	0.9±0.2	1.2±0.2
N4	Surface	4.3±0.2	2.6±0.3	2.1±0.3	1.8±0.2
	Bottom	1.2±0.2	<1.3	1.1±0.2	0.7±0.2
N5	Surface	-	4.2±0.4	2.6±0.4	0.8±0.2
	Bottom	1.9±0.4	<1.3	1.3±0.3	1.2±0.2
N6	Surface	-	3.3±0.4	1.6±0.3	0.9±0.1
	Bottom	0.8±0.3	<1.3	1.1±0.2	0.5±0.1
N7	Surface	3.7±0.2	3.7±0.3	2.0±0.3	1.1±0.2
	Bottom	1.8±0.2	2.9±0.4	0.9±0.3	0.3±0.1
BG1	Surface	-	4.5±0.4	1.9±0.3	1.2±0.2
	Bottom	1.4±0.3	2.2±0.3	0.66±0.17	0.3±0.1
BG2	Surface	4.0±0.3	3.2±0.4	1.7±0.3	2.4±0.2
	Bottom	1.4±0.2	2.2±0.3	0.9±0.2	0.7±0.2

Note:

1. Lab.1:SPA "Typhoon" , Lab.2:Vladivostok Department of Roshydromet
2. By the data of Lab.1 the detection limit(ND) of ^{137}Cs and ^{134}Cs estimated with the assumption of 70% measurement error is 0.2-1.0 Bq/m^3.
3. By the data of Lab.2 the concentrations of ^{134}Cs and ^{60}Co are below the sensitivity level of the used method and equals 1.1 Bq/m^3 and 0.9 Bq/m^3, respectivily. The detection limit for ^{137}Cs is 1.3 Bq/m^3.
4. Uncertainties are shown by one mean square deviation.
5. Mark (-) means that the sample for the analysis was not taken.
6. Lab.1 have determined dissolved Pu-239,240 content in the surface water from Station 3 and BG-1. concentrations were accordingly 11±5 mBq/m^3 and 19±5 mBq/m^3.

Annex-4(b)

Analytical Results of Seabed Sediment (Russia)

Concentration of man-made radionuclides in seabed sediments.
Bq kg^{-1}(dry weight)

Sampling Station	Layer	^{137}Cs Lab.1	^{137}Cs Lab.2	^{90}Sr Lab.1	^{239,240}Pu Lab.1
N1	0-3cm	<0.5	3.4±1.2	0.040±0.015	0.15±0.04
	>3cm	<0.9	2.6±0.6	-	-
N2	0-3cm	<0.7	1.3±0.6	0.08±0.03	<0.06
	>3cm	<0.9	1.5±0.5	-	-
N3	0-3cm	1.1±0.2	2.0±0.7	0.8±0.2	0.15±0.05
	>3cm	<0.6	1.6±0.5	-	-
N4	0-3cm	<0.4	<1.3	0.85±0.20	0.06±0.04
	>3cm	<1.0	<1.3	-	-
N5	0-3cm	1.3±0.3	<1.3	0.14±0.05	0.14±0.04
	>3cm	<1.0	1.8±0.5	-	-
N6	0-3cm	2.3±0.8	3.4±0.6	0.16±0.05	0.40±0.07
	>3cm	<0.7	<1.3	-	-
N7	0-3cm	3.1±0.4	2.3±0.6	0.13±0.04	1.2 ±0.15
	>3cm	3.0±0.5	2.0±0.8	-	-
BG1	0-3cm	<0.7	2.8±0.9	<0.04	0.065±0.035
	>3cm	<0.7	2.8±0.9	-	-
BG2	0-3cm	0.8±0.5	1.5±0.6	-	0.23±0.04
	>3cm	<0.4	<1.3	-	-

Note:

1. Lab.1:SPA "Typhoon" , Lab.2:Vladivostok Department of Roshydromet
2. By the data of Lab.1 the detection limit(ND) for Cs-137 is 0.4-1.0 Bq/kg, Mn-54 0.8 Bq/kg, Co-60 0.6 Bq/kg and Sr-90 0.04 Bq/kg.
3. By the data of Lab.2 the concentrations of Mn-54, Co-60, Sr-90 and Cs-134 are below the sensitivity level of the used method (ND) which is 0.7-1.2 Bq/kg, 0.6-0.9 Bq/kg, 0.4 Bq/kg and 0.9-1.1 Bq/kg. The detection limit of Cs-137 is 1.1-1.3 Bq/kg.
4. Uncertainties are shown by one mean square deviation.
5. Mark(-) means that this type of analysis of the sample was not performed.

Annex-4(c)

Analytical Results of Surface Water by Adsorbent Method (Russia)

Concentration of ^{137}Cs on suspended matter (more than 1 micrometre) in surface waters (measurements of SPA "Typhoon")

Station	$^{137}Cs(Bq/m^3)$
N1	0.03±0.01
N2	<0.01
N3	<0.02
N4	<0.01
N5	-
N6	<0.01
N7	<0.02
BG1	<0.01
BG2	0.04±0.01

An estimation of concentration of ^{137}Cs in surface water determined by pumping large volumes of water through fiber sorbents, Bq/m^3 (measurements of SPA "Typhoon")

Sampling Station	Water volume, L	^{137}Cs On Board measurement	^{137}Cs Laboratory measurement
N1	4609	4.2±1.4	4.1±0.9
N2	4638	4.1±1.3	4.4±1.0
N3	4382	4.3±1.3	4.6±1.3
N4	4555	3.7±1.2	4.1±0.4
N5	5962	3.8±1.3	4.4±1.0
N6	6040	3.0±1.0	3.8±0.9
N7	3572	3.9±1.3	5.5±1.2
BG1	5166	2.9±0.9	3.7±0.8
BG2	4900	3.0±1.0	4.0±0.7

Analytical Results of Seawater (IAEA)

Sampling Station	Sample mass for analysis (kg)	Radionuclide Concentrations [1]			
		^{90}Sr mBq kg^{-1}	^{137}Cs mBq kg^{-1}	^{239,240}Pu μBq kg^{-1}	^{238}Pu μBq kg^{-1}
BG1 Surface	102.7	2.08±0.10	2.91±0.08	21.4±3.5	<2
BG1 3200 m	94.7	0.45±0.03	0.82±0.08	26.7±3.0	<1
N1 Surface	103.1	1.67±0.09	2.76±0.08	25.4±2.3	0.4±0.1
N1 3500 m	106.3	0.85±0.11	0.85±0.05	26.0±2.4	0.8±0.2
N2 Surface	105.6	1.9 ±0.7	2.80±0.09	17.0±1.5	0.4±0.1
N2 200 m	104.7	1.98±0.10	2.64±0.07	19.6±1.8	0.3±0.1
N2 500 m	105.7	1.74±0.09	2.54±0.07	34.9±3.0	0.8±0.2
N2 750 m	86.0	0.99±0.18	2.30±0.09	37.4±3.4	0.6±0.3
N2 1000 m	95.9	1.27±0.08	2.00±0.08	38.2±3.5	0.4±0.2
N2 2000 m	95.5	0.51±0.04	0.65±0.05	29.8±3.0	0.5±0.2
N2 3500 m	105.4	0.39±0.08	0.61±0.06	27.0±2.4	0.7±0.2
N3 Surface	96.9	1.58±0.11	2.45±0.09	19.6±3.0	<2
N3 3500 m	103.7	0.64±0.04	1.05±0.07	30.5±3.0	0.5±0.2
N4 Surface	76.5	1.76±0.09	2.69±0.10	16.4±1.6	0.5±0.3
N4 3500 m	97.9	0.66±0.04	1.08±0.07	30.4±3.0	0.6±0.2
N5 Surface	92.1	1.96±0.11	2.55±0.13	20.6±2.0	0.7±0.2
N5 3500 m	71.5	1.03±0.06	1.65±0.11	27.5±3.0	0.4±0.2
N6 Surface	96.3	1.71±0.09	2.44±0.08	24.6±2.4	0.3±0.1
N6 3100 m	98.5	0.36±0.03	0.63±0.04	29.0±2.8	0.4±0.1
N7 Surface	96.9	1.49±0.11	2.75±0.09	21.1±2.0	<0.6
N7 1500 m	93.9	1.07±0.05	2.52±0.09	27.6±3.1	0.8±0.4
BG2 Surface	95.1	2.08±0.10	2.89±0.10	8.5±1.0	0.3±0.2
BG2 3000 m	95.9	<0.4	1.62±0.16	29.2±2.6	1.0±0.3

1) The errors denote ±1σ counting statistics. The systematic errors are ^{90}Sr: 2%, ^{137}Cs: 2%, $^{239+240}$Pu: 5%.

Annex-5(b)

Analytical Results of Seabed Sediment (IAEA)

Sampling Station	Sample Layer	Radionuclide Concentrations per unit dry weight [1]			
		^{90}Sr Bq kg^{-1}	^{137}Cs Bq kg^{-1}	^{239,240}Pu mBq kg^{-1}	^{238}Pu mBq kg^{-1}
BG1	Surface	<0.3	0.24±0.08	8.9 ±1.4	<0.8
BG1	Bulk	<0.2	<0.3	9.6 ±1.5	<3
N1	Surface	<0.1	0.3 ±0.1	55 ±6	<3
N1	Bulk	<0.3	<0.2	10.4±1.6	<3
N2	Surface	<0.1	<0.4	35 ±4	1.8 ±0.8
N2	Bulk	<0.2	<0.4	9.3 ±1.7	<4
N3	Surface	<0.2	0.40±0.09	84 ±9	<3
N3	Bulk	<0.2	<0.5	7.2 ±1.4	<1
N4	Surface	<0.05	<0.5	10 ±3	<3
N4	Bulk	<0.2	<0.5	7.9 ±1.3	<1
N5	Surface	0.06±0.03	1.12±0.13	105 ±10	4.1 ±1.0
N5	Bulk	<0.2	0.52±0.11	40 ±4	<1.5
N6	Surface	0.19±0.03	1.62±0.10	235 ±21	5.6 ±1.4
N6	Bulk	<0.1	0.35±0.09	38 ±4	<3
N7	Surface	0.20±0.02	2.99±0.09	840 ±73	22 ±3
N7	Bulk	<0.3	2.27±0.14	760 ±65	14.2±2.1
BG2	Surface	0.16±0.06	0.66±0.10	120 ±11	4.6 ±1.3
BG2	Bulk	<0.3	<0.5	66.4±9.6	9.0 ±2.4

1) The errors denote $\pm 1\sigma$ counting statistics. The systematic errors are ^{90}Sr: 2%, ^{137}Cs: 5%, $^{239+240}$Pu: 5%.

Analysis of Biota (Japan and Korea)

According to the original plan of the first Japanese-Korean-Russian joint expedition, plankton was planned as an option for analysis of biota samples. However, we were not able to obtain enough plankton for analysis.

In addition, during occupation of station N7, we recieved fish samples from a Russian fishing boat operating in the area. However, as the sampling locations are unknown and the sample represents several catches, the analytical results should be regarded as information values only.

1. Sampling and pretreatment

1.1 Zooplankton

Zooplankton samples were collected by a Juday plankton net (diameter 37cm, mesh 168μm) from 200 m depth to the surface (6 casts).

Immediately after collection, the samples were mixed, concentrated and divided by the Japanese and Korean sides. Samples were stored in a refrigerator. The individual sample weights were about 10-20 grams (wet weight).

1.2 Benthos

In order to collect macrobenthos in sediment samples, the remaining sediment after subsampling for radionuclides analysis was sieved through a 1mm mesh. Macrobenthos were preserved by formalin solution (4%) to determine species composition of benthos on land. However, the limited size of Benthos samples obtained did not allow for radiochemical analyses.

1.3 Fish and shrimp

Large quantities of fish (atka mackerel and flounder) and shrimp were obtained from the Russian fishing boat. These samples were distributed to three parties (Japan, Korea, Russia), then packed into plastic containers and stored in a refrigerator.

2. Methods of Laboratory Analysis

2.1 Japan

(1) Gamma emitters

Since the amount of zooplankton was very small, it was only dried and not ashed. The sample size (a few g dry weight) was too small to ensure analytical precision.

Fish samples were dissected and then dried at 105℃. The sample was carbonized at 420℃ in a gas-carbonization equipment.

Dried or ashed samples were weighed and placed in polystyrene containers (55mmH, 48mmϕ) for gamma spectrometry.

(2) Strontium-90

The fish samples were dried and ashed (see above 2.1(1)). Stable Sr was added to the samples and the samples were subject to acid digestion.

The residue was filtered and discarded. Sr in the filtrate was separated for subsequent analyses.

The analysis of ^{90}Sr in plankton samples was not performed due to the small sample quantities.

(3) Plutonium

The fish samples were dried and ashed (see above 2.1(1)) A known amount of ^{242}Pu chemical yield tracer was added to the samples and the samples were subject to HNO_3 and H_2O_2 digestion. The residue was filtered and discarded. Pu in the filtrate was separated for subsequent analyses.

The analysis of plutonium in plankton samples was not performed due to small sample quantities.

2.2 Korea

(1) Gamma emitters

Flesh, head and shell of the fish and shrimp were separated, weighed (fresh weight), and ashed at 450℃ for subsequent gamma spectrometric analysis using a HPGe detector.

(2) Strontium-90

The fish and shrimp samples were dried and ashed at 500℃. ^{242}Pu, ^{85}Sr and stable Sr were added to the samples and the samples were subject to acid and H_2O_2 digestion. The residue was filtered and discarded. Pu and Sr inthe filtrate were recovered by oxalate precipitation, and then Sr fraction was isolated from Pu fraction by iron hydroxide co-precipitation.

(3) Plutonium

Pu separated from 2.2(2) above as iron co-precipitate was treated as described in 3.2.3(1) for seawater. The zooplankton samples were dried and ashed (see above 3.2.3(3) Suspended particulate matter on the filters). A known amount of ^{242}Pu chemical yield tracer was added to the samples and the samples were digested with 8M HNO_3. The residue was filtered and discarded. Pu in the filtrate was separated by iron co-precipitation. The iron co-precipitate was dissolved in acid and Pu was separated by an ion-exchange resin (AX1-8) followed by electrodeposition onto stainless steel discs and analysis by alpha spectrometry using surface barrier detectors.

3. Results

3.1 Japan

Concentrations of ^{137}Cs, ^{90}Sr and ^{239,240}Pu in plankton, fish and shrimp samples are given in Appendix-1. Concentrations of ^{137}Cs and ^{239,240}Pu in the atka mackerel, flounder and shrimp ranged from <0.07 to 0.29 Bq kg^{-1} and 0.00033 to 0.010 Bq kg^{-1} fresh weight, respectively.

Concentrations of ^{137}Cs in plankton and ^{90}Sr, ^{238}Pu in fish samples were less than the detection limits.

3.2 Korea

Concentrations of ^{137}Cs, ^{90}Sr and ^{239,240}Pu in plankton, fish and shrimp samples are given in Appendix-1. Concentrations of ^{137}Cs and ^{239,240}Pu in the atka mackerel, flounder and shrimp ranged from 0.10 to 0.25 Bq kg^{-1} and <0.04 to 17.3 mBq kg^{-1}, respectively. The ^{90}Sr concentration in fish samples was less than the detection limits. ^{137}Cs was more concentrated in fish than in shrimp, while ^{90}Sr was less concentrated in fish than in shrimp. ^{239,240}Pu was concentrated in the heads rather than in the meat. ^{238}Pu was found only in the fish heads. ^{239,240}Pu concentration in zooplankton was 0.1-0.4 μBq kg^{-1}(dry weight).

4. Discussion

The concentrations of these radionuclides, which are of the same magnitude as those observed in marine samples around Japan in the past (National Research Institute of Fisheries Sciences, Fisheries Agency, 1982-1992; Nakamura, I., et al, 1993; Fukui Environmental Radiation Monitoring Council, 1982-1992 : Fowler, S.W., 1982, 1990) were extremely low.

Biota (Zooplankton)

		^{137}Cs (Bq kg^{-1} fresh)	$^{239,240}Pu$ (Bq kg^{-1} dry)
This joint study	Japan	ND(<0.44)	———
	Korea	———	0.08-0.39
Past data (during the past about 10 years)	Far Eastern sea areas around Japan	ND	0.16-0.48

Note: ND(Not detected) indicates that the net count is less than three times the counting error.

Biota (Fishes)

(Bq kg^{-1} fresh)

		^{90}Sr	^{137}Cs	^{238}Pu	$^{239,240}Pu$
This joint study	Japan	ND(<0.17)	ND(<0.07) -0.29	ND(<0.0038)	0.00033 -0.010
	Korea	ND(<0.01)	0.10-0.25	ND(<0.0004) -0.00075	ND(<0.0004) -0.0173
Past data (during the past about 10 years)	Far Eastern sea areas around Japan	ND-0.28	ND-1.6	ND-0.0031	ND-0.21

Notes:

1. ND(Not detected) indicates that the net count is less than three times the counting error.
2. Japanese results regard data of wholebody, muscle, internal organs and ovary samples.
3. Korean results regard data of meat, head and shell samples.

Annex-7

Sources of anthropogenic radionuclides in the studied sea

There are several possible sources which could contribute to the present levels of anthropogenic radionuclides in the studied sea, as follows:

- direct fallout from nuclear weapon tests,
- direct fallout from the Chernobyl accident,
- input from rivers connecting to the sea,
- marine transport from adjacent seas,
- input from authorized low-level discharge of liquid radioactive waste from nuclear sites in the region,
- input from dumping of liquid radioactive wastes,
- input from leakage of solid waste dumped in the sea.

The global fallout from the atmospheric nuclear weapon tests during the period 1950-1980 and the deposition of radionuclides from the Chernobyl accident are well documented (e.g. UNSCEAR, 1988, 1993) and it may be used to estimate the deposition densities.

The input of radionuclides from adjacent seas comes mainly from the Tsushima current. The water input is about 3-8 · 10^4km^3/year(Nishimura, 1983), which is not insignificant, but may be compensated bythe outflow.

The input from rivers connecting to the sea is not well documented, but is probably insignificant in view of the marginal water input (about 200 km^3/year (Nishimura, 1983)) compared to the sea volume (about 1.7 · 10^6 km^3 (Menard and Smith, 1966)).

Based on the above information , an estimate was made of the total input of anthropogenic radionuclides to the studied sea (Table-A).

Table-A Estimated integrated inputs of ^{90}Sr, ^{137}Cs and ^{239,240}Pu to the studied sea.

Source	^{90}Sr (PBq)	^{137}Cs (PBq)	^{239,240}Pu (PBq)
Global atmospheric nuclear weapon test fallout 1)	2.4-3.3	3.8-5.2	0.04-0.06
Chernobyl accident derived fallout 2)	negligible	0.2	negligible
Waste disposal 3) LRW : SRW :	0.44 0.14 Total activity(^{90}Sr equivalent)		

1)Derived from UNSCEAR(1993) data on ^{90}Sr integrated deposition densities for latitudes 30° -50° N and by using a surface area of 1.01 · 10^6 km^2 for the sea (Menard and Smith, 1966).

2)Derived from UNSCEAR(1988) data on average deposition densities for Japan. A sea surface area of 1.01 · 10^6 km^2 was used for the calculation (Menard and Smith, 1966).

3)Derived from the White Book (1993).

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시료채취정점	시료	핵종	연구 기관
N1	해수, 해저퇴적물	^{137}Cs, ^{90}Sr, $^{239, 240}$Pu	KORDI
	동물플랑크톤	$^{239, 240}$Pu	
N2	해수, 해저퇴적물		KINS
	동물플랑크톤	$^{239, 240}$Pu	KORDI
	^{137}Cs 흡착제	^{137}Cs	KORDI
	부유입자		KORDI
N3	해수, 해저퇴적물	^{137}Cs, ^{90}Sr, $^{239, 240}$Pu	KORDI
	동물플랑크톤	$^{239, 240}$Pu	
	^{137}Cs 흡착제		
N4	해수, 해저퇴적물		KINS
	동물플랑크톤	$^{239, 240}$Pu	KORDI
	^{137}Cs 흡착제		KORDI
N5	해수, 해저퇴적물		KORDI
	동물플랑크톤		
	^{137}Cs 흡착제		
	부유입자		
N6	해수, 해저퇴적물		KINS
	동물플랑크톤		KORDI
	^{137}Cs 흡착제		KORDI
N7	해수, 해저퇴적물		KINS
	동물플랑크톤		KORDI
	새우		KINS
	어류		KINS
	^{137}Cs 흡착제		KORDI
	부유입자		KORDI
BG1	해수, 해저퇴적물		KORDI
	동물플랑크톤		
	부유입자		
BG2	해수, 해저퇴적물		KINS
	동물플랑크톤		KORDI

제 3 장 동해표층수의 ^{137}Cs 과 $^{239, 240}$Pu 분포

Abstract: Surface and subsurface water samples for ^{137}Cs and ^{239,240}Pu analysis were collected in the East Sea (Sea of Japan) during August 1993. The ^{137}Cs levels of the surface waters are quite homogeneous in the East Sea (average = 3.1 ± 0.2 mBq Kg^{-1}). The ^{239,240}Pu levels vary from 6 to 10 μBq Kg^{-1} in the surface. ^{239,240}Pu to ^{137}Cs ratios in the surface water are within 0.002 to 0.003.

^{137}Cs and ^{239,240}Pu levels in the surface waters of the East Sea appear to be primarily controlled by the atmospheric input, direct fallout and Yellow Dusts.

However, since our sampling was made just two months prior to the widely publicized Russian dumping incident on the 17th October 1993, our measurements may provide background data to assess the immediate impact of the Russian dumping on the levels of ^{137}Cs and ^{239,240}Pu in the East Sea.

INTRODUCTION

Since the world's first atomic bomb explosion at Alamogordo in New Mexico USA, in 1945, substantial amounts of artificial radionuclides derived from nuclear explosions have been dispersed as global fallout over the earth's surface. ^{137}Cs ($\tau_{1/2}$ = 30.02 yr), and ^{239,240}Pu ($\tau_{1/2} = 2.4 \times 10^4$, 6.57×10^3 yr, respectively) are important radionuclides among many fission products, which have imposed threat to the marine environments especially due to their long half-life and toxicity. Since the discovery of a large scale radioactive contamination in the equatorial region of the North Pacific in 1954 associated with underwater nuclear weapon test in Bikini Atoll by Japanese scientists (Miyake *et al.*, 1955), the distributions of these radionuclides contaminants have been widely investigated in the Pacific ocean and adjacent seas (Miyake & Saruhashi, 1964; Nagaya & Nakamura, 1976, 1981, 1984, 1987, 1992; Bowen *et al.*, 1980; Ohmomo & Nakahara, 1980; Zhu *et al.*, 1991; Hirose *et al.*, 1992). In addition to their radiological significance, ^{137}Cs has been also utilized as a valuable tracer for water circulation because of its conservative behavior in seawater (Kupferman *et al.*, 1979; Du Bois *et al.*, 1993), and Pu isotopes for particle transport due to their strong particle reactiveness (Fowler *et al.*, 1993).

There are several sources of these artificial radionuclides entering the sea: atmospheric direct fallout including aerial particles, riverine input, lateral transport from the open ocean, deliberate sea dumping of radioactive wastes, and controlled discharges from nuclear power plants. The largest input of ^{137}Cs and ^{239,240}Pu to the world ocean derived from the atmospheric fallout resulting from the atmospheric testing of nuclear weapons (Kupferman *et al.*, 1979). The riverine input appears to be significant in the coastal area (Ohmomo & Nakahara, 1980; Pattenden & McKay, 1994).

Aerial dusts from the Central Asia (Yellow Dust Storms) have also contributed artificial radionuclides continuously into the East Sea in recent decades, despite the cessation of atmospheric nuclear weapon testing in 1980. A significant input of artificial radionuclides to coastal seas by resuspended soils has been noted earlier (Koide *et al.*, 1975).

In recent years, the levels of the artificial radionuclides in the East Sea draw more attention because the record of nuclear waste dumping by the former Soviet Union and the Russian Federation for the past thirty years has become publicly known (Yablokov *et al.*, 1993). Liquid radioactive waste dumping from a surface vessel on 17th October 1993 was widely publicized throughout the world. The Soviet government disposed wastes with activities of more than 558 TBq in the northern part of the East Sea (Japan Basin) since 1966 (Yablokov *et al.*, 1993).

Various artificial radionuclides in the East Sea have been determined (^{3}H : Watanabe *et al.*, 1991; ^{14}C : Gamo & Horibe, 1983; ^{90}Sr, ^{137}Cs, ^{239,240}Pu : Nagaya & Nakamura, 1981, 1987; Miyake *et al.*, 1988). However, their sampling areas were limited and especially they lacked the representative samples to the Japan Basin where most nuclear wastes were disposed by the Soviet Union.

The purpose of this study was to provide the synoptic distribution of ^{137}Cs and ^{239,240}Pu levels in the East Sea.

MATERIALS AND METHODS

Nineteen surface seawater samples and five subsurface (150 m, 300 m deep) water samples were collected in the East Sea during the first expedition of the Korea-Japan-Russia joint program on the Circulation Research of Eastern Asian Marginal Seas (CREAMS '93) aboard the R/V *Professor Khromov* for the period of 14 ~ 29 August 1993 (Fig. 1), prior to the Russian dumping of liquid radioactive wastes 17th October 1993 (14 GBq, Russian Government Announcements).

Sixty liters of surface seawater samples were collected with submerged water pump and subsurface samples with twelve 5 *l* Niskin bottles mounted on a Rosette water sampler. The samples were stored in three of precleaned 20 *l* polyethylene bottles after acidification with 50 *ml* of 6N HCl in each bottle.

The plutonium and cesium in seawater were sequentially concentrated with manganese oxide and ammonium molybdate phosphate (AMP), respectively (Wong *et al.*, 1994). ^{242}Pu spike and a small amount of stable Cs were introduced as yield tracers. Manganese oxide coprecipitates were digested using 6 N nitric acid. After purification through the anion exchange resin, plutonium was plated on stainless steel disc by electro-deposition. The ^{239,240}Pu contents were measured by α-spectrometry (CANBERRA series 35 MCA with PIPS-detectors). After dissolving the AMP precipitates, the contents of ^{137}Cs were measured by γ-spectrometry (CANBERRA series 90 MCA with well-type high purity Ge-detector). The chemical yields are ranged 80 to 96 % (average = 90 ± 4 %). A standard reference solution (Isotope Product Laboratories) was used for calibration of counting efficiency and geometric effect of a γ detector. All errors reported here are one standard deviation from the mean value. For radiometric measurements, propagated errors associated with sampling and detector background are considered. The activities of ^{137}Cs are decay-corrected to the date of sampling.

Precisions of our measurements were also checked using quadruple water samples. The relative standard deviations of the ^{137}Cs and ^{239,240}Pu analysis are 4.3 % and 2.1%, respectively (Table 1). In order to verify the accuracy, a standard reference material and some intercomparison samples were also analyzed. Since seawater reference materials were not readily available, sediments and biological materials were used. Our results agree within 0.08 ~ 1.0 % and 1.4 % to the certified or recommended and measured values in ^{137}Cs and ^{239,240}Pu, respectively (Table 2).

RESULTS AND DISCUSSION

Hydrological data, ^{137}Cs and ^{239,240}Pu activities in the surface and subsurface samples in the East Sea during August 1993 are summarized in Table 3. In general, the surface waters of the East Sea may be characterized into two groups: low temperature, high salinity (T = 16 ~ 20 °C, S = 33.6 ~ 34.5 psu) waters in the north and high temperature, low salinity (T = 21 ~ 24 °C, S = 31.3 ~ 34 psu) waters in the south separated by a polar front at 38 ~ 40 °N in latitude. However, the distribution of ^{137}Cs in the surface seawaters is quite uniform over the entire basin, with average 3.1 ± 0.2 mBq Kg^{-1} (Fig. 2). There was no significant correlation between salinity and ^{137}Cs contents.

There could be several sources of ^{137}Cs into the East Sea such as direct fallout from the atmosphere including the Yellow Dust, riverine input, lateral transport from the ocean, and deliberate disposal as mentioned above.

The direct fallout input affects the distribution of ^{137}Cs in the East Sea as well as the Pacific Ocean. The ^{137}Cs contents of the fallout near the western north Pacific have been measured since the middle of 1950's in Japanese islands (Katsuragi, 1983; Katsuragi & Aoyama, 1986; Hirose *et al.*, 1987; Aoyama *et al.*, 1991). Activities have decreased in time following the maximum level in 1963 (Fig. 3).

Though the Yellow Dust flux to the East Sea varies annually depending upon meterological conditions in or near the source regions and the large scale atmospheric circulation (Gao *et al.*, 1992), the mean flux of the Yellow Dust into the East Sea is about 13 g m^{-2} yr^{-1} (Irino & Tada, 1994). Since, the ^{137}Cs activities in the Yellow Dust are not known, the ^{137}Cs activity of the surface soil was used instead of the ^{137}Cs activity of the Yellow Dust. The ^{137}Cs activity in undisturbed surface soils collected in the Korean Peninsula is about 60 mBq g^{-1} (Lee, 1994). The ^{137}Cs input through the Yellow Dust is estimated from Yellow Dust flux and the activity of the surface soil (0.8 Bq m^{-2} yr^{-1}), which is comparable to the total fallout input in late 1980's (Fig. 3). Direct measurements of radionuclides fallout shows a seasonal peak during the Yellow Dust Storm period in Japan and Korea (Katsuragi & Aoyama, 1986; Lee, 1994). Therefore, the Yellow Dust is likely to be the most important source of ^{137}Cs in this region since the 1980's.

The ^{137}Cs contents in the surface seawaters of the western north Pacific and the East Sea are well correlated with the annual deposition of ^{137}Cs from the atmosphere through direct fallout (Fig. 4). In April 1986 when the accident at Chernobyl nuclear power plant occurred, atmospheric deposition increased, but no response in the surface seawaters of the North Pacific is apparent due to the lack of ^{137}Cs measurements after the accident.

In coastal regions, riverine input could contribute significantly to the ^{137}Cs contents of the seawater (Ohmomo & Nakahara, 1980; Pattenden & McKay, 1994). However, our sampling stations were remotely located from the direct influence of rivers. Consequently, the riverine contributions of artificial radionuclides are not well known in this region.

The lateral transport of seawater to the East Sea is through the Korea Strait from the western north Pacific as a branch of the Kuroshio, the western boundary current of the subtropical circulation of the North Pacific (Nitani, 1972; Huh, 1982; Lie & Cho, 1994). Tsushima Warm Current, a branch of the Kuroshio supplies heat and salt to the East Sea and controls the upper layer circulation in the East Sea (Lie & Cho, 1994). The surface waters of the East Sea can have been refreshed by the western north Pacific surface waters.

The ^{137}Cs contents of the surface seawaters in the western north Pacific and the East Sea have decreased steadily since the middle 1960's to the present levels, about 2 ~ 4 mBq Kg^{-1} (Fig. 5). The measured ^{137}Cs contents in the East Sea during this study (1993) are in the same range. Therefore, the surface water of the East Sea may be regarded as a part of the North Pacific ocean in terms of ^{137}Cs dispersal.

It appears that there are no significant differences between the ^{137}Cs levels in the surface seawaters of the East Sea and the western north Pacific (Nagaya & Nakamura, 1981, 1987; Miyake *et al.*, 1988). In the late 1950's, the ^{137}Cs contents of the western north Pacific surface seawaters were more than ten times higher than the eastern north Pacific (Fig. 5), resulting from the large scale radioactive contamination occuring in the equatorial region of the north Pacific due to nuclear weapon testing. However, as a result of the horizontal movement and mixing of ocean waters, the difference in surface water ^{137}Cs activities between the western and eastern north Pacific has gradually decreased with time, bt the mid-1960's had largely disappeared. Hence, in the past, the ^{137}Cs contents in the East Sea also must have been much higher (more than 20 mBq Kg^{-1}) as was the case in the western north Pacific.

The former Soviet Union and the Russian Federation have disposed 558 TBq of the radioactive wastes in the northern East Sea since 1966 (Yablokov *et al.*, 1993) which may cause a localized elevation of artificial radionuclides disposed. However, contents of ^{137}Cs of the surface seawater are not significantly high even in the dumping zone for radioactive wastes. Although there are also quite a few nuclear power plants along the eastern coast of the Korean Peninsula and the western coast of Japanese Islands, significant contamination of ^{137}Cs released from the nuclear power plants has not been reported.

Therefore, the contents of ^{137}Cs in the surface seawaters in the East Sea and the western north Pacific seems to be primarily controlled by the atmospheric input, that is, direct fallout including the Yellow Dust rather than lateral transport or direct disposal as deliberate dumping of radioactive wastes and discharge from the nuclear power plants. However, the quantitative contribution of the probable individual sources mentioned above cannot be made from these surface data alone since the East Sea has deep basins of more than 3000 m depth, and artificial radionuclides inventories in the bottom sediment are not determined.

The ^{239,240}Pu contents ranged from 6 ~ 10, 9 ~ 26, 18 ~ 35 μBq Kg^{-1} in the surface, 150 m, and 300 m depths, respectively (Table 3). The ^{239,240}Pu contents increase with depth though the ^{137}Cs contents do not change in the upper 300 m depth. If the vertical distribution of ^{239,240}Pu is the same with that of the Pacific or East China Sea, maximum concentrations should appear at around 500 ~ 1000 m depth (Nagaya & Nakamura, 1984, 1992; Miyake *et al.*, 1988).

The ratios of ^{239,240}Pu to ^{137}Cs in the surface seawaters are from 0.002 to 0.003, which are lower than integrated fallout on land (0.006: Miyake *et al.*, 1988). This is most likely due to differences in chemical behavior between plutonium and cesium in seawater. The activity ratio of ^{239,240}Pu to ^{137}Cs in the fallout to the East Sea can be estimated by multiplying scavenging rate constants of plutonium and radio cesium to the ratio in the surface seawater. The scavenging rate constants of plutonium and ^{137}Cs out of the surface mixed layer in the western north Pacific are estimated to be 0.25 and 0.11 yr^{-1}, respectively (Hirose *et al.*, 1992). The activity ratio of these two radionuclides in the fallout should be 0.005 ~ 0.007 (Miyake *et al.*, 1988), which is similar to those of global fallout. It suggests that ^{239,240}Pu and ^{137}Cs are largely from the atmospheric fallout. However, those of subsurface waters are higher than surface waters (0.006 ~ 0.012) because of the difference between the vertical distributions of ^{137}Cs and ^{239,240}Pu. These values are within the same ranges of other studies in this region (Miyake *et al.*, 1988; Hirose *et al.*, 1992; Nagaya & Nakamura, 1992).

The vertical distributions of ^{137}Cs and ^{239,240}Pu must be determined in order to fully understand their behavior in the deep East Sea.

CONCLUSION

^{137}Cs activities in the surface seawater of the entire East Sea have been measured during this study. The ^{137}Cs levels of the surface seawaters are quite homogeneous in the East Sea (average = 3.1 ± 0.2 mBq Kg^{-1}). Since the ^{137}Cs contents in the surface seawater of the East Sea are in the same range as measurements made in the western north Pacific, they might have been as high (more than 20 mBq Kg^{-1}) in the past as those in the western north Pacific. The ^{239,240}Pu activities are 6 ~ 10 and 9 ~ 35 μBq Kg^{-1} in the surface and subsurface waters, respectively, which are in the same ranges as other measurements in the East Sea. The ratios of ^{239,240}Pu to ^{137}Cs in the surface waters vary from 0.002 ~ 0.003. Considering the differnces in scavenging rates between ^{239,240}Pu and ^{137}Cs, these radionuclides are likely to have originated from the global fallout.

The levels of ^{137}Cs and ^{239,240}Pu in the surface seawaters in the East Sea appear to be primarily controlled by the atmospheric input, direct fallout and the Yellow Dust. The effect of deliberate dumping on the ^{137}Cs levels in the East Sea is not immediately apparent in our data, but a conclusive and quantitative assessment will require sampling over the whole water column and in the sediments. Riverine and lateral transport from the ocean into the East Sea appear to be minimal in this study.

Since our measurement was made just two months before the widely publicized 17th October 1993 Russian dumping of liquid radioactive wastes in the northern part of the East Sea, our results may provide background information to assess the immediate impact of Russian dumping on the levels of ^{137}Cs and ^{239,240}Pu in the East Sea.

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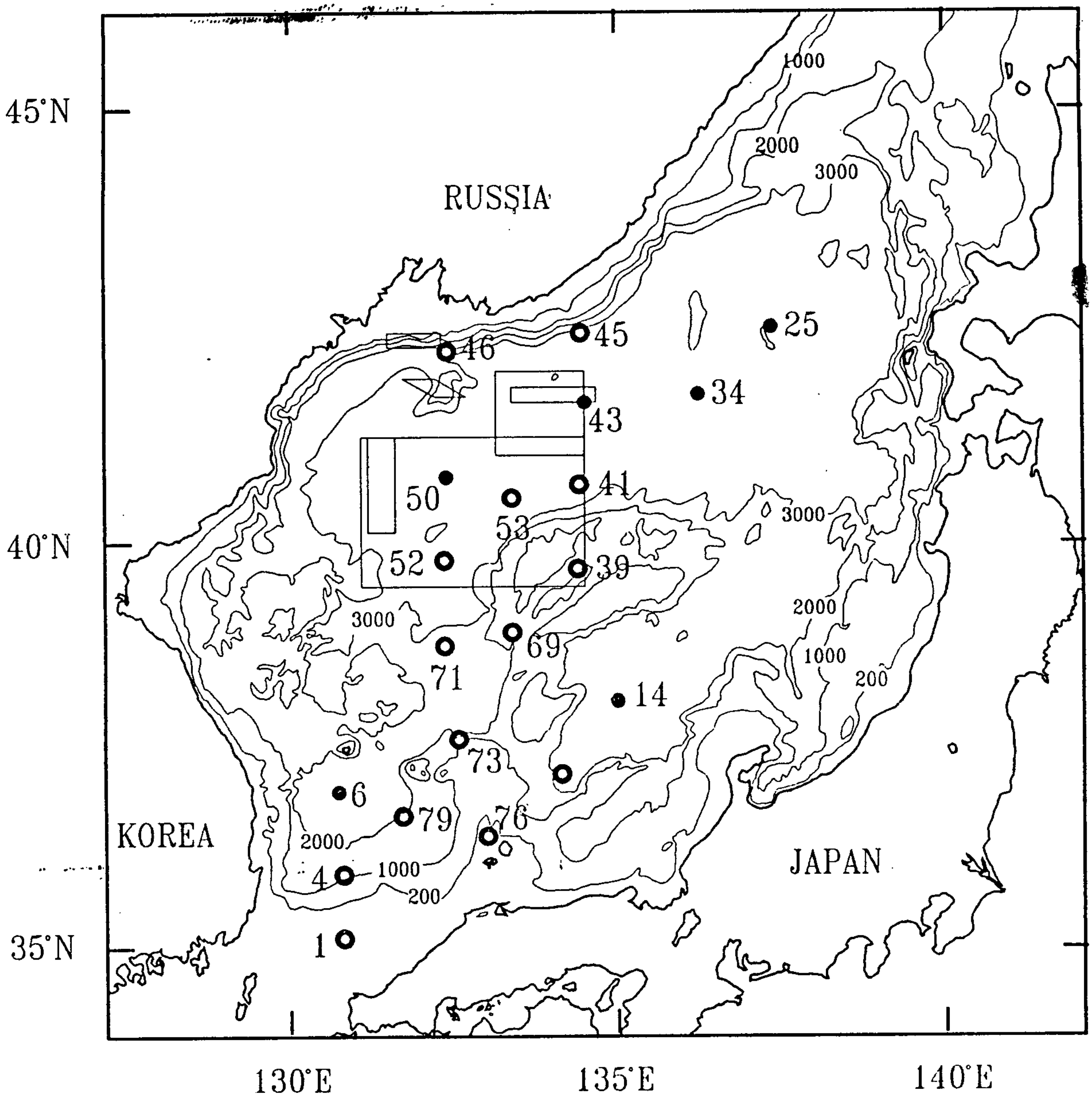

Fig. 1. A map showing the sampling stations and bathymetry in the East Sea (Sea of Japan) during August 1993. The numbers represent the station numbers. Open and closed circles are representative to the stations where sampled at only surface and at 150 m and 300 m depths as well as surface, respectively. The squares drawn in the figure are the former Soviet dumping areas of radioactive wastes over the past thirty years. Isobaths in meters.

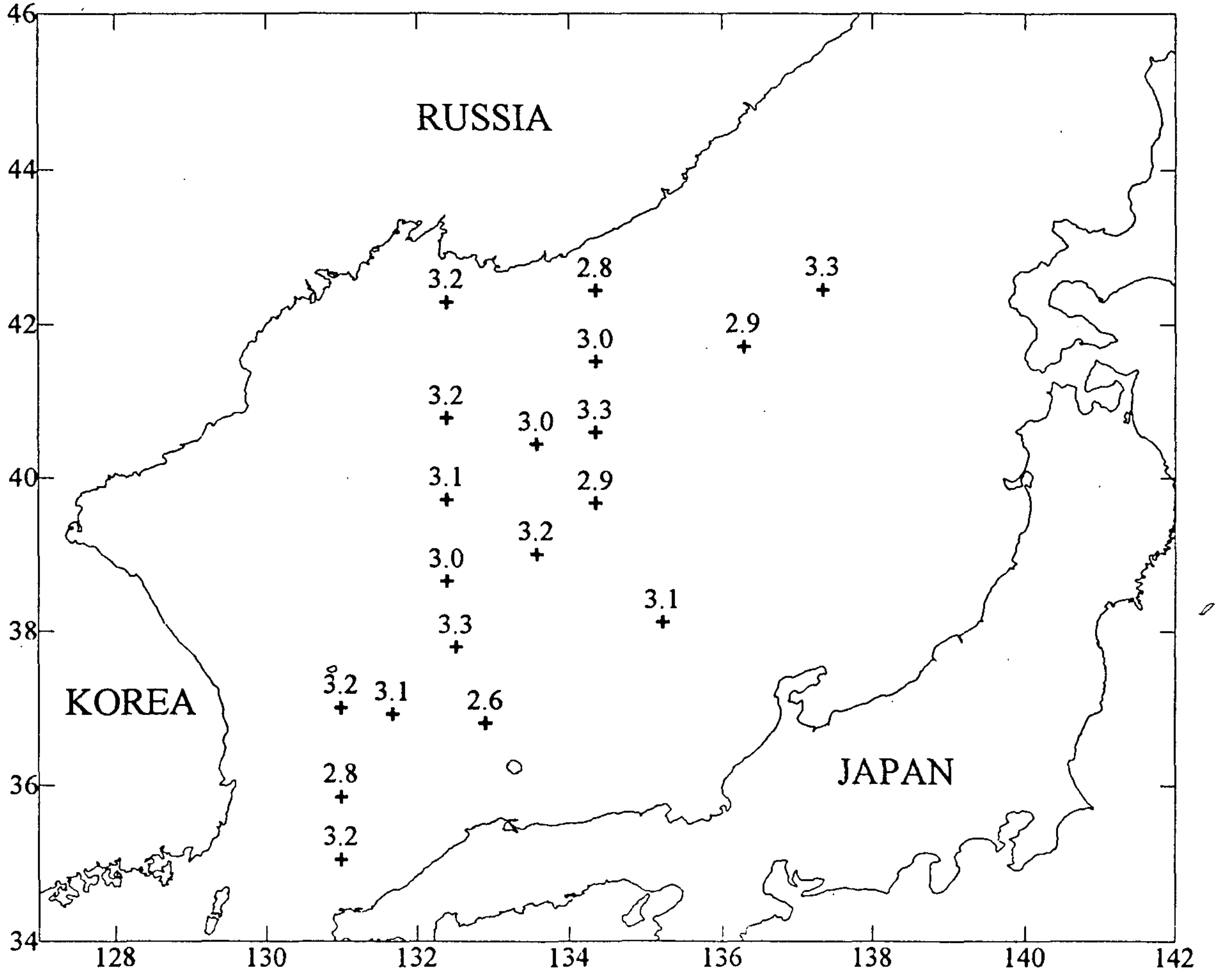

Fig. 2. A map showing the distributions of the ^{137}Cs contents in the surface seawaters of the East Sea. Units are mBq·kg^{-1}.

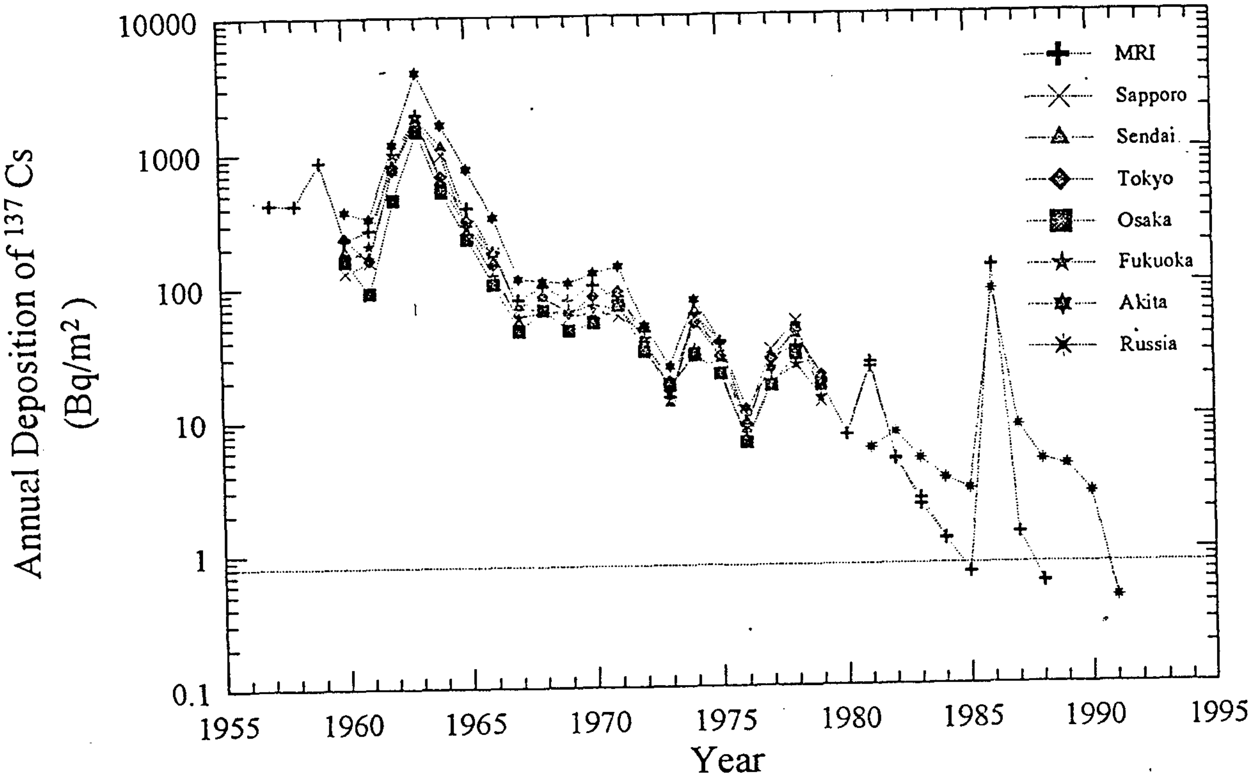

Fig. 3. The secular variation of the annual direct fallout of ^{137}Cs (Bqm^{-2}) at thestations in the Japanese Islands. Data of Meteorological Research Institute (MRI), Japan have been collected in Tokyo from 1957 to 1980, and in Tsukuba Science City since 1980 (Katsuragi & Aoyama, 1986). The data at other Japanese stations are after Katsuragi (1983), Katsuragi & Aoyama (1986), and Aoyama *et al.* (1991). The fallout records of ^{137}Cs in the Russian Far East Region from 1980 to 1989 are also included (Government of the Russian Federation, 1994). Horizontal line represents the estimated ^{137}Cs input through the Yellow Dust deposition(0.8 Bq m^{-2}yr^{-1}).

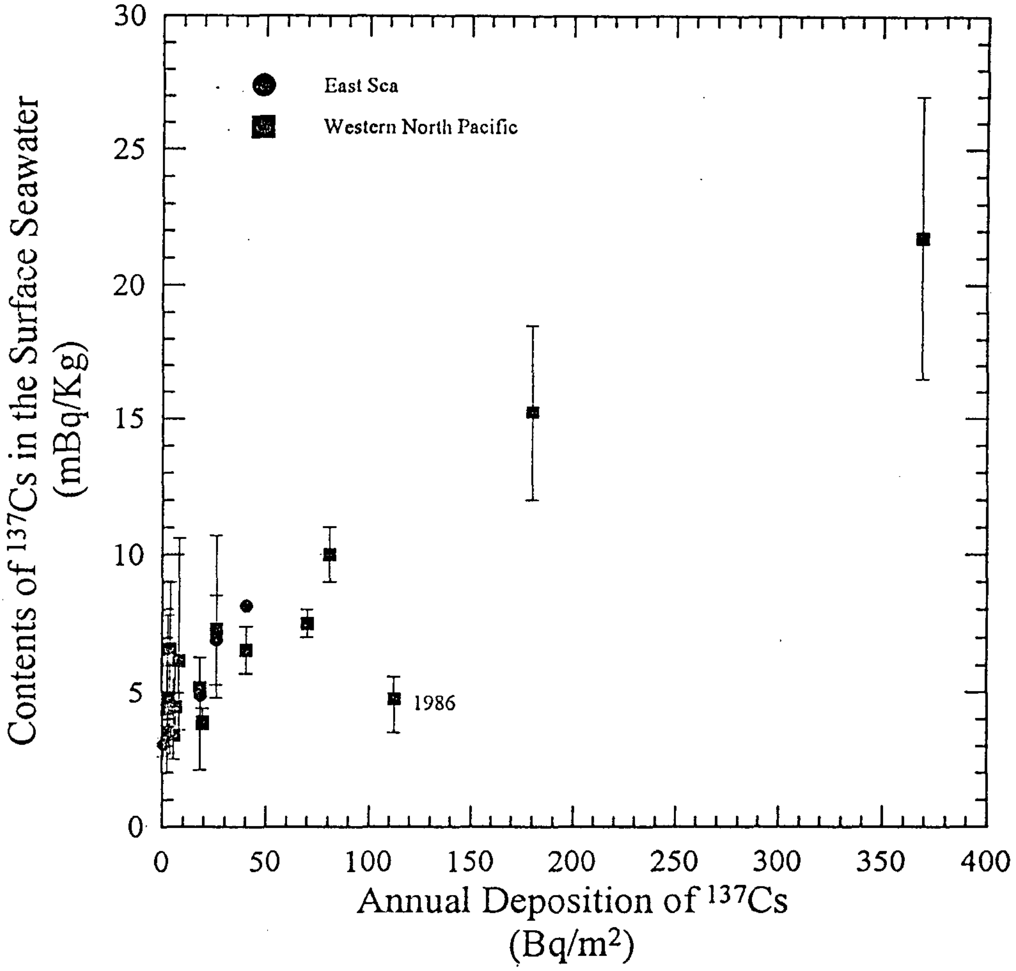

Fig. 4. A plot of ^{137}Cs contents (mBq·kg^{-1}) in the surface seawaters of the western North Pacific (filled square), and the East Sea (filled circle) versus the annual deposition of ^{137}Cs (Bq m^{-2}) through direct fallout. The symbols are representative of the annual mean value. The top and bottom of the error bars represent the maximum and minimum values in each year, respectively.
The values of the Western north Pacific are after Hirose *et al.* (1992), Miyake *et al.* (1978, 1988), Nagaya & Nakamura (1976, 1981, 1984, 1987, 1992), Ohmomo & Nakahara (1980).
Those of the East Sea are after Miyake *et al.* (1988), Nagaya & Nakamura (1981, 1987), and this study.
The sources of annual deposition of ^{137}Cs are same in Fig. 3.

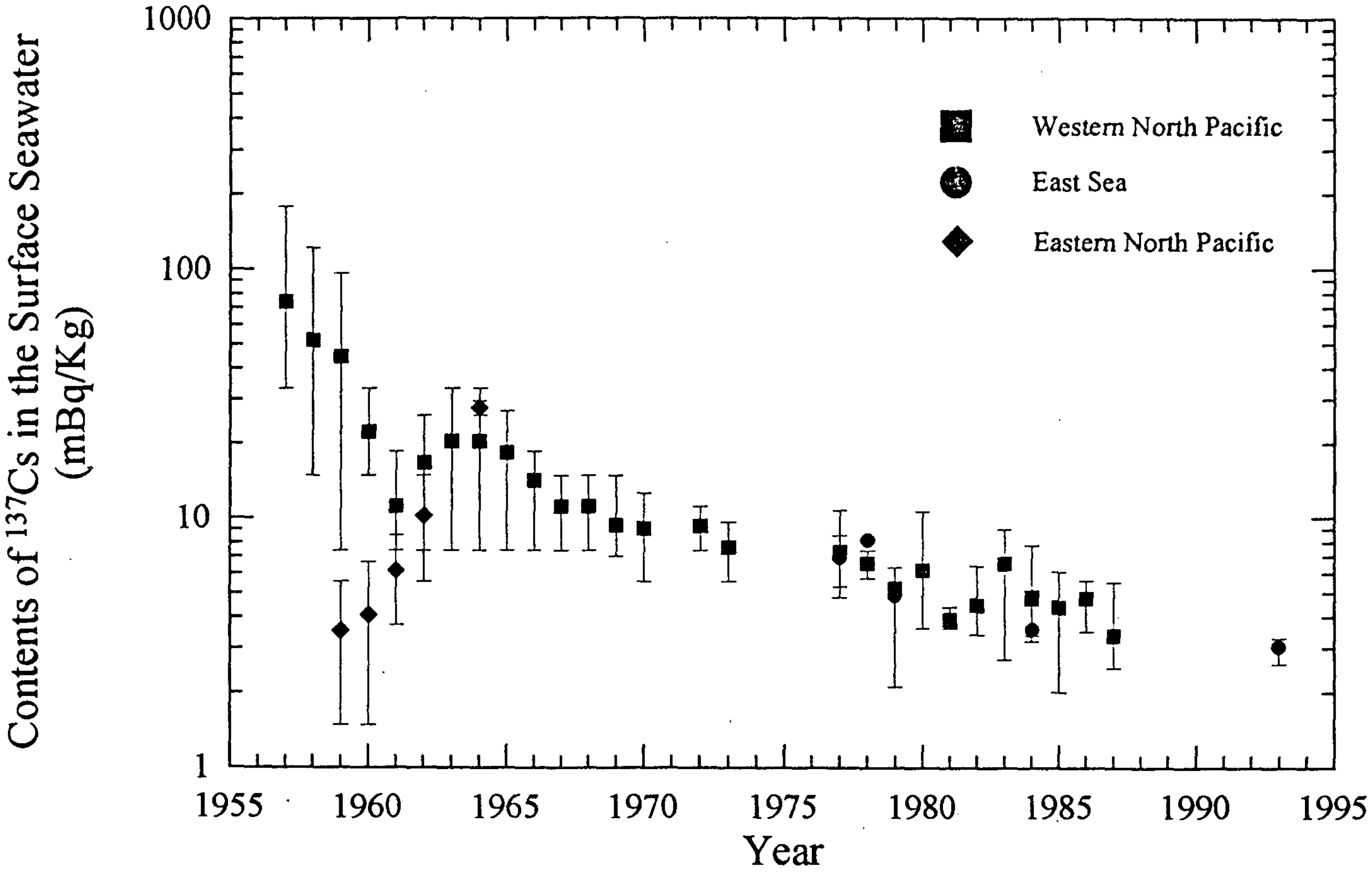

Fig. 5. The variation of the ^{137}Cs contents in the surface waters of the western (filled square), eastern North Pacific (filled diamond), and the East Sea (filled circle) from 1957 to 1993. The symbols represent the mean values in each year. The maximum and minimum values are represented by the error bars. Data sources are the same in Fig. 3.

Table 1. The results of the precision check experiment for the ^{137}Cs and ^{239,240}Pu analysis in seawater. The sample is collected at the coast of the Yellow Sea by water pump. The sample is filtered through 1μm filter.

Trial No.	^{137}Cs (mBq Kg^{-1})	^{239,240}Pu (μBq Kg^{-1})
1	3.0 ± 0.1	1.2 ± 0.5
2	3.1 ± 0.2	1.2 ± 0.3
3	2.8 ± 0.2	1.2 ± 0.3
4	3.1 ± 0.2	
Mean	3.0	1.2
SD.	0.1	0.03
RSD (%)	4.3	2.1

Table 2. The comaprison of ^{137}Cs and ^{239,240}Pu activities of a standard reference material (SRM) and intercomparison samples (ISs) between certified (for SRM), recommended (for ISs) and measured values in this study. The values in parenthesis present the confidence intervals.

Identification	Description of Material	^{137}Cs			^{239,240}Pu		
		Certified (Recommended) Bq Kg^{-1}	Measured Bq Kg^{-1}	Difference %	Certified (Recommended) Bq Kg^{-1}	Measured Bq Kg^{-1}	Difference %
NBS 4350B*	River Sediment	29.0**	30.1 ± 0.8	1.0	-	-	-
IAEA306	Baltic Sea Sediment	201 (194 ~ 206)	200 ± 6	0.7	5.7 (5.5 ~ 6.3)	5.8 ± 0.2	1.4
IAEA134	Marine Cockle Flesh	49.8 (48 ~ 50.6)	50 ± 1	0.4	-	-	-
IAEA135	Irish Sea Sediment	1108 (1086 ~ 1150)	1109 ± 4	0.08	-	-	-

* Standard reference material

** Certified values

Table 3. The sampling date and location, temperature, salinity and the results of radionuclides analysis in the CREAMS 1993 cruise.

ST.	Date yr/mm/dd	Latitude	Longitude	Depth	T °C	S psu	^{137}Cs mBq Kg^{-1}	^{239,240}Pu μBq Kg^{-1}	^{239,240}Pu/^{137}Cs ×1000
1	93/08/29	35° 02.7'N	131° 00.2'E	surface	24.51	31.29	3.2 ± 0.2		
4	93/08/29	35° 50.5'N	130° 59.9'E	surface	21.86	33.23	2.8 ± 0.2		
6	93/08/28	37° 00.0'N	131° 00.0'E	surface	18.09	34.16	3.2 ± 0.2		
				150 m	10.23	34.25		9 ± 1	
				300 m	3.75	34.05	3.0 ± 0.3	18 ± 2	6
14	93/08/14	38° 09.2'N	135° 15.5'E	surface	20.37	33.91	3.1 ± 0.2		
				150 m	3.63	34.08	2.9 ± 0.2	15 ± 1	5
				300 m	0.91	34.07	3.1 ± 0.3	33 ± 2	11
25	93/08/16	42° 28.1'N	137° 23.0'E	surface	17.76	33.86	3.2 ± 0.2	10 ± 1	3
				300 m	0.70	34.07	2.4 ± 0.3	23 ± 2	10
34	93/08/18	41° 42.8'N	136° 17.1'E	surface	16.02	33.54	2.9 ± 0.2		
39	93/08/20	39° 40.4'N	134° 20.8'E	surface	20.43	33.77	2.9 ± 0.2		
41	93/08/20	40° 35.6'N	134° 22.1'E	surface	19.23	33.63	3.3 ± 0.2		
43	93/08/21	41° 30.8'N	134° 21.7'E	surface	15.17	33.55	2.9 ± 0.2	6 ± 1	2
				150 m	1.05	34.07	3.0 ± 0.2	26 ± 1	9
				300 m	0.55	34.07	2.9 ± 0.2	35 ± 3	12
45	93/08/21	42° 26.6'N	134° 20.6'E	surface	18.56	33.36	2.8 ± 0.2		
46	93/08/24	42° 17.3'N	132° 23.4'E	surface	18.18	33.47	3.2 ± 0.2		
50	93/08/25	40° 45.7'N	132° 24.2'E	surface	18.86	33.53	3.2 ± 0.2	7 ± 1	2
				150m	1.34	34.07	3.2 ± 0.3	16 ± 2	5
				300m	0.61	34.07	3.0 ± 0.3	31 ± 3	10
52	93/08/25	39° 42.7'N	132° 23.9'E	surface	20.81	33.58	3.1 ± 0.2		
53	93/08/26	40° 26.7'N	133° 35.4'E	surface	19.80	33.60	3.0 ± 0.1		
69	93/08/27	38° 59.9'N	133° 35.0'E	surface	20.72	34.07	3.2 ± 0.2		
71	93/08/27	38° 38.7'N	132° 23.8'E	surface	20.89	34.54	3.0 ± 0.2		
73	93/08/27	37° 47.6'N	132° 31.6'E	surface	20.36	33.68	3.3 ± 0.2		
76	93/08/27	36° 48.4'N	132° 53.9'E	surface	22.89	31.87	2.6 ± 0.2		
79	93/08/28	36° 55.6'N	131° 40.7'E	surface	20.33	33.13	3.1 ± 0.2		

제 4 장 동해동물플랑크톤에 함유된 $^{239,\ 240}Pu$ 분포특성

동해 동물플랑크톤에 함유된 $^{239,\ 240}$Pu의 분포 특성

^{239,240}Pu activities in zooplankton in the East Sea (Sea of Japan)

Abstract

Results of the radiochemical determination of $^{239,\ 240}$Pu in zooplankton were determined from the East Sea (Sea of Japan) in 1993 (AW9310) and 1994 (N9403). The contents of $^{239,\ 240}$Pu in zooplankton ranged from 0.20 ±0.04 to 0.64±0.08 Bq/kg, mean concentrations being 0.39 ± 0.04 Bq/kg (AW9310), those in N9403 were 0.08±0.01 ~ 0.39±0.08 Bq/kg, mean concentration being 0.15 Bq/kg (uncorrected for salts). the data are compared with those obtaind from other seas (Northeastern Pacific, Mediterranean Sea, Ionian Sea) , the contents of $^{239,\ 240}$Pu in zooplankton in the East Sea are lower than the Northeastern Pacific whereas are higher than other seas. Concentration Factor (CF) of the East Sea sample were determined to be 0.7×10^3 ~ 2.25×10^4, which are consistent with Pacific but showed somewhat high value than the IAEA data (1×10^3).

I. 서 론

Transuranic 핵종 ($^{239,\ 240}$Pu 와 ^{241}Am) 은 과거 40 여년동안 해양 환경의 주요오염원으로서 존재해 왔다. 이들은 반감기가 10^2 년 이상이며 수괴내에서 입자성 물질과 높은 친화력을 갖고 있고 해양 생물에 농축되는 원소들로 알려져 있다 (Pentreath 1981). 해양 환경에서 원소 순환및 분포는 그 해역에 존재하는 생물상

에 의하여 영향을 받으며, 특히 동물플랑크톤은 친입자성 원소들의 체류 시간과 수직 분포를 결정해주는 중요한 기여자이다(Fowler 1982, Fowler & Knauer 1986).

동물플랑크톤은 수괴속에 있는 친입자성 원소를 먹이와 함께 섭취한다. 만약 이들 원소들이 체내에서 동화된다면 표층에서 재순환되어 긴 체류시간을 갖게 되고, 동화되지 않고 곧바로 배출된다면 훨씬 짧은 체류 시간을 갖게된다. 한편 동물플랑크톤 분변립 (fecal pellets) 은 표층에서 친입자성 원소들을 응집시켜 빠르게 심층수로 침강된다. 침강도중이나 해저/해양경계면에 도달한 후 친생물 원소 재분해나 용해등에 의하여 수층에서 재생되기도 한다. 따라서 친입자성 원소의 농도는 심층수에서 증가하게 된다 (Broecker and Peng 1982, Fisher *et al,* 1983b).

본 연구의 목적은 $^{239,\ 240}$Pu 핵종의 동해에서의 분포양상 및 거동을 이해하기 위한 기초작업의 일환으로 동물플랑크톤 체내 함량을 정량하고 생물 농축 인자를 평가하여 $^{239,\ 240}$Pu 방사능 생태 영향을 평가하고 Pu 와 화학적 성질이 비슷한 금속 원소들의 동해에서의 거동 이해의 기초자료를 제공하는 것이다.

II. 재료및 방법

i. 동물플랑크톤의 채집

1993년 10월과 1994년 4월 2차에 걸쳐 동해의 동물플랑크톤에 존재하는 $^{239,\ 240}$Pu 의 분포를 알아보기 위하여 시료를 채취하였으며 채취위치를 Fig. 1. 에 표시하였다. 1993년 10월 (AWARES9310) 시료를 봉고 채집망 (Bongo net: 망목 250 ㎛) 과 IKMT (Isaacs-Kidd midwater trawl) 를 사용하여 3정점에서 경사 채집하였다.

1994년 4월 시료는 동해상의 구쏘련 및 러시아의 방사성 투기지정해역 총 5 개 해역에 대하여 7개의 조사 정점을 선정하고 투기 해역의 방사능 오염 정도를 비교하기 위하여 동해내에서 투기 지점으로부터 원거리에 위치한 2 개 정점을 선정하여 비교 정점으로 취하였다. 각 정점에서 동물 플랑크톤 시료는 쥬데이 플랑크톤

채집망 (Juday Plankton Net: 구경 37 cm, 망목 168 ㎛) 으로 수심 200m 에서 표층까지 6회 예인하여 채취하였다. 채집 직후 동물 플랑크톤 시료는 분석전까지 냉동 보관하였다.

ii. 실험 방법

1. 전처리

1) 냉동건조시킨 시료 (1-20g) 를 곱게 빻아서 무게를 달아 수 g의 oxalic acid 와 함께 도가니에 담아 전기로에 넣고 온도를 점진적으로 550℃까지 올린 다음 24시간 동안 태워준다.
2) 시료에 적당량의 tracer ^{242}Pu (20mBq) 를 넣고 8N HNO_3를 넣어 시료와 잘 섞어준 후 가열해 준다. 시료를 충분한 양으로 씻어 비이커에 옮긴다.
3) 용해시키면서 H_2O_2 몇 방울을 첨가 하며 저어 준다. acid 50ml 당 $NaNO_2$ 100mg 을 넣어주고 천천히 가열해준다. 그 다음 ion exchange 과정으로 들어 간다.

2. PLUTONIUM 분리

1) 증류수와 anion exchange resin (AG1X8, 100-200 mesh) 를 잘 섞어 column (diameter 0.8 cm, height 10 cm) 을 채운 후 증류수 30 ml 로 씻어준 후 8 M HNO_3 50 ml 를 흘려서 resin 을 conditioning 시킨다.
2) 시료를 1 - 2 ml/min. 의 속도로 column 을 통과 시킨다. 8 M HNO_3 80 ml 를 시료와 같은 속도로 column 을 통과시켜 column 을 씻어준다.
3) 100 ml 의 10 M HCl 를 사용하여 resin 을 씻고 나중에 Plutonium 의 회수율이 안 좋을 경우 다시 column work 을 하기 위하여 씻은 용액을 보관한다.
4) 100 ml 의 9 M HCl - 0.1M NH_4I (실험 직전에 준비) 로 Plutonium 을 용리 (elute) 시킨다. 용리 (elute) 시킨 용액을 100ml 비이커에 담아 hot plate 에서 거의 증발시킨 후에 여분의 iodine을 제거하기 위하여 conc. HNO_3 5 - 10 ml 를 부은 다음 H_2O_2 를 여러 방울 가하면서 증발시킨다. iodine 의 갈색이 남아 있으면 이 과정을 반복한다.

5) 다시 한번 purification 과정을 거치면 더 좋은 결과를 얻을 수 있다. 4) 에서의 용액을 dryness 로 만든 다음 10 M HCl 에 녹이고 5 cm AG1X8 resin column 에 통과시킨다. 이 단계를 마친 후에 electrodeposition 과정으로 들어간다.

3. ELECTRODEPOSITION

1) plutonium elutes에 0.3M Na_2SO_4 1ml를 넣어주고 증발시킨다.
2) conc. H_2SO_4 300㎕ 를 넣어주고 시료가 녹아 하얀 fume이 나타날 때까지 가열한다.
3) 4 ㎖의 H_2O 를 가하고 thymol blue 2 방울를 넣어준다. NH_4OH 를 사용하여 pH 2 (orange) 로 맞추어준다.
4) 시료를 electrodeposition cell (stainless steel disc가 담긴) 로 옮긴 다음 1 % H_2SO_4 5 ml 를 사용하여 원래의 비이커를 잘닦아 cell 에 옮긴다. 그 다음 ammonia 를 이용하여 pH 2.1-2.4 로 맞춘다. 총 부피는 20 ㎖ 를 넘지 않도록 한다.
5) anode (platinum rode) 를 disc 에서 3 mm 간격으로 떼어놓는다.
6) 1 시간동안 1A (Ampere) 에서 electroplating 하고 종료 1분전에 conc. NH_4OH 1 ㎖ 를 넣어준다.
7) disc 를 1 % ammonia 로 닦아 주고 aceton 으로 닦은 다음 disc 끝에 종이를 대고 aceton 을 흡수한다. disc 를 천천히 가열하여 말린다.
8) 이 disc 를 alpha spectrometry 에 넣고 계수한다.
Note: 시료를 electrodeposition 하기전에 electrode 의 clean-up 을 위하여 시료와 똑같은 조건하에서 blank solution 으로 electroplating 해준다(Lovett *et al* 1990, Volchok & Planque 1983, Wong, K. M. 1971). 플루토늄분석을 flow chart Fig. 2. 에 도시하였다.

4. 표준물질 검증

본 시료 분석 방법의 검증을 위하여 표준 물질 IAEA134 (생물시료 : cockle fresh) 와 IAEA135 (sediment) 를 함께 분석하여 정확도와 정밀도를 측정하였으며 그 결과는 다음과 같다(Table. 1).

Ⅲ. 결과 및 고찰

1. 동해의 생물학적 생산량

동해에서 1차 생산량을 조사해 보면 지역에 따라 크게 2 부분으로 구분된다. 즉, 동해의 북서부 해역은 높은 생산량을 보이고 남동해역은 낮은 생산량을 보인다. 1차 생산량의 연간 평균 생산율은 75 - 100 g C $m^{-2}yr^{-1}$ 이며 순 (net) 1차 생산량은 0.9 - 1.3 (wet wt. 10^{9}t yr^{-1}) 이다(Koblentz - Mishke, 1965 ; Sanger, 1972 ; Taniguchi, 1972, 1973 ; Fukataki , 1974). 식물플랑크톤의 밀도는 남동 온수 해역 (10^{3} - 10^{5} cells ℓ^{-1}) 보다 북서 냉수해역 (보통 10^{2}-10^{3} cells ℓ^{-1}) 에서 낮다. 또한 분포밀도에 있어 계절별 최대량과 최소량과의 비는 남동 온수해역(약 200) 보다 북서 냉수해역 (약 50) 에서 작으며 계절별로 보면 가을과 겨울보다 봄과 여름에 더욱 그 차이가 크다 (Ohwada and Ogawa, 1966). 냉수 지역의 규조류의 소규모발생은 동해의 1차 생산량의 공간적 분포와는 반대의 모습을 보인다. 한편 동물플랑크톤의 생물량 (Biomass) 은 남동지역보다 북서 지역에서 크며 양 지역 모두 봄에 최대량이 관측되었다 (Nishimura, 1983).

이 지역의 동물플랑크톤를 구성하는 주요 종은 요각류 *Calanus plumchrus, Calanus cristatus,* 유파우시아류 *Euphausia pacifica, Thysanoessa longipes,* 부유성 단각류 *Parathemisto japonica* (Morioka, 1975) 이며 이 중 특히 *Calanus plumchrus* 는 가장 풍부한 종으로서 동해의 중앙부에 존재하는 총 동물 플랑크톤의 65 ~ 90 % 를 차지한다(Nakai, 1942; Meshcheryakova, 1960).

일반적으로 동해의 동물플랑크톤 계절 변동은 북서태평양과 일치한다. Morioka (1976)는 동해 동물플랑크톤의 생물량을 북서 냉수괴역 (northwestern coldwater) 과 남동 온수괴역 (southeastern warmwater) 으로 구분하여 조사했는데, 북서 냉수지역 (평균 118.25 mg wet wt. m^{-3}) 이 남동 온수지역 (평균 52.25 mg wet wt. m^{-3}) 보다 2 배이상 높은 값을 보였다. 얕은 깊이 (shallow depth) 에서 동물플랑크톤 유생은 식물 플랑트톤을 포식함으로 빠르게 성장하여 immature 단계에 이르게 된다. 그다음 이들은 bathypelagic level로 가라앉고 그곳에서 그들 일생의 가장 긴 시간을 보내며 성숙된다. 동해 북서지역은 동해 남동지역보다 식물플랑크톤

의 생물량 (biomass) 이 적은데 이는 식물플랑크톤 bloom이 초식성 동물플랑크톤 성장과 일치하고 남동지역에서는 일치하지 않기 때문이다 (Nishimura, 1965).

2. 동물 플랑크톤의 $^{239,\ 240}$Pu 분포

1993년 10월 (AW9310) 에 채취한 동물플랑크톤의 Pu 농도 분포를 보면 일본분지 동부 (정점1) 에서 0.33±0.09 Bq/kg 의 분포를 보였고, 야마토 해령 (정점2) 에서 0.20±0.04 Bq/kg 의 분포를 보였다. 또한 한국 대지 (Korea plateau) (정점 4) 에서 가장 높은 0.64±0.08 Bq/kg 의 농도를 나타냈으며 평균 농도는 0.39±0.04 Bq/kg 이다(Table. 2).

채집된 동물플랑크톤은 3정점 모두 Euphausia 와 Hyperiid, Copepode 가 우세하게 나타났다. 각 종에 따른 농도 분포특징을 보면 Euphausia 가 Hyperiid 나 Copepode 보다 낮은 농도 (0.11±0.03~0.35±0.08 Bq/kg) 를 보였고 Copepode 가 가장 높은 농도 (1.14±0.28 Bq/kg) 를 나타냈으며 Hyperiid 가 비교적 높은 값 (0.29±0.09~1.08±0.27 Bq/kg) 을 보였다(Table. 3).

1994년 3월 (N9403) 동해북부 일본분지 서쪽에서 조사된 동물플랑크톤의 각 정점별 $^{239,\ 240}$Pu 농도 변화를 보면 0.08±0.01~0.39±0.08 Bq/kg 의 분포를 보였으며 평균 0.15 Bq/kg 을 나타내었다. 정점 2에서 0.39 Bq/kg 으로 가장 높은 값을 보였고 정점 6에서 가장 낮은 0.08 Bq/kg 의 값을 보였다. 그러나 정점 2와 6을 제외한 전 지역에서 비교적 고른 분포(0.10~0.14 Bq/kg) 를 나타내었다(Table 4). ^{238}Pu 은 시료양이 타 정점보다 많은 정점 BG2 에서만 검출되었는데 농도는 0.01 Bq/kg 이며 ^{238}Pu/$^{239,\ 240}$Pu 비는 0.083으로 나타났다. N9403 의 분석결과는 AW9310 시료보다 약 2 배 적은 양이 검출되었는 데 이는 N9403 의 시료분석시 염분보정을 하지 못한 결과에서 비롯되었다. 따라서 실제 농도를 알 수 없으나 같은 지역의 동물플랑크톤 시료 다량을 실험실에서 수차례 염분 보정해 본 결과 50-60 % 가량의 염분이 함유되어 있는 것으로 나타나 분석값보다 실제로 약 2 배 이상의 값을 보일 것으로 생각된다. 그러므로 실제로는 농도값이 거의 차이가 나지 않는 것으로 보인다. 동해 각 정점별 동물플랑크톤과 해수에서의 플루토늄 상관관계를 구하여 본 결과 뚜렷한 상관성을 보여주지 않아(R= 0.24) 해수의 Pu 농도가

동물 플랑크톤의 Pu 농도에 직접적인 영향을 미치지 않는 것으로 나타났다.

동해의 동물플랑크톤의 ^{239,240}Pu 함량(AW9310)은 지중해보다는 24배 높으나 북동태평양에서 보고된 값보다는 약간 낮은 값을 보였으며(Table. 5), Pu의 함량은 해역에 따라 비교적 큰 차이를 나타냈다. 제한된 자료이나 동해 전체 동물플랑크톤에 함유된 Pu량은 동해의 동물 플랑크톤 생물량, 동해체적, 동물플랑크톤 Pu 함량에 의거하여 평가하면 총 9.04×10^9 Bq 이다. 여기서 동물플랑크톤 생물량은 85.25 mg wet wt·m^{-3} (Morioka, 1976), 동해체적은 1.36×10^6 km (Tokyo Astronomical Observatory, 1978) 이고 평균 동물 플랑크톤 Pu 함유량은 0.39 Bq/kg (건중량 기준), 건중량 Pu 함량의 20 % 를 습중량 Pu 함량으로 환산하였다 (IAEA, 1985).

3. 농축 인자(Concentration Factor)

플랑크톤은 해수내 방사성핵종과 미량원소들을 그들의 세포막을 통하여 흡수하거나 그들의 몸표면에 흡착시켜 받아들인다. 그리고 이 원소들은 세포막 교환과정을 통하여 정상상태 (steady state) 인 동위원소 평형 (isotopic equlibrium) 에 도달한다. 유기물내 물질 농도와 해수의 물질 농도와의 관계, 즉 입자상 (particulate phase) 과 용존상 (dissolved phase) 관계는 분배 계수 (K_d : distribution coefficient) 로 나타내어진다. 또한 생물체내 물질의 농축의 경우 같은 개념인 농축 인자 (CF : concentration factor) 를 쓴다. CF는 해수속의 핵종 농도와 생물체간의 함량비를 나타내는데 이 때, 생물체는 습중량 (wet weight) 을 기준으로 한다. 본 시료는 건중량 (dry weight) 을 기준으로 분석한 시료이기 때문에 IAEA에서 권장한 방법 (건중량×0.2) 으로 환산하여 습중량의 농도를 구하였다(IAEA, 1985).

동해 일본분지 서부, 야마토 해령, 한국 대지의 93년 10월의 경우 해수중 Pu 함량이 3.9~5.7 μBq/kg (Hong *et al.*, unpublished data) 으로 CF값은 1.1~2.3×10^4 이고 94년 동해 북부에서는 해수중 Pu 함량이 평균 20 μBq/kg (3국 공동조사, 미발표) 으로 CF는 1.5×10^{3}이었다(Table. 6, 7). 94년 3월 동해북부시료의 CF값이 93년 10월 시료보다 작은 것은 염분 미보정과 겨울철 수직 혼합으로 말

미암아 고 (high) Pu 함유 중층수가 표층으로 용승하여 표층해수의 Pu 함량을 증가시켰기 때문이다.

AW9310 시료의 CF는 태평양 동물플랑크톤의 CF값과 거의 유사한 값 (Fowler, 1983) 을 보였으나 IAEA TEC-DOC-211의 자료에서 이는 일반적인 동물플랑크톤의 CF값 (1×10^3 IAEA, 1985) 보다는 다소 높은 결과를 나타내었다. N9403의 CF값은 Macrozooplankton (Euphausiids: 1×10^2 Fowler, 1990) 보다는 훨씬 크고 Phytoplankton ($3 \times 10^4 \sim 6 \times 10^5$ Fisher *et al.*, 1983) 보다는 작으며, 주로 copepods로 구성된 microplankton값 (5×10^3 Fowler, 1990) 과 상당히 유사한 값을 보여주었다.

각 해역간의 CF값의 차이는 다음과 같은 이유로 설명될수 있다. CF값은 동물플랑크톤 생명현상 즉 흡수 (uptake) 와 배설 (excretion) 이 주위 환경인자, 식물플랑크톤양, 체형 (body size) 과 온도, 빛, 염분에 따라 영향을 받기 때문이다. 또한 핵종의 흡수 반응 (uptake process) 에 결정적인 영향을 주는 것은 표면적 (surface area) 이다. Fisher (1987) 등은 핵종의 흡수 반응 (uptake process) 에 있어 표면적의 중요성을 규명하기 위하여 미세한 식물플랑크톤에서부터 copepods, euphausids 류 같은 생물까지 다양한 타입의 플랑크톤 표면적과 초우란 핵종 (transuranic) 흡수 관계를 조사하였는데 그 결과 Am, Pu, Cm의 경우 뚜렷한 상관 관계를 보여 윗 사실을 뒷받침하였다. 따라서 각 정점간의 CF값의 차이는 이러한 복합적인 영향으로 결정된다.

4. 농축 인자와 먹이사슬

오염인자와 유기물 분석에 있어서 가장 커다란 과제는 먹이 사슬에 대한 생물농축이다. 많은 연구가 먹이사슬를 통한 오염물의 생물 농축에 관하여 진행되어왔다. 이는 오염물이 생물들에 의하여 섭취되고 그 생물들은 다른 생물에 의하여 포식당하고 결국은 최상위포식자 (top predator) 인 인간에게 영향을 준다는 것으로서 이 연쇄적인 먹이사슬 과정을 통하여 상위 포식자로 갈수록 높은 농도를 나타낸다. 해양에서 생물 농축 (biomagnification) 의 대표적인 미량 원소는 methyl-Hg으로서 이 원소는 해양생물에 의하여 섭취되면 배설되지 않고 체내에 축적된다. 또한 방사

성 동위원소중 ^{137}Cs은 칼륨 (K) 과 유사한 행동양식을 갖고 있으며 특히 담수 (fresh water) 생물에 그 영향이 크다 (Thomann, 1981). Fowler (1982,1990) 는 생물 기원 입자와 동물 플랑크톤의 Pu함량을 분석하였는데 동물플랑크톤의 Pu 함량이 분변립 (fecal pellets) 등 생물 기원 입자의 Pu농도보다 훨씬 낮음을 보여주었다. 이는 Pu이 신진대사적으로 꼭 필요한 원소가 아니기 때문에 섭취하는대로 곧바로 분변립형태로 배출하기 때문이다. Fowler는 체내에 들어온 Pu 의 90 % 이상이 배출되고 축적되는 양은 10 % 에도 못미친다고 보고 하였다. 또한 동물플랑크톤에 존재하는 대부분의 Pu 은 체내보다는 외피에 흡착되어있다고 보고되었으며 식물플랑크톤이 동물플랑크톤보다 Pu 함량이 높은 것은 식물플랑크톤이 Pu을 더 많이 흡수하기보다는 동물플랑크톤보다 단위 무게당 표면적이 커서 흡착 되는 양이 많기 때문으로 알려졌다.

Broecker 등은 (1982) 일반적으로 lanthanides, actinide 계열의 원소들은 강한 친입자성으로 화학적으로 hydrolysis 성질을 갖고 있고 식물플랑크톤의 세포질 속에 직접 침투하지 못하며 동물플랑크톤 체내 잔류시간 (retention time) 은 매우 짧다고 하였다. 대기나 강 또는 투기등에 의하여 수괴속에 유입된 Pu 은 일차적으로 용존된 형태로 미소 플랑크톤 (microplankton) 같은 작은 생물에 의하여 흡수되고 동물 플랑크톤이 이를 포식함으로서 보다 농축되어 거대 입자인 분변립 (fecal pellets) 로 배설된다. 분변립은 밀도에 따라 다르나 최고 2700 m/일 규모의 빠른 속도로 침강하여 효과적으로 표층수에 유입된 Pu 을 심층수로 이동시키고 해저 퇴적물에 축적시키는 중요한 역할을 한다 (Fowler 1987). La Rosa (1986) 등은 생물학적 활동에 의한 핵종의 속성 제거 (rapid removal) 를 연구하기 위하여 지중해에서 동물플랑크톤 배양기기를 사용하여 플랑크톤과 분변립 (fecal pellets) 을 채집하였다. 실험 결과 체르노빌사건을 통하여 대기로 방출된 핵종이 지중해에 도달한뒤 해수 속의 동물플랑크톤에 의하여 포집되어 분변립 (fecal pellets) 형태로 배출되고 침강하여 저층에 공급시키는 주요 역할을 함을 저층에 설치한 퇴적물 트랩 (sediment trap) 을 이용하여 밝혀냈다. 이는 Copepode의 포식 (grazing) 과 이에 따른 분변립 (fecal pellets) 이 수괴속에서 방사능의 수직 이동에 중요한 기구임을 증명한 것이다. 따라서 Pu 의 수괴내 이동과 순환을 이해 및 감시하기 위하여서 친생물입자와 동물플랑크톤의 정보가 항시 제시되어야 함을 보여준다.

Ⅳ. 결 론

동해에서 ^{239,240}Pu 의 분포양상 및 거동을 이해하기 위하여 동물플랑톤의 체내 Pu 함량을 정량하고 생물 농축인자를 구하여 ^{239,240}Pu 방사능 생태 영향을 평가하였다. 분석 시료는 각각 1993년 10월과 1994년 3월 채집하였고 일부 정점 시료는 종분류를 하여 분석하였으며 그외 시료는 혼합하여 분석하였다.

분석 결과 1993년 10월에 채집한 시료 (AW9310) 는 0.20±0.04 ~ 0.64±0.08 Bq/kg 의 범위를 나타냈으며 평균 농도는 0.39±0.04 Bq/kg 이었다. 종분류 분석결과 Euphausia와 Hyperiid, Copepode가 우세하게 나타났으며 Copepode (1.14±0.28 Bq/kg) 가 Euphasia (0.11±0.03 ~ 0.35±0.08 Bq/kg) 와 Hyperiid (0.29±0.09 ~ 1.08±0.27 Bq/kg) 보다 높은 농도를 보였다. 1994년 3월 (N9403) 동해 북부 일본분지 서쪽에서 조사된 동물플랑크톤의 각 정점별 ^{239,240}Pu 농도는 0.08±0.01 ~ 0.39±0.08 Bq/kg 의 분포를 보였고 평균 0.15 Bq/kg 의 농도를 나타냈다. 이 값은 염분보정을 하지 않은 것으로 실제 농도는 이보다 2 배이상 높을 것으로 사료된다. 동해의 동물플랑크톤의 ^{239,240}Pu농도는 북동태평양에서 조사된 값보다는 다소 낮으나 지중해나 이오니안해보다는 크게 높았다. 또한 농축인자 (Concentration Factor) 는 $0.7\times10^3 \sim 2.25\times10^4$ 으로 북동태평양의 동물플랑크톤 값과 유사하나 IAEA에서 보고한 일반적인 동물플랑크톤의 CF 값 (1×10^3) 보다는 다소 높았다.

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Table 1. Intercomparison of IAEA recommended values and measured values for standard reference materials.

IAEA 134 (cocklefresh)

recommended value	confidence interval	sample No.	measured activity (Bq/kg)	accuracy (%)	precision (%)
		$^{239,\ 240}$Pu-1	15.2±0.6		
		2	15.4±0.5		
15	13.8-16.2	mean	15.3±0.5	2	0.9
		^{238}Pu-1	3.0±0.1		
		2	3.1±0.1		
3.1	3-3.4	mean	3.1±0.1	0	2.3

IAEA 306 (sediment)

recommended value	confidence interval	sample No.	measured activity (Bq/kg)	accuracy (%)	precision (%)
		^{239,240}Pu-1	5.8±0.2		
		2	6.0±0.3		
		3	6.0±0.2		
5.7	5.5-6.3	mean	5.9±0.2	3.5	1.9
		^{238}Pu-1	0.15±0.2		
		2	0.17±0.3		
		3	0.19±0.2		
0.17	0.14-0.19	mean	0.17±0.2	0	11.7

Table 2. $^{239,240}Pu$ mean concentrations of zooplankton in the East Sea.(AW9310)

Station	Latitude(north)	Longitude(east)	Depth(m)	$^{239,240}Pu$(Bq/kg)	^{238}Pu(Bq/kg)
1	41° 00	136° 17	3300	0.64±0.08	
2	39° 67	134° 33	1650	0.20±0.04	
4	38° 00	129° 00	1002	0.33±0.09	

Table 3. Contents of $^{239,240}Pu$ in various marine zooplanktons from the East Sea(AW9310). (Bq/kg dry wt.)

Sample station	Plankton identification	Activity(Bq/kg)
1(Japan basin)	Euphausia	0.18±0.04
	Hyperiid	0.47±0.14
2(Yamato trough)	Euphausia	0.11±0.03
	Hyperiid	0.29±0.09
4(Korea plateau)	Euphausia	0.32±0.10
	Hyperiid	0.72±0.28

Table 4. ^{239,240}Pu mean concentrations of zooplankton in the East Sea.(N9404)

(uncorrected for salts)

Station	Latitude(north)	Longitude(east)	Depth(m)	^{239,240}Pu(Bq/Kg)	^{238}Pu(Bq/Kg)
1	41° 55	133° 15	3200	0.13±0.04	
2	41° 40	133° 50	3200	0.39±0.08	
3	41° 55	134° 20	2500	0.12±0.09	
4	41° 05	134° 20	3100	0.10±0.04	
5	41° 05	133° 15	3400	0.16±0.04	
6	41° 55	132° 00	3100	0.08±0.01	
7	42° 19	132° 19	2500	0.14±0.04	
BG1	40° 47	134° 52	3245	0.14±0.05	
BG2	38° 00	134° 57	2990	0.12±0.01	0.01±0.00

Table 5. Mean concentration of ^{239,240}Pu in zooplanktons of the various seas.

Sites	sample	Activity(Bq/Kg)	sampling date	Reference
Vertex I (Northeastern Pacific)	Zooplankton	0.481	1980	Fowler *et al* 1983.
Ionian Sea	Zooplankton	0.015	1975	Triulzi & Marchionni 1982
Mediterranean Sea	Zooplankton	0.016	1986.5	Fowler *et al.,* 1987.
East Sea(AW9310)	Zooplankton	0.20±0.04~0.64±0.08 (mean 0.39±0.04)	1993.10	This study
East Sea(N9403)	Zooplankton	0.08-0.39(mean 0.15: uncorrected for salts)	1994.4	This study

Table 6. $^{239,240}Pu$ Concentration Factor for Zooplankton(AW9310)

Station	Zooplankton (μBq/Kg dry wt..)	Zooplankton (μBq/Kg wet wt..)	Concentration Factor
st.1	3.30×10^5	6.60×10^4	1.86×10^4
st.2	2.00×10^5	4.00×10^4	1.12×10^4
st.4	6.40×10^5	1.28×10^5	2.25×10^4

Table 7. $^{239,240}Pu$ Concentration Factor for Zooplankton(N9403).

Station	Zooplankton (μBq/Kg dry wt..)	Zooplankton (μBq/Kg wet wt..)	Concentration Factor
st.1	1.30×10^5	2.60×10^4	1.09×10^3
st.2	3.90×10^5	7.80×10^4	4.56×10^3
st.3	1.20×10^5	2.40×10^4	1.36×10^3
st.4	1.00×10^5	2.00×10^4	2.53×10^3
st.5	1.60×10^5	3.20×10^4	1.51×10^3
st.6	0.80×10^5	1.60×10^4	7.02×10^2
st.7	1.40×10^5	2.80×10^4	1.08×10^3
Bg.1	1.40×10^5	2.80×10^4	1.34×10^3
Bg.2	1.20×10^5	2.40×10^4	1.16×10^3

Zooplankton(μBq/Kg wet weight) = zooplankton(μBq/Kg dry weight) × 0.2
(IAEA, 1985. Tech. Reps. Ser. No.247)

Concentration factor = zooplankton(μBq/Kg wet weight) / seawater(μBq/Kg)

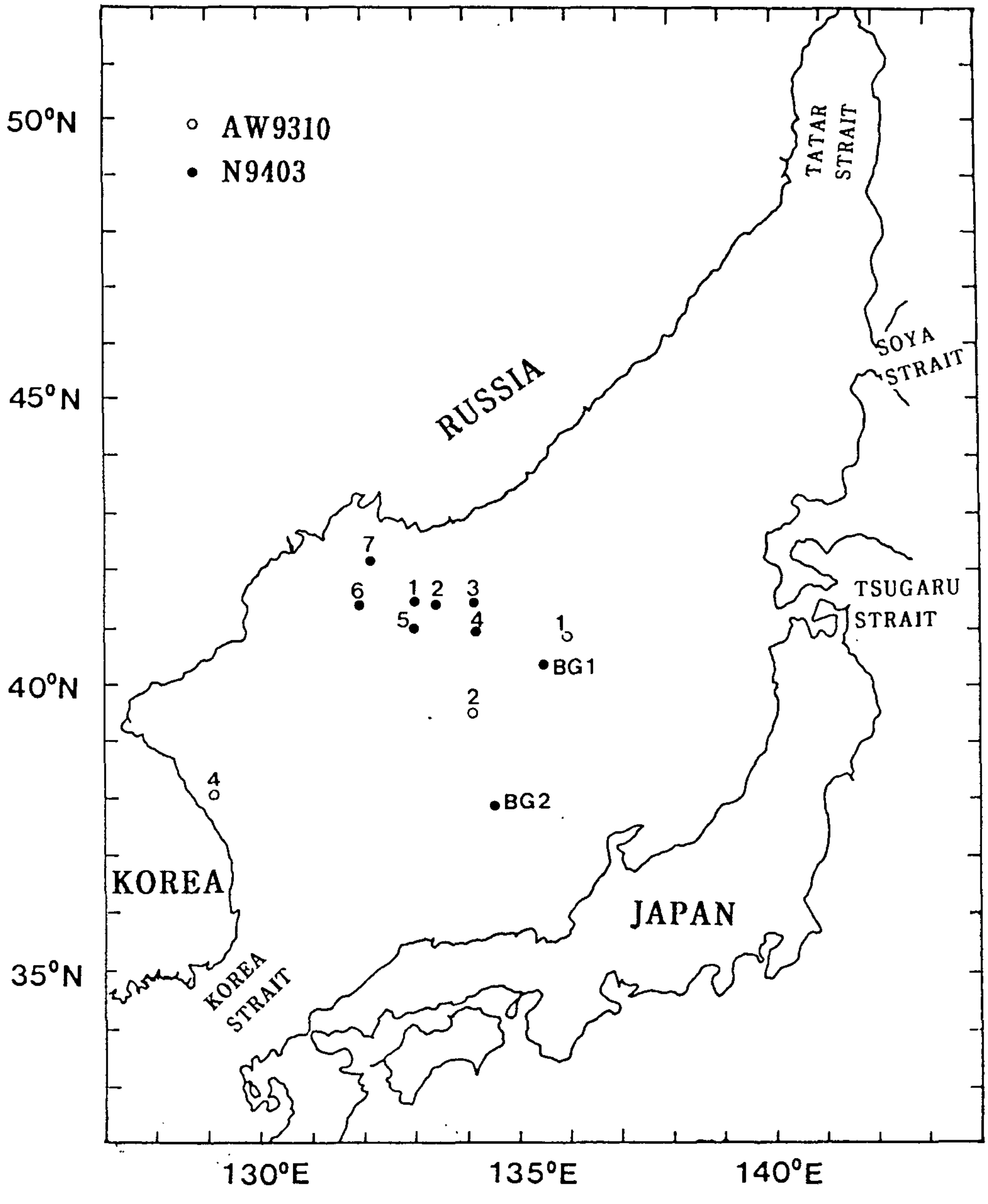

Fig. 1. Sampling station in the East Sea

Analytical procedure for Pu in Plankton

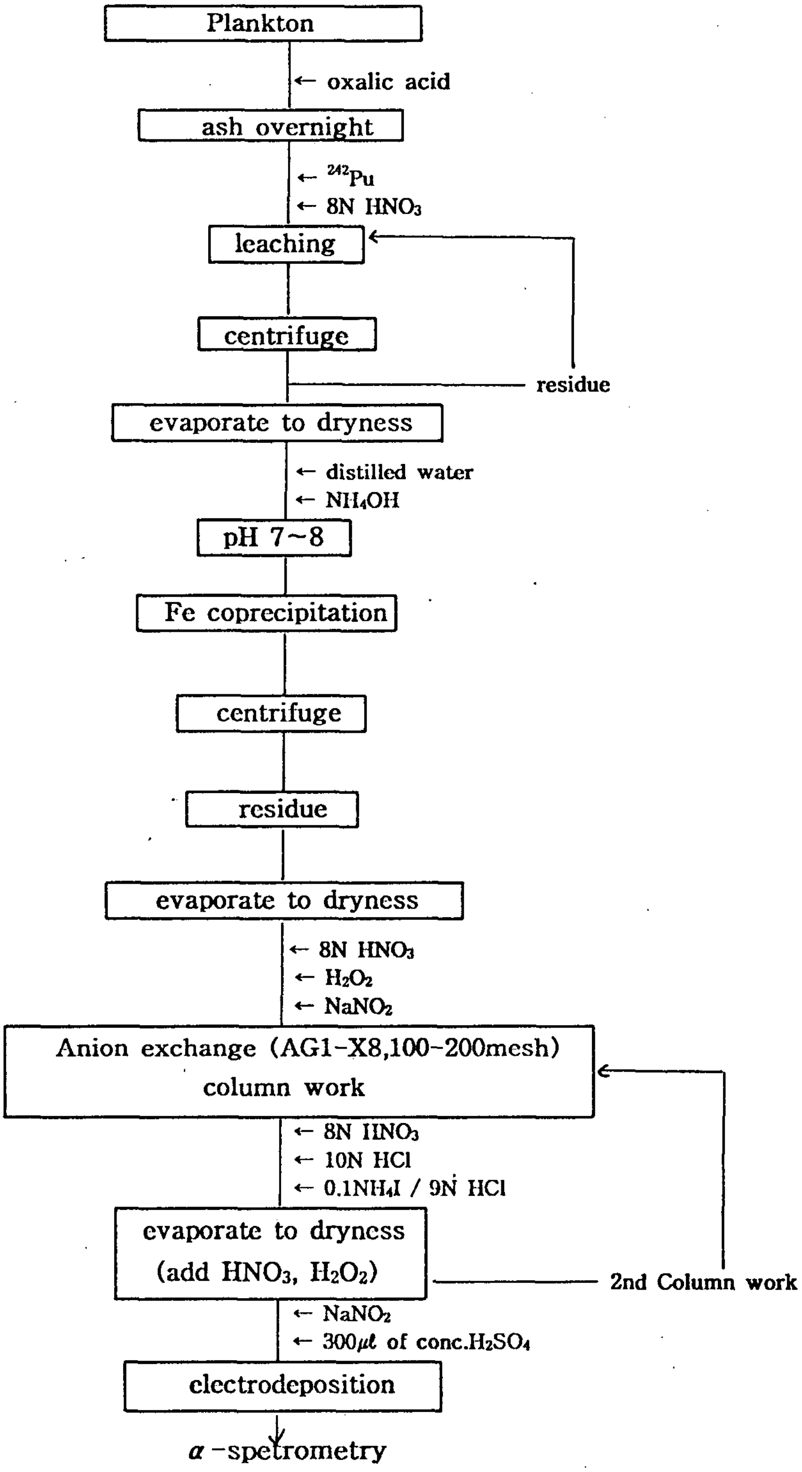

Fig. 2. Flow diagram for Plutonium procedure

제 5 장 대기를 통하여 한반도 지표면으로 공급되는 인공 방사성 핵종 ^{137}Cs 과 천연방사성 핵종 ^{210}Pb

대기를 통하여 한반도 지표면으로 공급되는 방사성 핵종(^{137}Cs과 ^{210}Pb)에 관한연구

A Study on the Atmospheric Deposition of Radionuclides (^{137}Cs and ^{210}Pb) on the Korean Peninsula

Abstract

In order to investigate the amount and geochemical behavior of artificial radionuclides, the fallout deposition of artificial radioisotopes were measured from May to October in 1994 at the Korea Ocean Research and Development Institute(KORDI), Ansan, Kyunggido, Korea. And soil samples were collected from Kwang-Leung Forest, Kyungkido, to study radioisotopic behavior and cumulative action in soil, artificial radioisotope, ^{137}Cs, and natural radioisotope, ^{210}Pb, were also determined.

The amount of wet deposition of ^{137}Cs in May was 4.95 - 11.96 mBq m^{-2}. The amounts of dry deposition of ^{137}Cs in May and October were 4.0 mBq g^{-1} and 3.0 mBq g^{-1}, respectively. The cumulative amount of ^{137}Cs in soil was about 311 mBq cm^{-2}, which was 83% of the total inputs from atmospheric fallout (374 mBq cm^{-2}) since 1960s. Artificial radioisotopes were mainly from the stratosphere and soil resuspension of continental China through the troposphere. The accumulation rate and the annual flux of ^{210}Pb into soils were 0.32 cm yr^{-1} and 34 mBq cm^{-2}yr^{-1}, respectively.

1. 서 론

핵 실험에 의해 생성되는 인공방사능 핵종은 성층권 (stratosphere) 과 상층 대류권 (upper troposphere) 으로 이동되어 대기입자 (airborne particle) 형태로 대기중에 머물다가 습상 및 건상낙하에 의해 육지나 바다에 축적되며 육상에 낙하된 방사성 물질은 부상과 낙하를 반복 (Katsumi and Yukio,1984) 하므로 대기를 통하여 낙하하는 인공방사능의 정량분석및 거동에 관한 연구는 국민의 건강과 외부세계의 핵활동이나 핵사고를 감지하는 수단으로서 대단히 중요하다.

습상 및 건상낙하는 대기에서 방사능물질을 제거하는 가장 중요한 과정중의 하나로 이러한 기작에 의한 제거과정에 대한 이론적 및 실험적 연구가 일부 수행되어 왔으나 (Burchfield *et al.*, 1983; Hirose *et al.*, 1987), 습상 및 건상낙하 과정은 매우 많은 요인이 복합적으로 작용하므로 이에 따른 구체적인 과정은 거의 알려진 바가 없다.

핵활동등에 의한 인공방사능 핵종의 유입 및 거동을 알기 위해서는 비교적 반감기가 긴 ^{137}Cs, ^{90}Sr 같은 인공 방사성 핵종의 낙하량에 대한 자료가 필요하다. 특히 최근까지 20여회나 핵실험을 수행한 중국의 동쪽에 위치한 한반도는 강한 편서풍의 영향으로 대기를 통한 방사성 핵종의 유입이 많을 것으로 사료되나 현재까지는 자료가 극히 적은 상태이다.

본 연구에서는 인공방사능 핵종의 습상 및 건상 낙하량을 정량적으로

분석하고 지표에 도달한 후의 인공방사능의 침적율 및 거동을 규명하기 위하여 토양의 인공방사능의 수직분포를 조사하여 한반도 지표면으로 유입되는 인공방사능 핵종의 이동경로 및 그 기원과 지표에 낙하하는 인공방사능 핵종의 수지를 정량적으로 추정하였다.

2. 시료 채취 및 분석

빗물 시료는 1994년 5월부터 10월까지 한반도 중부 서해안의 경기도 안산에 위치한 한국해양연구소 (37°17′N, 126°50′E)의 제3연구동 옥상에서 1.5m X 1.8m의 PVC로 된 채집기를 2개 사용하여 매회 내리는 빗물을 채취하였다(그림 1). 채취된 시료는 HCl (6N)을 가하여 pH를 2-3으로 하여 방사능 핵종이 시료 보관통에 흡착되지 않고 미생물의 번식이 억제되도록 한 다음, 분석시까지 실온에서 보관하였고, ^{137}Cs 의 분석을 위하여 80-140*l* 의 시료를 그림 2에서와 같이 ammonium phosphomolybdate (AMP) 공침법을 사용하여 전처리를 한후 γ- spectrometry (Canberra International: Intrinsic high-purity germanium crystal) 로 계측하였다.

건상낙하 시료는 빗물과 동일한 위치에서 가로, 세로, 높이 가 각각 1 m 인 정방형의 PVC 채집기를 사용하여 1개월간 계속적으로 채취하여 수분을 즈발시켜 제거한 후 시료를 도가니에 옮겨 담아 가열로에서 500 ℃로 가열한 후 γ- spectrometry로 계측하였다.

토양 시료는 광릉 수목원의 보호림내에서 1994년 10월 비교적 인공적인 교란이 적은 것으로 알려진 활엽수만 있는 소리산 중턱 (37° 44′N, 127° 00′E, 그림 1) 의 경사가 완만한 지역을 선택하여 내경이 66.25 mm 인 PVC 튜브를

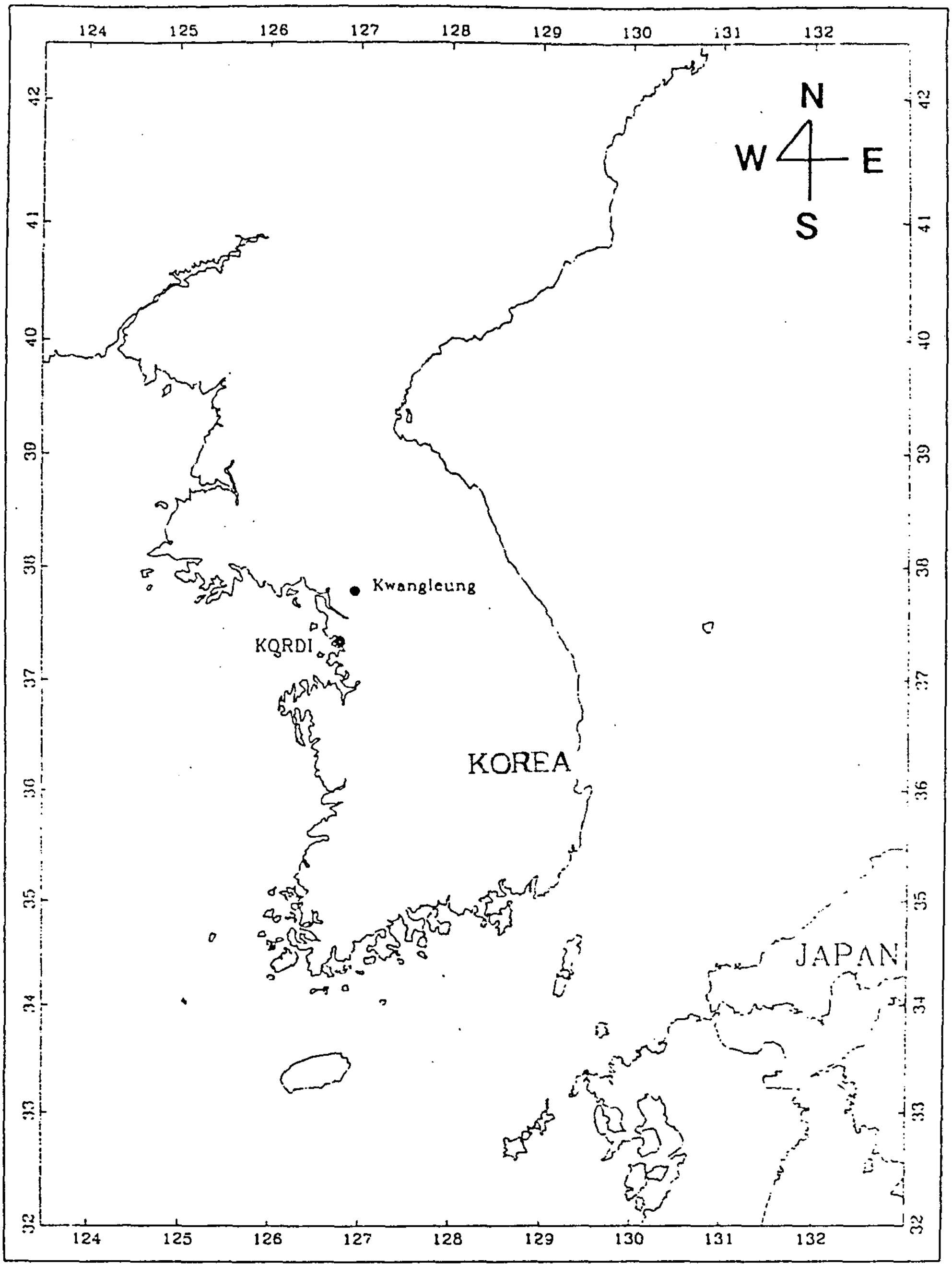

Fig. 1. Map showing two study areas(Ansan and Kwangleung).

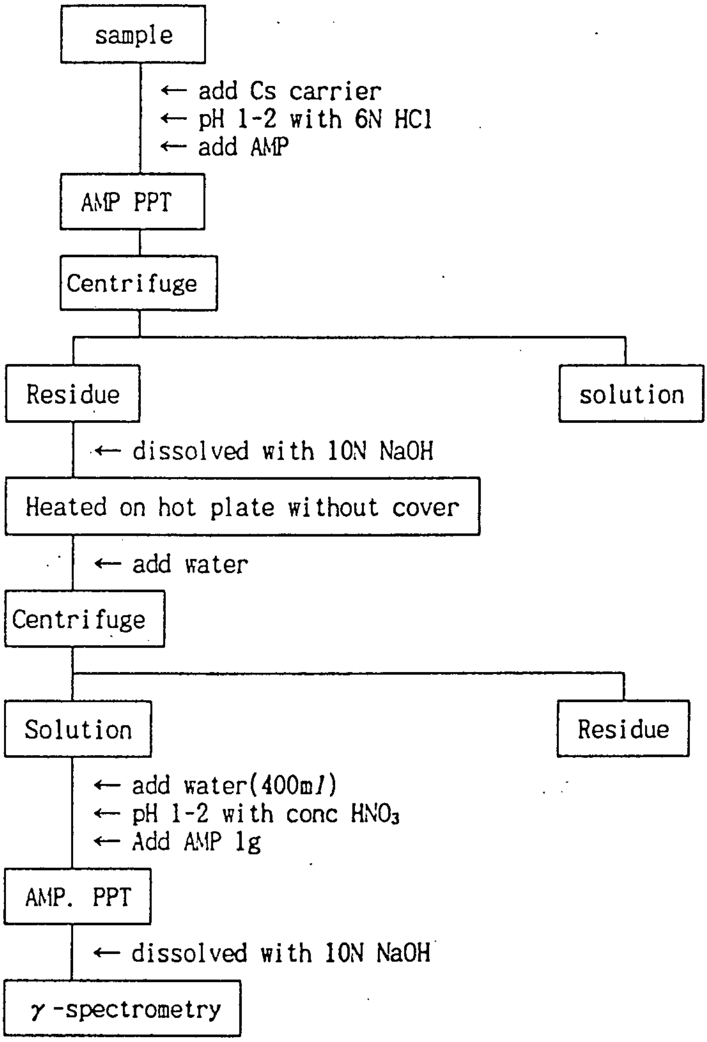

Fig. 2. A flow diagram of analytical procedure for ^{137}Cs.

이용하여 주상 시료를 채취한 후, 실험실로 옮겨 표층부터 1 cm 간격으로 잘라 각각 부시료를 취하였다. 깊이별로 분리된 분석용 시료는 105 ℃ 의 건조로에서 24시간 건조시켜 함수율을 측정한후 막자사발로 분말을 만든 뒤, 100-mesh 플라스틱 체로 걸러 이를 통과한 것을 다시 105 ℃ 의 건조로에 수시간 건조 수분을 제거한 뒤 γ - spectrometry로 계수하였다.

방사능 세기는 건조된 시료 무게에 따라 Bq g^{-1} 으로 표시하였고, 통계적인 계수 오차는 ±1σ 표준편차로 나타내었다.

3. 결과 및 고찰

3. 1 대기를 통한 ^{137}Cs 의 강하

습상낙하량에 대해서는 매번의 강수시마다 시료를 채취하여 강수량이 적었던 날에는 1개월 단위로 시료를 80*l* 이상이 되게 합하여 분석하였고 그 외에는 매회 측정하였다. 건상낙하량은 한 달 단위로 시료를 채취하여 분석하였다. 시료의 채취기간이 6개월로 제한되어 있어서 전체적인 년간 낙하량과 계절 변화를 정확하게 추론하는 데는 어려움이 따른다. 그러나 이 자료를 가까운 일본에서의 자료 (Katuragi, 1983; Katsuragi *et al*, 1986; Hirose *et al*., 1987; Aoyama *et al*., 1991)등과 비교하고 이 기간동안의 인공 방사능핵종의 한반도에서의 낙하량 및 낙하유형을 살펴봄으로써 앞으로의 낙하량에 대한 비교치로 삼는데 중요하다고 판단된다.

습상낙하량은 총 10개의 시료중에서 5월에 내린 3번의 강수에서 ^{137}Cs의 농도가 0.09-0.23 mBq l^{-1} 로 측정되었으며 그 외 시기의 강수에서는 측정하한치 이하로 검출되었다. 단위 면적당 낙하량으로 계산하면 5월중 3번의

Table 1. Cumulative depositoin and concentration of ^{137}Cs at Ansan, Korea, during May-September 1994.

Collection date	Rain fall*(mm)	^{137}Cs		
		mBq/m^2	mBq/l	M.D.L**(mBq/l)
'94 5. 3	27.95	6.39±1.49	0.23±0.05	
5. 14-15	54.60	4.95±1.77	0.09±0.03	
5. 24-25	58.20	11.96±1.32	0.21±0.02	
6. 23-26	22.45			7.27E-2
6. 30	51.55			8.24E-2
7. 1-31	87.25			5.16E-2
8. 1-25	143.30			9.77E-2
8. 28	96.70			7.46E-5
9. 2	14.35			4.87E-2
9. 5-26	114.60			6.54E-2

* 수원, 인천 지방 측우소 강우량의 평균치.

** MDL:minimum detection limit

강수에서 4.95-11.96 mBq m^{-2}, 평균 7.77 mBq m^{-2} (표 1)이었다. 이 때의 강수량은 기상월보에 의하면 27 - 58 ㎜, 총 강수량은 141 ㎜ ,한회 평균 47 ㎜로 지역별로 평년보다 10 - 170 ㎜ 정도 많은 강우량을 보였다.

일반적으로 북반구에서 성층권에 머물던 인공방사능 핵종이 대류권으로 유입되는 시기는 봄과 초여름에 최대가 되고 가을에 최소가 된다고 알려져 있으며, 이것은 1960년 6월 부터 익년 5월까지 네덜란드의 리쯔비즈크 (52° 3′N, 4° 20′E)에서 조사한 결과 실제로 대류권계면의 고도가 늦봄에 다소 낮아지며 특히 북위 30°N, 고도 13Km 부근에서 성층권의 대기가 대류권으로 유입됨이 밝혀져 (Bleichrodt and van Abkoude, 1963) 위의 결과를 뒷받침 한다. 이외에도 기상현상에 의한 뇌우나 천둥을 겸한 태풍이 발생할때 역시 성층권과 대류권의 교환량이 증가하게 된다 (Bleichrodt and van Avkoude, 1963; Noyce *et al*, 1971; Burchffield *et al.*, 1983; Dibb. 1989).

한반도에서 검출된 인공 방사능 핵종은 성층권에서의 유입과 대류권으로의 이동 그리고 재부상에 의한 부유물질의 재낙하를 생각해 볼수 있다. 1960년 부터 88년까지 29년에 걸친 ^{137}Cs 와 ^{90}Sr 의 낙하량에 대한 일본의 자료 (Katsuragi, 1983; Aoyama, 1991)에 의할 것 같으면 ^{137}Cs 낙하량은 봄철에 최고치를 보이며 가을에 최소치를 나타내어 (그림 3), 5월중에는 ^{137}Cs이 검출되나 가을철에는 검출되지 않는 본 연구의 결과와 일치하였다. 1994년 5월에 검출된 ^{137}Cs 의 양을 1988년 일본에서 측정된 자료 (Aoyama, 1991) 와 비교해 보면 약 1/3 수준이며 이것은 일본에서의 ^{137}Cs의 낙하량이 시간에 따라 지수함수적으로 감소하는 선상에 해당된다. 따라서 한반도에서의 인공방사능 핵종의 낙하양은 이웃 일본과 비슷할 것으로 추론할 수 있다.

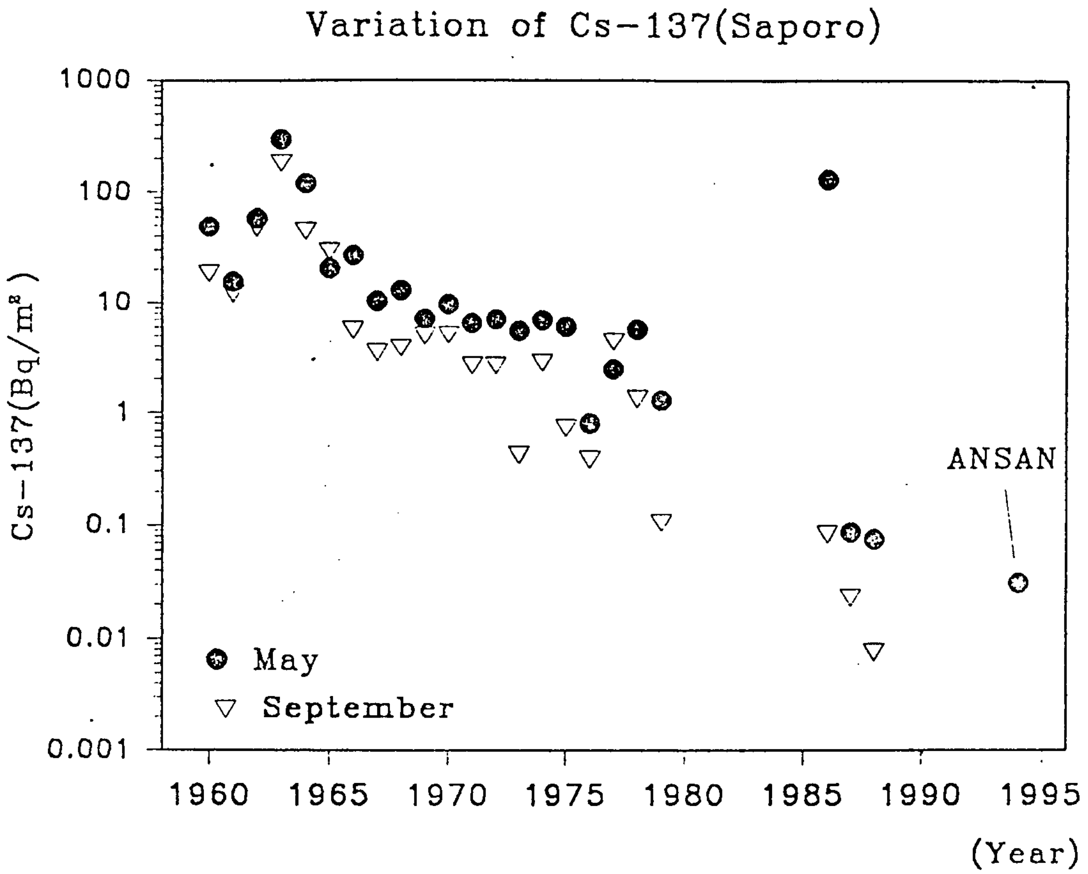

Fig. 3. The trends of measured May and September months ^{137}Cs deposition from 1960 to 1988.

^{137}Cs 의 성층권에서의 잔류시간을 1.4년, 대류권에서의 잔류시간을 약 25일로 보면 (Aoyama *et al.*, 1991) 최근에 일어난 체르노빌 원전 사고가 1986년에 일어났는데 이로 인한 인공방사능 핵종이 대류권에 유입된 것은 거의 제거되었다고 볼 수 있어 성층권에 유입되어 있는 현재 량은 미미하다고 볼 수 있다. 또한 성층권에서 형성된 ^{7}Be 의 양이 천둥과 번개를 동반한 태풍이 발생할 때 성층권과 대류권의 혼합으로 한반도 중부 서해안에 내린 빗물에서 증가치를 보인다는 박 (1993) 의 결과에 의하면 성층권과 대류권의 혼합으로 ^{7}Be 의 양이 증가하면 ^{137}Cs의 양도 증가하여야 겠지만, 본 연구에서는 ^{137}Cs 의 양이 태풍이 분 7월 (2회), 8월 (2회), 9월 (1회) 에 검출되지 않는 것은 한반도에서 성층권에서 대류권으로 유입되는 ^{137}Cs 의 양이 적었다고 볼 수 있다. 따라서 5월에 측정된 ^{137}Cs 는 봄철에 성층권과 대류권의 혼합으로 인한 성층권의 잔류 인공방사능 핵종의 유입과 봄철 한반도를 지배하는 고온 건조한 양쯔강 기단에서 떨어져 나오는 이동성 고기압이 변질되어 한반도를 통과할때 부는 서풍 그리고 제트기류의 영향으로 상층기류를 타고 유입하는 황사의 영향을 생각할수 있으나 예년과는 달리 1994년에는 황사현상이 일어나지 않았으므로 황사에 기인한 중국대륙으로의 재부상에 의한 유입도 또한 미미하다고 볼 수 있다.

건상낙하량은 1994년 5월에서 10월까지의 총 6개의 시료에서 ^{137}Cs의 월별 낙하량을 조사하였는데 5월 시료에서는 4.0±0.4 mBq g^{-1}이 검출되었으며 6, 7, 8 및 9월의 시료에서는 정량화 할수없는 미미한 양이 검출되었고 10월 시료에서는 3.0±0.5 mBq g^{-1}이 검출되었다. 이것은 빗물 시료에서 5월에 ^{137}Cs가 검출되고 6, 7, 8 및 9월 시료에서는 검출되지 않는 것과 일치한다.

또한 10월달에는 이동성 고기압이 충분히 변질되지 않아 간혹 북서기류에 의해 중국의 대기가 한반도로 유입될 경우가 있어 (국립환경연구원, 1991), 10월에 건상낙하에서 검출된 ^{137}Cs는 기원이 중국 대륙일 가능성을 시사해 준다고 하겠다.

3. 2 토양중의 ^{210}Pb

대기를 통하여 공급된 인공방사능핵종의 토양에서의 축적률 및 거동을 알기 위하여 광릉 수목원의 소리산 중턱에서 채취한 토양 시추시료에서 ^{137}Cs과 ^{210}Pb 의 농도를 깊이별로 조사하였으며 그 결과는 표 2과 그림 4와 5에 나타나 있다.

대부분의 토양에서 ^{210}Pb 의 평균체류시간이 물이나 침식에 의한 제거에 대해 수천년 시간단위이기 때문에 (Benninger *et al.*, 1975) 과거 약 100년동안 강한 침식작용이나 혼합등에 의해 손상되지 않았고 ^{210}Pb 의 공급률이 그 시간에 걸쳐서 일정한 토양일 경우에 대기를 통하여 공급된 ^{210}Pb 의 농도 자료는 다른 핵종들의 축적 및 거동을 연구하는데 유용하게 이용되어질 수 있다.

이러한 계에 있어서는 대기를 통하여 공급된 ^{210}Pb 이 정상상태에 놓여 있기 때문에 단위시간에 단위 면적당 ^{210}Pb이 토양으로 전송되는 양을 Q 라 하면, 시간 t의 경과후 단위 부피의 토양중 ^{210}Pb 의 농도, Ct 는

$$Ct = Q\ e^{-\lambda t} \quad \cdots\cdots\cdots\cdots\cdots\cdots \quad (1)$$

로 나타낼수 있다. 여기서 λ는 ^{210}Pb 의 붕괴상수로써 0.0311 yr^{-1}이다.

Table 2. Concentration of ^{210}Pb and ^{137}Cs from soil samples of Kwangleung, Korea.

Depth(cm)	^{210}Pb (mBq g^{-1})	^{137}Cs (mBq g^{-1})
0 - 1	263 ± 7.97	59.8 ± 5.33
1 - 2	223 ± 37.5	44.7 ± 4.00
2 - 3	157 ± 29.0	39.8 ± 3.67
3 - 4	192 ± 36.3	41.5 ± 3.67
4 - 5	----*	----
5 - 6	144 ± 23.7	37.0 ± 3.33
6 - 7	133 ± 21.8	37.7 ± 4.33
7 - 8	121 ± 24.2	37.7 ± 3.33
8 - 9	138 ± 19.2	40.7 ± 3.67
9 - 10	85.2 ± 17.0	24.0 ± 2.17
10 - 13	----	----
13 - 14	57.7 ± 12.0	4.67 ± 0.50
14 - 17	----	----
17 - 18	68.2 ± 13.5	1.33 ± 0.17

*not determined

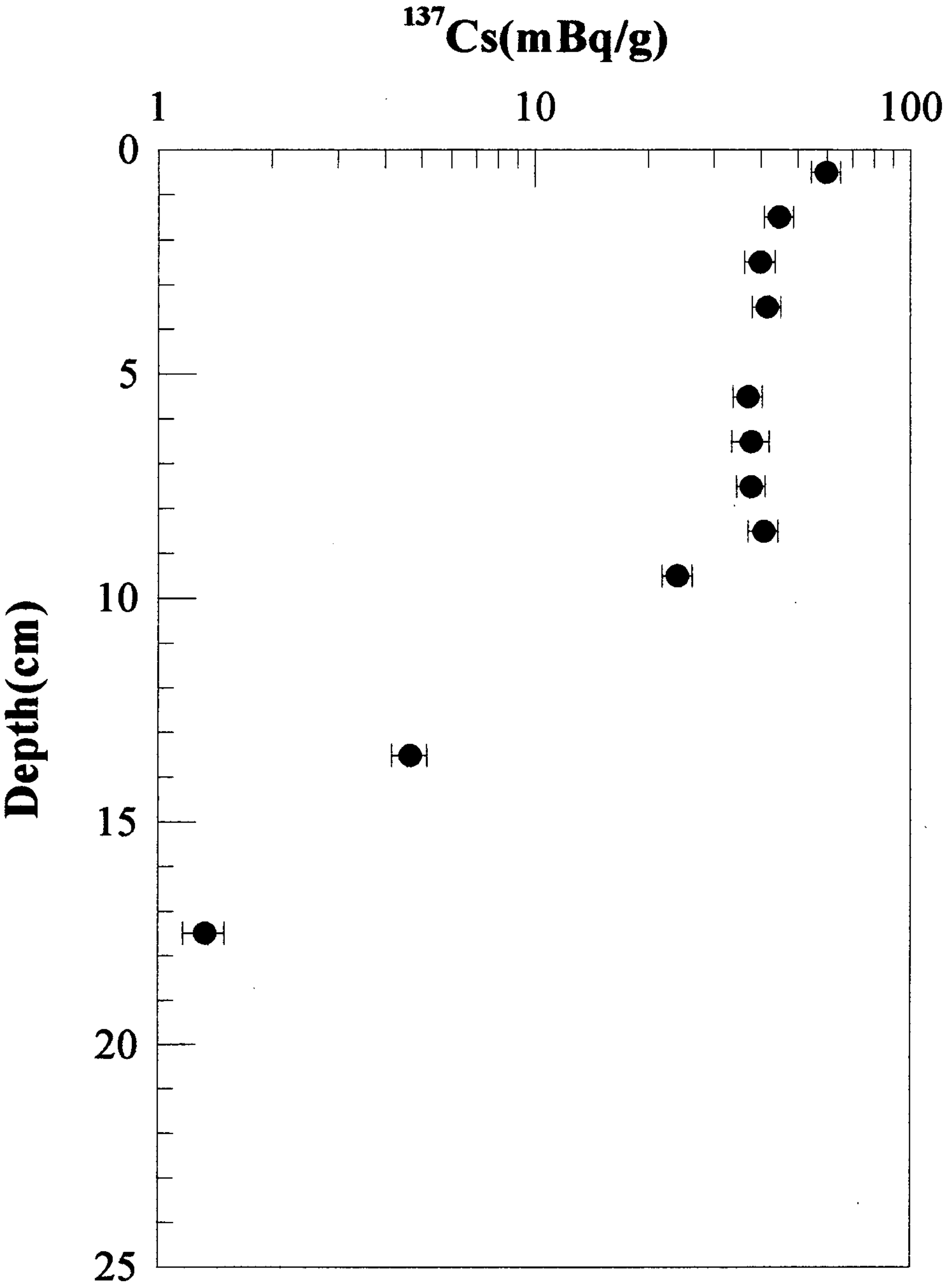

Fig. 4. The depth profile of ^{137}Cs concentration in the soil from Kwangleung, Korea.

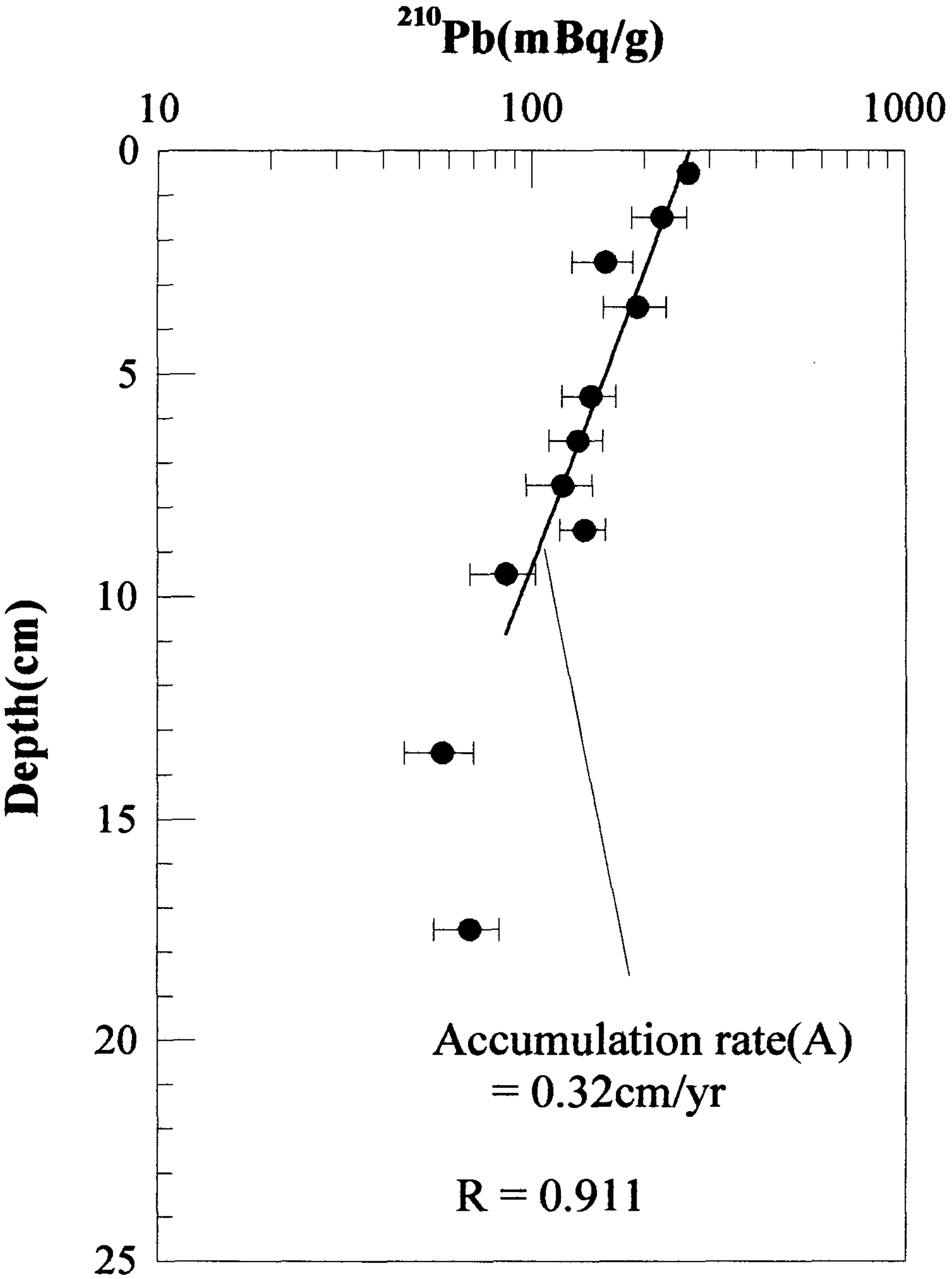

Fig. 5. The depth profile of ^{210}Pb concentration in the soil from Kwangleung, Korea.

채취한 토양시추시료 중의 ^{210}Pb 의 농도는 표층에서 깊이 10cm 까지는 지수함수적으로 감소하여 위의 식을 이용하여 광릉 수목원에서 채취한 토양 시료에서 ^{210}Pb 을 이용해서 구한 축적율은 약 0.32 cm yr^{-1} 였다.

한편 대기를 통하여 공급되어 토양에 있는 ^{210}Pb의 총량이 ^{210}Pb의 붕괴상수에 의한 축적률과 관계되기 때문에 대기로부터의 ^{210}Pb 의 공급률은 식(2)로부터 구해질 수 있다(Benninger *et al.*, 1975; Moore and Poet, 1976; Nozaki *et al.*, 1978).

$$\text{Flux} = \lambda\,^{210}\text{Pb} \times \text{Inventory} \cdots\cdots\cdots\cdots\cdots\cdots\cdots \quad (2)$$

토양중에 있는 ^{210}Pb의 총량은 각 토양 깊이에서의 농도에다 단위 면적당 토양의 무게를 합산하면 된다. 윗식에 의해 ^{210}Pb의 대기에서 포획되어 떨어지는 년 공급률을 토양의 단위면적에 존재하는 과량 ^{210}Pb의 총량으로부터 계산하면 20.3 mBq cm^{-2} yr^{-1} 가 된다 (그림 6). 박 (1993)의 자료에 의하면 한반도 서해안에서 대기를 통한 년간 ^{210}Pb의 습상 강하량은 24.8 mBq cm^{-2} yr^{-1}인데, 토양에 존재하는 과량의 ^{210}Pb의 축적률과 비교하면 광릉수목원 소리산 중턱에서 채취한 토양에는 대기를 통하여 공급되는 ^{210}Pb이 약 81%가 남아 있는 것으로 된다. 여기서 ^{210}Pb의 습상 강하량이 전부 대기로 방출된 ^{222}Rn의 분리에 의해 생성된 것이라고 가정하고 그외 건상 낙하량을 무시할 경우 그 나머지 부분인 약 19%는 유실 된다고 생각할 수 있다.

그러나 대기를 통하여 제거되어 공급된 ^{210}Pb이 과거 수백년 동안 그대로 남아 있다고 가정하고 (Benninger *et al.*, 1975) 대기로부터 공급된 입자중에

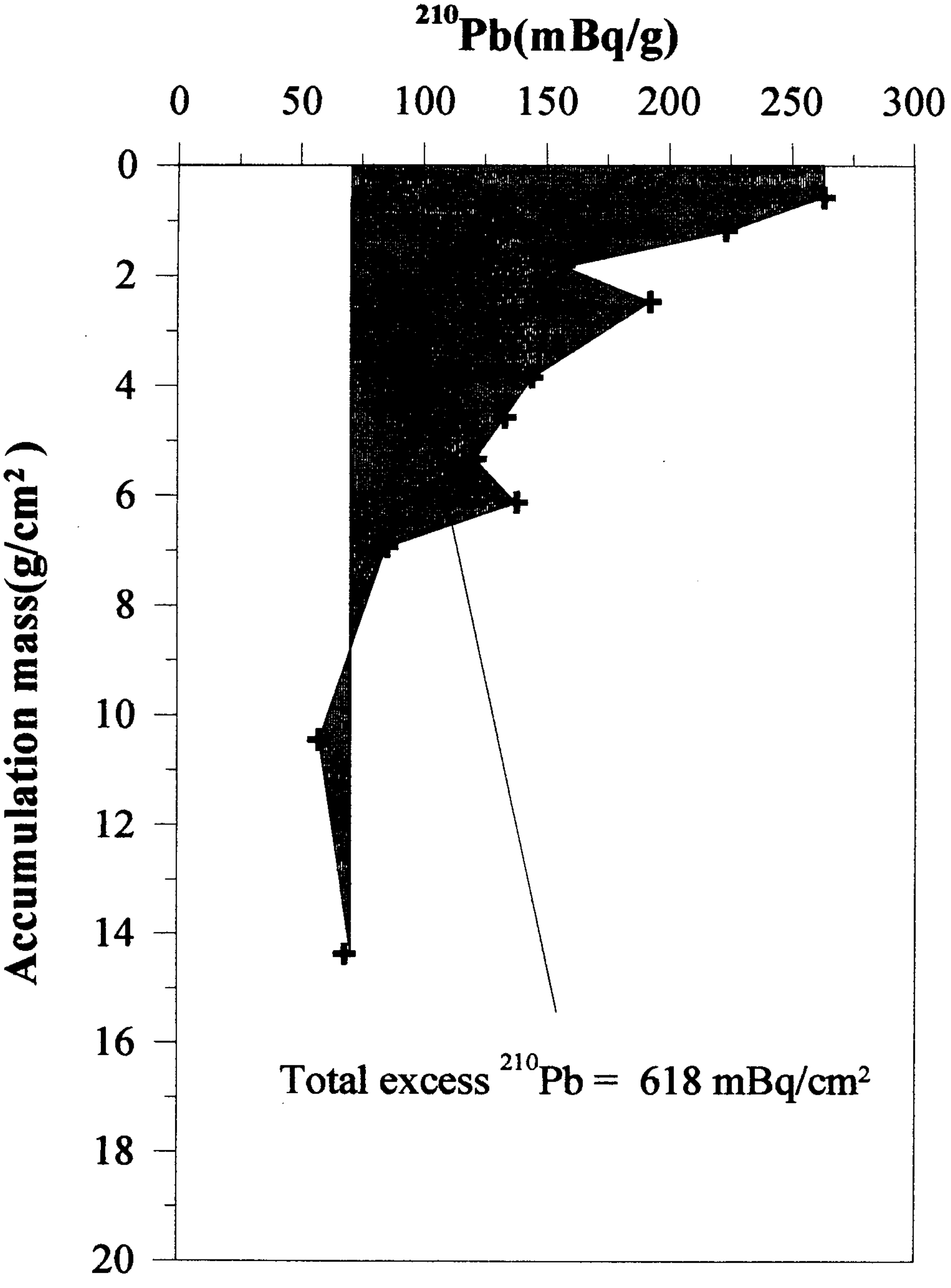

Fig. 6. Inventory profile of ^{210}Pb concentration in the soil from Kwangleung, Korea.

본래 존재하는 ^{226}Ra의 농도까지를 고려한 전체 ^{210}Pb의 총량은 앞에서 구한 시간을 고려했을 때 년간 공급량은 34.2 mBq cm^{-2} yr^{-1}로, 박(1993)에 의한 습상강하량의 약 1.6배에 해당한다. 이것은 대기를 통한 ^{210}Pb 의 공급중에서 습상강하량에는 대기중에서 포획되지않고 입자 자체내에 존재하는 ^{226}Ra에 의한 ^{210}Pb의 양이 약 19 %가 된다고 할수 있으며 그외의 부분은 건상 낙하를 통하여 상당부분 공급 되어 진다는 것을 뜻한다.

이토양의 계를 정상상태라고 가정하고 건상 낙하의 양을 계산하면, 대기에서 습상 및 건상 강하에 의하여 지표면으로 들어오는 양은 34.2 mBq cm^{-2} year^{-1}이고 습상 낙하량을 박 (1993)의 논문에 근거해 24.8 mBq cm^{-2} year^{-1}이라고 하면 건상낙하에 의한 양은 9.33 mBq cm^{-2} year^{-1}가 된다.

본 연구기간동안 조사한 건상 낙하의 플럭스는 월 평균 249±28 mBq g^{-1} month^{-1}로 국립환경연구원에서 1990년 12월부터 1991년 5월까지 조사한 강하분진의 년 평균 317.5 ton km^{-2} year^{-1} 을 이용하여 계산하면 7.83 mBq cm^{-2} year^{-1}인데 약 84 %로 비교적 잘 일치한다. 여기서 건상낙하량은 주로 육상으로부터의 재부유에 의한 것으로 생각되며 재부유되는 입자는 주로 육상등의 침식이 활발한 지역에서 행하여짐을 알수있다.

위의 결과를 종합하면 한반도에 강하하는 습상과 건상의 비율은 3 : 1 정도가 되고 건상 낙하하는 대부분이 바람, 빗물 및 침식작용에 의하여 제거되는 것으로 사료되나 여기에 대하여는 습상 및 건상 낙하에 대한 더 구체적인 연구가 뒷받침되어야 한다고 사료된다.

3. 3 토양중의 ^{137}Cs

1949년 7월의 핵실험이후 많은 양의 인공방사능 핵종이 대기권과 성층권으로 배출되어 입자형태로 지표면으로 낙하하였다. 방사능 핵종을 운반하는 입자의 평균 직경은 대부분 0.1-0.5 ㎛로 알려져 있으며 (Graustein and Turekian, 1986). Volchok (1980)은 인공방사능 낙하 감시소 근처에서의 ^{123}Cs의 양을 낙하량과 비교해 봄으로써 대부분의 토양은 ^{127}Cs에 대한 좋은 포획체라는 결론을 내렸다.

연구지역의 토양중 ^{137}Cs의 총량은 311 mBq cm^{-2}이다 (그림 7). 이것은 일본에서 1988년까지 측정한 총 강하량 375 mBq cm^{-2}의 약 83%에 해당한다. ^{137}Cs은 ^{210}Pb와는 달리 인공방사능 핵종으로 순간 입력의 성질을 가져 토양이나 퇴적물의 퇴적당시의 대기중 농도를 잘반영하고 있기 때문에 ^{210}Pb로 연대를 측정하고 나서 혼합정도를 밝히는데 이용할수 있으나 연구지역 토양중의 ^{137}Cs의 깊이별 농도는 Fig. 3과 같이 표층의 0-1 cm 깊이에서는 59.8±5.33 mBq g^{-1}으로 최대치를 보이고 그 아래에서 9cm까지는 큰 변화를 보이지 않고 있다. 그리고 9-10 cm층에서 24.0±2.17 mBq g^{-1}으로 위층에 비해 거의 절반 가량의 농도를 보이고 그이후 부터는 급격히 감소하여 13-14 cm 층에서 4.67±0.50 mBq g^{-1} 그리고 17-18 cm층에서는 1.33±0.17 mBq g^{-1}으로 극히 미량만이 검출되었다. 만약에 대기를 통하여 공급된 ^{137}Cs가 토양에서 수직적으로 이동되지 않고 그대로 보존된다면 시간에 따른 강하량의 형태가 깊이별로 그대로 보존되어 있어야만 한다.

앞의 ^{210}Pb의 토양에서의 깊이별 분포에서 보듯이 연구지역의 토양은 상부에서의 공급이 깊이별로 정상 상태로 잘 보존되어 있다는 것을 보여주고

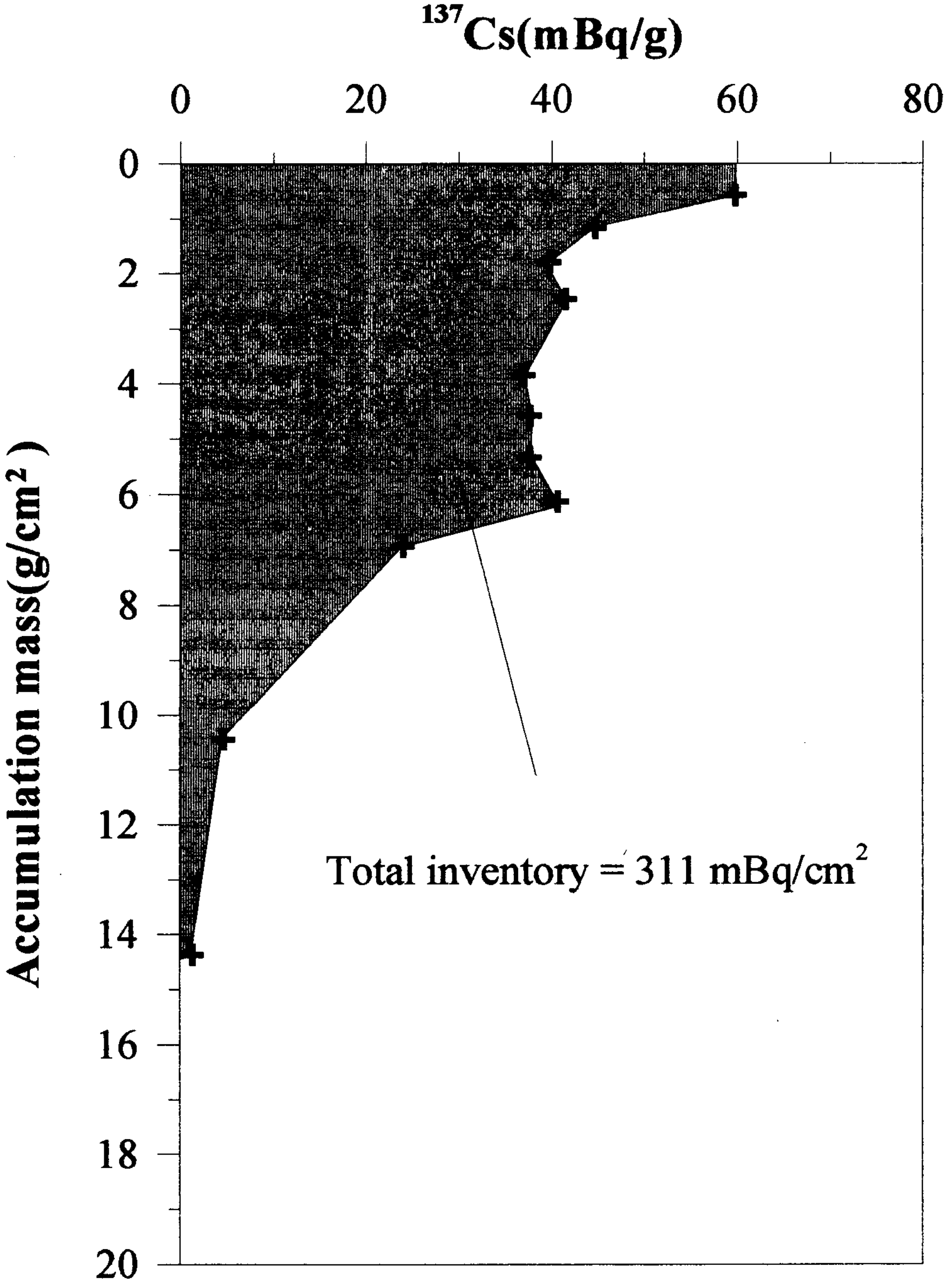

Fig. 7. Inventory profile of ^{137}Cs concentration in the soil from Kwangleung, Korea.

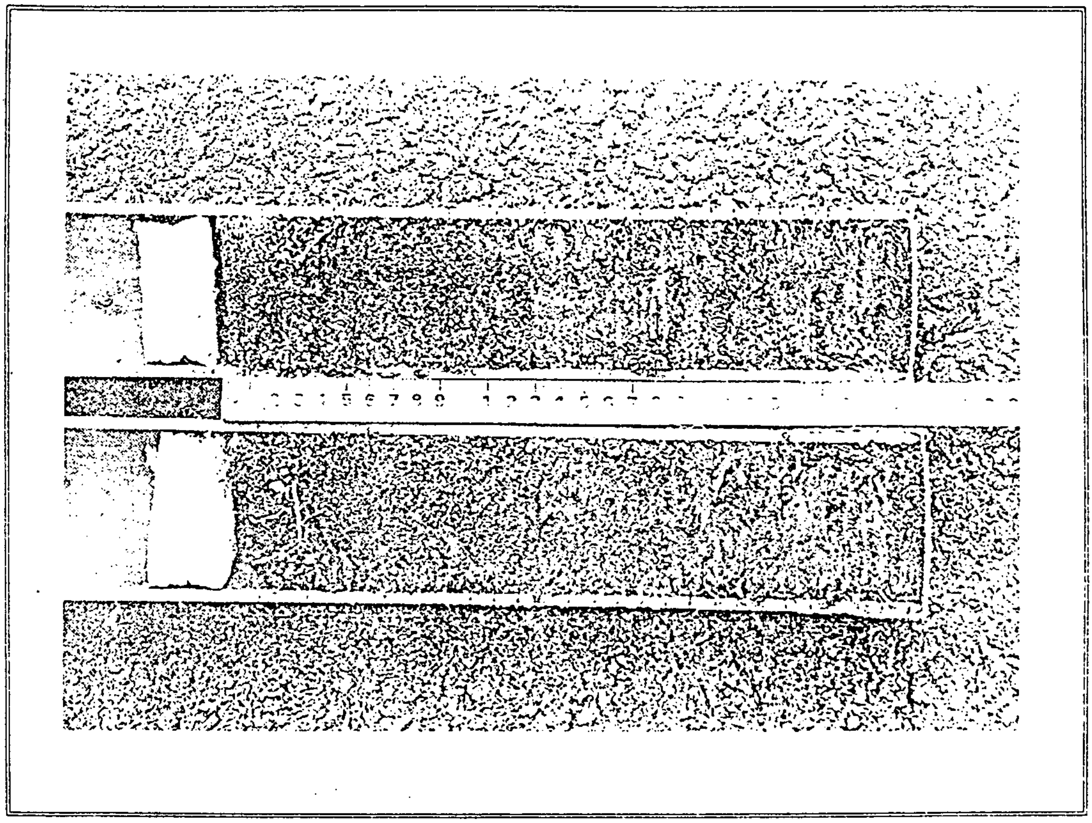

Fig. 8. Photograph of the soil core.

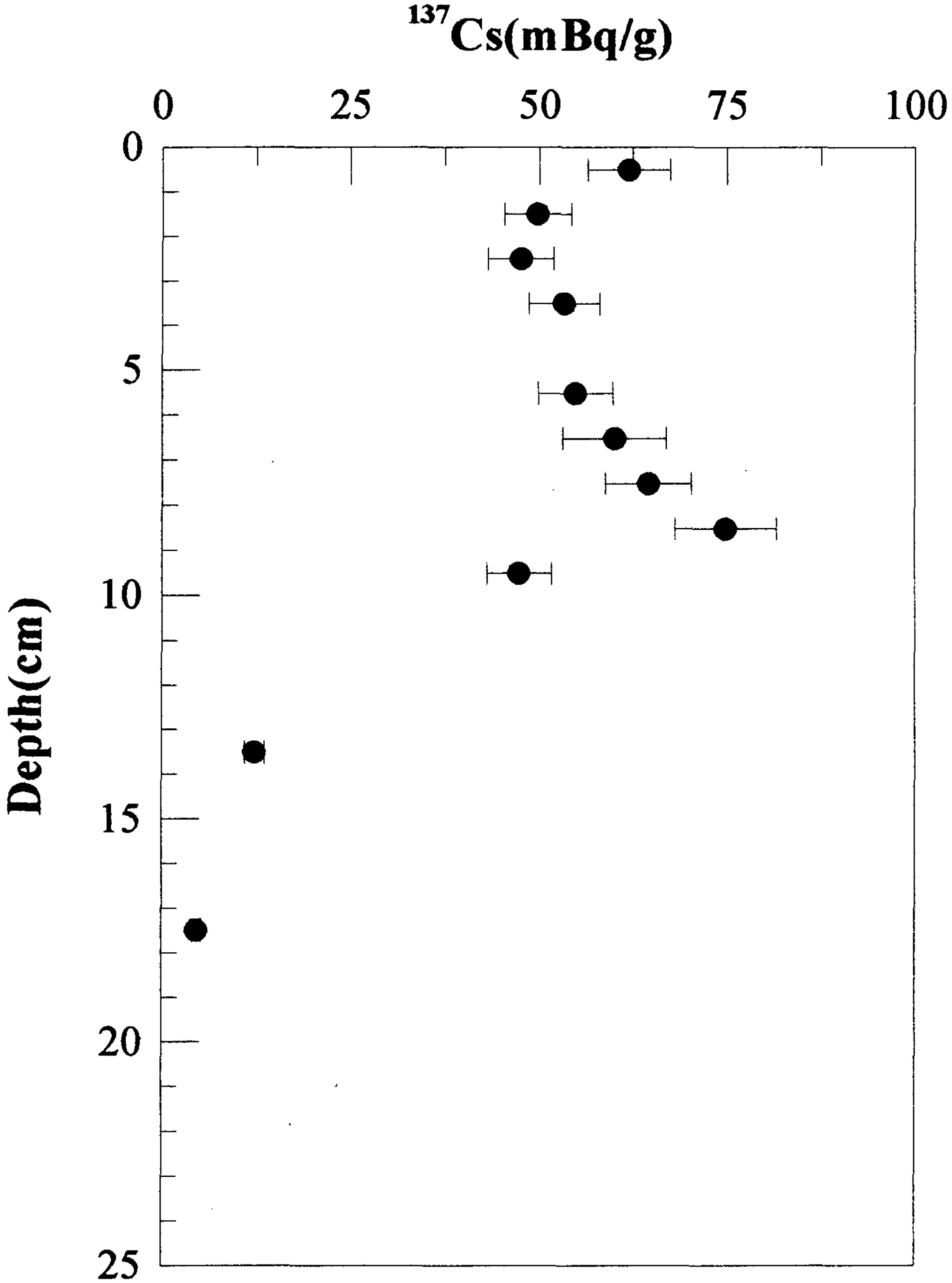

Fig. 9. Aged corrected distribution of ^{137}Cs from Kwangleung, Korea.

있다. 이것은 대기로부터 공급된 ^{210}Pb와 ^{137}Cs의 토양에서의 축적 및 이동형태가 다르다는 것을 뜻한다. 일반적으로 ^{137}Cs의 낙하는 핵폭발실험등에 의해 대류권의 상층부와 성층권 하부까지 올라간 것등이 강수에 의해 대부분 지상으로 떨어지며 그것은 아주 미세한 입자 (0.1-0.5㎛)나 이온의 형태로 토양으로 스며들게 된다.

따라서 토양에서의 상부 공극율이 큰 투수층에 머무르면서 대부분 토양입자에 흡착되기 때문일 것으로 사료된다. 이것은 연구지역의 토양이 표층에서 약 10 cm는 푸석푸석한 형태를 띠고 그 하층부에서는 다소 경화된 모습을 보여주는 것과 일치한다 (그림 8). 깊이 10 cm의 연대는 ^{210}Pb의 농도로 부터 계산한 연령이 30년에 달한다. ^{137}Cs는 상부 10 cm층에서만 과량이 발견되는 것이다.

^{137}Cs의 수직분포를 토양에 입력된 당시의 농도를 알기 위하여 ^{210}Pb을 사용하여 구한 축적율을 이용하여 깊이별로 붕괴된 양을 보정을 해주고 밀도에 따른 보정을 하여 그림 9와 같은 결과를 얻었다. 그림 8에서 깊이 8.5 cm가 핵실험에의한 대기중 농도가 가장 높은때인 1963년이고 표층의 연도는 체르노빌 원자력발전소 사고가 있은 1986으로 추정된다.

4. 결 론

한반도 중부 서해안에 내리는 인공방사성 핵종의 양 및 거동을 알기 위하여 경기도 안산에 위치한 한국해양연구소 옥상에 습상낙하 및 건상낙하 채집기를 설치하여 습상낙하 시료는 1994년 5월부터 9월까지 건상낙하 시료는 5월에서 10월까지 채취하여 ^{137}Cs 를 분석하였다. 또한 토양에 침적되는 방사능의 농도

및 거동을 파악하기 위하여 경기도 광릉수목원에서 토양시료를 채취여 인공 방사성 ^{137}Cs 및 천연 방사성 ^{210}Pb 을 분석하였다.

빗물시료의 분석 결과 5월은 총 강우량이 140.75 mm 로 일회 평균 강우량은 46.72 mm 를 기록하였고 이때 빗물속에 포함된 ^{137}Cs 의 양은 4.95 - 11.96 mBq m^{-2} 의 분포를 보였으며 평균 7.77 mBq m^{-2} 를 나타냈으나 6, 7, 8 및 9월에는 측정 하한치 이하의 농도를 보였으며, 건상시료에서는 5월에 4.00 ±0.33 mBq g^{-1} 10월 시료에서는 3.00 ±0.50 mBq g^{-1}이 검출 되었고 그 나머지 달에는 측정 하한치 이하의 농도를 보였다.

토양의 ^{137}Cs 및 ^{210}Pb 을 분석 결과 ^{137}Cs 은 농도 범위가 1.33 - 59.8 mBq g^{-1} 의 분포를 보였고, 반감기를 고려한 연대보정으로 산출한 깊이별 분포는 8.5 cm에서 최대값을 보였다. 이는 ^{210}Pb를 이용하여 측정한 축적율 (0.32cm yr^{-1})과 대기중 핵실험이 최대였던 1963년에 ^{137}Cs의 낙진량이 최대였음을 고려하였을때의 결과와 거의 일치한다. 토양에 잔존하는 ^{137}Cs 의 양은 311 mBq cm^{-2}으로 1960년도 부터 대기를 통하여 유입되어 지표면에 도달한 총량 (374 mBq cm^{-2})의 83 % 를 함유하고 있으며, 인공방사능의 주 유입원은 성층권으로 부터의 유입과 대류권을 통한 중국대륙 토양의 재부상에 의한 것으로 나타났다.

토양 시료에서 ^{210}Pb의 분석 결과는 깊이에 따라 지수함수적으로 감소하는 양상을 보였으며 이를 이용하여 토양의 축적율을 구하여 본 결과 0.32 cm yr^{-1} 로 나타났다. 이때 ^{210}Pb 의 연간 플럭스는 34.2 mBq cm^{-2}yr^{-1} 로 추산되었다.

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제 6 장 블라디보스톡 주변해역 방사능 오염현황

제 6 장 블라디보스톡 주변 해역 방사능 오염 현황

블라디보스톡은 캄챠카의 Ribachy 만과 더불어 극동해군의 2개 주요기지이다. 또한 블라디보스톡은 동해 북부에 위치한 러시아 극동해군기지로서 잠수함 작전이 흔하게 행하여지는 곳이다. 따라서 블라디보스톡 연안퇴적물의 방사능 오염 여부의 정밀조사는 동해 환경보전에 주요한 사항이다. 러시아 극동수리기상연구소로부터 3개의 시료를 제공받아 분석한 결과는 표 1 에 정리하였다.

러시아측의 분석결과는 지도에 함께 수록하였다. 향후 블라디보스톡 주변 해역의 환경 감시에 주의를 기울여야 할 것이다.

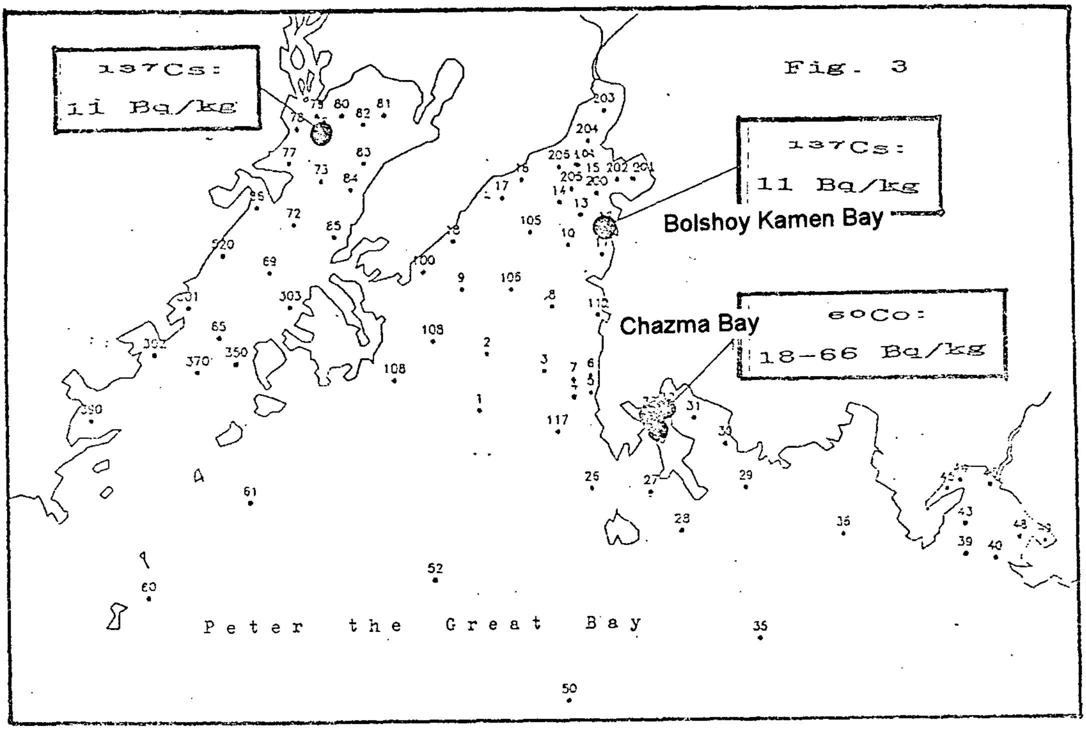

Fig. 1. Sampling stations in the Peter the Great Bay (1994)

Stn.	Cs-137 (Bq/kg)	Pu-239,240 (Bq/kg)	Sr-90 (Bq/kg)
81 surface	17.36+0.92	1.15+0.05	1.60+0.26
85 surface	13.43+1.05	1.14+0.04	1.80+0.39
85 subsurfac	16.68+1.56	0.90+0.04	1.64+0.43

Table. 1. Artificial radionuclides in the coastal sediments near Vladivostok, 199