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Environmental Monitoring of the Angra Reactor Site

Program and Results for Unit 1, Monitoring Period 1982 - 1984

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Preface

The Federative Republic of Brazil and the Federal Republic of Germany signed an Agreement of Nuclear Cooperation in 1975. Within the framework of this accord, a special agreement providing for scientific and technical cooperation between the Brazilian National Nuclear Energy Commission (CNEN) and the Karlsruhe Nuclear Research Center (KfK) was signed on March 8, 1978. The exchange of scientists and research workers that ensued between the Institute for Radioprotection and Dosimetry (IRD) of CNEN and the Central Safety Department of KfK led to programs of cooperation in environmental monitoring at nuclear facilities.

The Preoperational Environmental Monitoring Program for the Angra Nuclear Power Plant Site (ANPPS) was started in 1979. It was elaborated with the advice and assistance provided by the Central Safety Department of KfK. In conclusion of the preoperational period, the results obtained by IRD were published in the first joint CNEN/KfK report and presented at the International Meeting on Radiological Protection and Dosimetry at Centrecon, Itaipava, in March 1983.

Monitoring of the environmental radioactivity has been performed continuously by IRD since the beginning of operation of the nuclear power plant, i. e. in March 1982 when Unit 1 of the ANPPS reached criticality. The measurement results obtained during the operational period up to December 1984 were analyzed and checked by IRD and KfK staff and they are published in this report.

On behalf of CNEN and KfK we take great pleasure to present this second joint report on environmental monitoring of the Angra reactor site which constitutes another example of successful international cooperation.

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Rio de Janeiro, December 1985

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Summary

The IRD/CNEN Preoperational Environmental Monitoring Program for the Angra Nuclear Power Plant Site (ANPPS) was started in September 1979. The background measurements were performed continuously until March 1982 when Unit 1 of the site reached criticality. In this report, the Operational Environmental Monitoring Program for Unit 1 of ANPPS is outlined and discussed. The single and summarized results obtained under this program during the period from March 1982 to December 1984 are presented and compared with those obtained during the preoperational period in order to find out whether there has been any influence of Unit 1 on its environment.

Direct radiation was measured with a solid-state dosimeter network. The concentration levels of natural and artificial radionuclides were determined in primary media like air, surface and sea water, in accumulators like soil, sand and sediments, in indicators like grass and seaweed, and in the main local foodstuff, which includes marine produce (fish, shellfish and shrimps), milk, bananas, manioc and oranges. The measurements included gross alpha and beta activity measurements and gamma spectrometry. Specific techniques were used for the measurement of the activity concentration of tritium in sea water and surface water and of I-131 in air and milk.

Though the minimum detection limits for the measurement of fission and activation products by gamma spectrometry were continuously improved during the operational period, the only detectable artificial radionuclide was Cs-137 whose occasional presence in milk, pasture, fish and manioc can be attributed to world-wide fallout. On the other hand, the direct radiation levels do not differ from those observed during the preoperational period. It is concluded that the operation of ANPPS Unit 1 did not result in any radiological impact on the environment.

Die Umgebungsüberwachung des Kernkraftwerkstandortes Angra - Programm und Ergebnisse für Block 1, Überwachungszeitraum 1982 - 1984 -

Zusammenfassung

Mit dem Umgebungsüberwachungsprogramm des Institutes für Strahlenschutz und Dosimetrie (IRD) der Nationalen Kernenergiekommission (CNEN) Brasiliens für die Vorbetriebsphase des Kernkraftwerkstandortes Angra (Angra Nuclear Power Plant Site = ANPPS) wurde im September 1979 begonnen. Die Nullpegelmessungen wurden ohne Unterbrechung bis März 1982 durchgeführt, als Block 1 zum ersten Mal kritisch wurde. Im vorliegenden Bericht wird das Umgebungsüberwachungsprogramm für die Betriebsphase von Block 1 des ANPPS beschrieben und diskutiert. Die von März 1982 bis Dezember 1984 im Rahmen dieses Programmes gewonnenen Einzelmeßergebnisse und zusammengefaßte Ergebnisse werden dargestellt und mit jenen verglichen, die sich während der Vorbetriebsphase ergaben, um feststellen zu können, ob es Auswirkungen des Betriebes von Block 1 auf seine Umgebung gegeben hat.

Die Direktstrahlung wurde mit Hilfe eines Meßstellennetzes von Festkörperdosimetern gemessen. Die Aktivitätskonzentrationen natürlicher und künstlicher Radionuklide wurden bestimmt in primären Medien wie Luft, Oberflächen- und Meerwasser, in Akkumulatoren wie Boden, Sand und Sedimente, in Indikatoren wie Gras und Seetang und in den wichtigsten örtlichen Nahrungsmitteln, zu denen Meeresprodukte (Fisch, Schalentiere und Garnelen), Milch, Bananen, Maniok und Orangen gehören. Die Messungen umfaßten Gesamtalpha- und Gesamtbeta-Aktivitätsmessungen und Gammaspektrometrie. Spezifische Verfahren wurden zur Messung der Aktivitätskonzentration von Tritium in Meer- und Oberflächenwasser und von I-131 in Luft und Milch angewandt.

Obwohl die unteren Nachweisgrenzen für die Messung von Spalt- und Aktivierungsprodukten mittels Gammaspektrometrie während der Betriebsphase von Block 1 immer weiter gesenkt werden konnten, war Cs-137 das einzige künstliche Radionuklid, das nachgewiesen werden konnte. Sein gelegentliches Auftreten in Milch, Grünfutter, Fisch und Maniok kann dem weltweiten Fallout zugeschrieben werden. Andererseits unterscheiden sich die Direktstrahlungspegel nicht von jenen, die während der Vorbetriebsphase festgestellt wurden. Daraus kann geschlossen werden, daß der Betrieb von Block 1 des ANPPS keinerlei radiologische Auswirkung auf die Umgebung hatte.

Monitoração Ambiental na Area da Central Nuclear de Angra dos Reis - Programa e Resultados para Unidade 1 no período 1982 - 1984 -

Resumo

O Programa de Monitoração Ambiental pré-Operacional do IRD/CNEN para a Central Nuclear Almirante Alvaro Alberto teve seu início em Setembro de 1979, visando caracterizar a radioatividade natural da região. As amostragens e medidas relacionadas a este programa foram realizadas de forma ininterrupta até Março de 1982, data em que a Unidade 1 da CNAAA entrou em criticalidade. No presente relatório, apresenta-se e discute-se o programa de Monitoração Ambiental Operacional para Unidade 1 da CNAAA. Apresenta-se também os resultados individuais e sumarizados obtidos neste programa no período de Março de 1982 a Dezembro de 1984, comparando-se os mesmos com aqueles referentes à fase pré-operacional, de forma a verificar eventuais impactos radiológicos da Unidade 1 no ambiente local.

Realizaram-se medidas diretas de radiação através de uma rede de dosímetros de estado sólido em diferentes pontos da região. Determinaram-se as concentrações de radionuclídeos naturais e artificiais em meios primários como ar e água do mar e de superfície, em integradores como solo, areia e sedimentos marinhos, em indicadores como pasto e algas, e nos principais alimentos produzidos localmente como frutos do mar (peixes, mariscos e camaroes), leite, banana, mandioca e laranja. Efetuaram-se medidas de atividade alfa e beta total e de espectrometria gama. Utilizaram-se técnicas específicas para a determinaçao das concentrações de H-3 em água do mar e de superfície e de I-131 em leite e no ar.

Apesar da nítida melhora, na fase operacional, dos limites de detecçao para as medidas de radionuclídeos de fissão e ativação por espectrometria gama, o único radionuclídeo artificial identificado em amostras ambientais foi Cs-137, cuja presença ocasional em amostras de leite, pasto, peixe, mandioca e alga pode ser atribuida ao "fallout". Por outro lado, os níveis de radiação direta não diferem daqueles registrados na fase pré-Operacional. Conclui-se que a operação da Unidade 1 da CNAAA não causou impacto radiológico no meio ambiente no período considerado.

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1. Introduction

The Angra Nuclear Power Plant Site operated by Furnas C. Eletricas S. A., comprises three power plants: Unit 1 is a Westinghouse PWR reactor of 626 MW elctric power which reached criticality in March 1982, and Units 2 and 3 are "BIBLIS" PWR reactors, presently under construction in cooperation with KRAFTWERK UNION (KWU), which will generate 1300 MW(e) each.

In addition to the operator's Environmental Monitoring Program, the Brazilian supervisory autority, CNEN (BRAZILIAN NUCLEAR ENERGY COMMISSION) runs an independent program carried out by the CNEN's Instituto de Radioproteção e Dosimetria (IRD).

IRD's Preoperational Environmental Monitoring Program was formulated, implanted and run in cooperation with the Central Safety Department of the Karlsruhe Nuclear Research Center (KfK). This program was run for two years from Sept. 79 to Sept. 81 and the results were published as a CNEN/KfK joint report. The preoperational program fulfilled satisfactorily its main objectives which were:

- to implant at IRD the necessary technical infrastructure, i. e. the sampling procedures and radiochemical and radiometric analyses of environmental samples, and to train the staff in the application of these techniques,

- to determine the direct radiation background and the background concentration levels of natural and artificial radionuclides in air, soil, water, sediments, plants and foodstuffs, within a radius of up to 15 km from the site, providing a basis for the future evaluation of the radiological environmental impact of the ANPPS, if any.

In addition to the fulfilment of these fundamental objectives, the experience gained during these two years allowed to evaluate the adequacy of the sampling and analytical techniques and also of the media

and locations previously selected for monitoring. This experience was the basis for the establishment of the operational monitoring program.

The main objectives of operational environmental programs are:

- to assess the actual or potential doses on critical groups of the population arising from the presence of radioactive materials or radiation fields in the environment under normal operating and accident conditions,

- to demonstrate compliance with authorized limits and requirements,

- to check the adequacy of effluent controls.

In addition, these programs pursue some additional objectives, namely:

- to inform the public,

- to make a distruction between the contributions by the plant and the contributions from other sources,

- to identify changes in the relative importance of transfer pathways and mechanisms, enabling the program to be revised in the light of experience in response to changing conditions.

For the purposes of this report, the start of the IRD Operational Environmental Monitoring Program for the ANPPS Unit 1 is considered to be 01/01/82, though environmental monitoring had been performed continuously from Sept. 79 and Unit 1 reached criticality as late as on March 1982. In this joint report the program is outlined and discussed, and the single and summarized results obtained in the period 01/01/82 to 31/12/84 are presented.

2. The Angra Nuclear Power Plant Site

2.1 Site Characteristics

The site characteristics have been described in detail in the Preoperational Report [1]. Therefore, only the modifications made during the operational period will be mentioned here. A general map of the site and its region is shown in Fig. 5 (see p. 22).

After the water circulating pumps of the condenser cooling seawater intake at Itaorna beach had been damaged by storms, a long transversal dike was built by Furnas to protect the Unit 1 water intake, and also the intakes of the future Units 2 and 3.

The 1984/1985 summer was characterized by exceptionally heavy rainfalls, which caused a number of serious landslides on the Serra do Mar which borders the coastline between Rio and Santos. One of these landslides was responsible for the total destruction of the operator's radioecology laboratory and blocked the access by land to the site.

2.2 Local Meteorology

In the course of licensing in the seventies four meteorological towers were built at the site, and data supplied by them made evident that the predominant atmospheric diffusion directions were NNE, NE and ENE for wind blowing from sea to land and WSW and SW for wind blowing seawards. One of the towers is located 50 meters above sea level and is 100 m high. Meteorological instrumentation was installed at 15, 50 and 100 m heights and a refrigerated housing was built to protect the associated computer station from heat and moisture. The collected data are used in the calculations of individual and population doses from gaseous effluents and in the development of more accurate micrometeorological models for the site.

In this connection and as a result of CNEN/KfK joint efforts, an atmospheric diffusion experiment campaign was initiated, the first five experiments were performed in late 1984. The 100 m tower was used for the release of tritiated water vapor, and network of sampling stations was used to collect air moisture. The results were published as a CNEN/KfK joint report [5]. The wind field at the site is complex, and as a rule the sea breeze predominates during the day in a layer up to 80 m, above which wind direction reversal can be expected.

Heavy rainfall is common, especially during the summer months, and the mean annual precipitation for the years 1980 - 1982 was 1513 mm.

2.3 Local Population

Before the construction of the Rio-Santos highway the region of the ANPPS was scarely habitated, usually by fishermen in isolated settlements accessible only by sea. Construction of highway and the subsequent development of complex industrial projects along the coastline implied a great socio-economic impact on the local population, and the considerable inflow of new inhabitantes caused sharp changes in the population structure and geograhical distribution. However, the population data presented in the preoperational report [1] can be considered as still valid for the purpose of a general description.

The more intensive touristic exploitation of the region as well as the resulting real-estate "boom" in the seventies were slowed down by the onset of the economic crisis and by the recent landslides which impeded access by land to this region.

2.4 Use of Water and Land

The local agricultural production is of minor and decreasing importance, since the existing farms are gradually being sold out to real-estate agents. The same applies to meat and milk production.

The diet of the local population is monotonous, it consists essentially of rice, beans, manioc and manioc flour. Meat is a constituent in about 14 % of the meals, and fish is found in 31 % of meals. Most of the fish consumed are not sedentary but are caught in Baia da Ribeira (see site map, Fig. 5, p. 22). The consumption of crustacea and mollusks is insignificant, the same as the consumption of locally produced vegetables, fruits or milk products. In short, the local population depends mainly on food supplies imported from other areas.

3. Operation of Unit 1

Electricity generation by Unit 1 had been irregular over the period considered. From March 1982 to June 1984 electricity was generated during eleven months at up to 30 % of the rated eletric output in 1982 and 1983, reaching 80 % in 1984. Relevant operational data, i. e. electricity generation, activity and volume of liquid and gaseous effluents are presented in a graphic form in Figs. 1 - 4.

Liquid effluent discharge began in the first quater of 1982 and up to late 1984, H, I, Cr, Co, Mn, Fe, Zr, Tc, Xe, Mo, Na, Sb and Nb radionuclides had been identified in the liquid effluents. The emitted activities were far below the admissible limits. The same applies to tritium and noble gases identified in the gaseous effluents first released in the second quarter of 1982.

Liquid effluents are normally mixed with the condenser cooling water which is discharged into the Piraquara de Fora Bay (see site map, Fig. 5, p. 22).

However, the cooling water discharge canal had to be closed on several occasions for repairs on the condenser circuit, so that many of the monitored liquid effluent discharges were directed to Itaorna beach waters. This fact led IRD to introduce some modifications in the monitoring program which will be discussed later-on (Section 4.2). During the operational period considered a total of eight uncontrolled effluent discharges were recorded. Five of them were liquid discharges either to Piraquara de Fora or to Itaorna. Activity concentrations in environmental samples taken by the operator and IRD (upon request by the CNEN headquarters) after these accidental discharges were always below the detection limits. Detectable values were found only in samples taken on the premises.

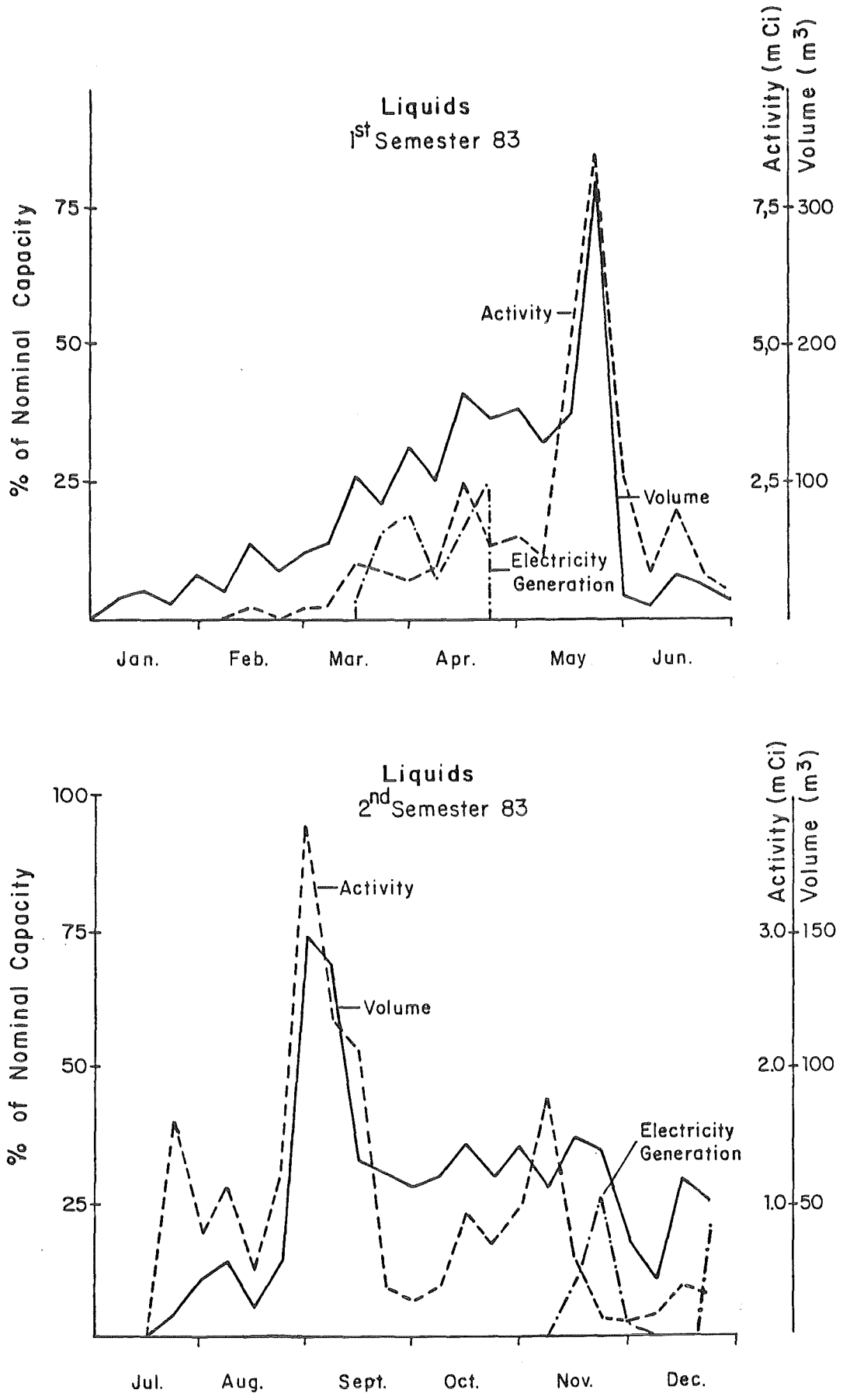

Fig. 1: Variations of power generation, volume and activities of liquid effluents in 1983.

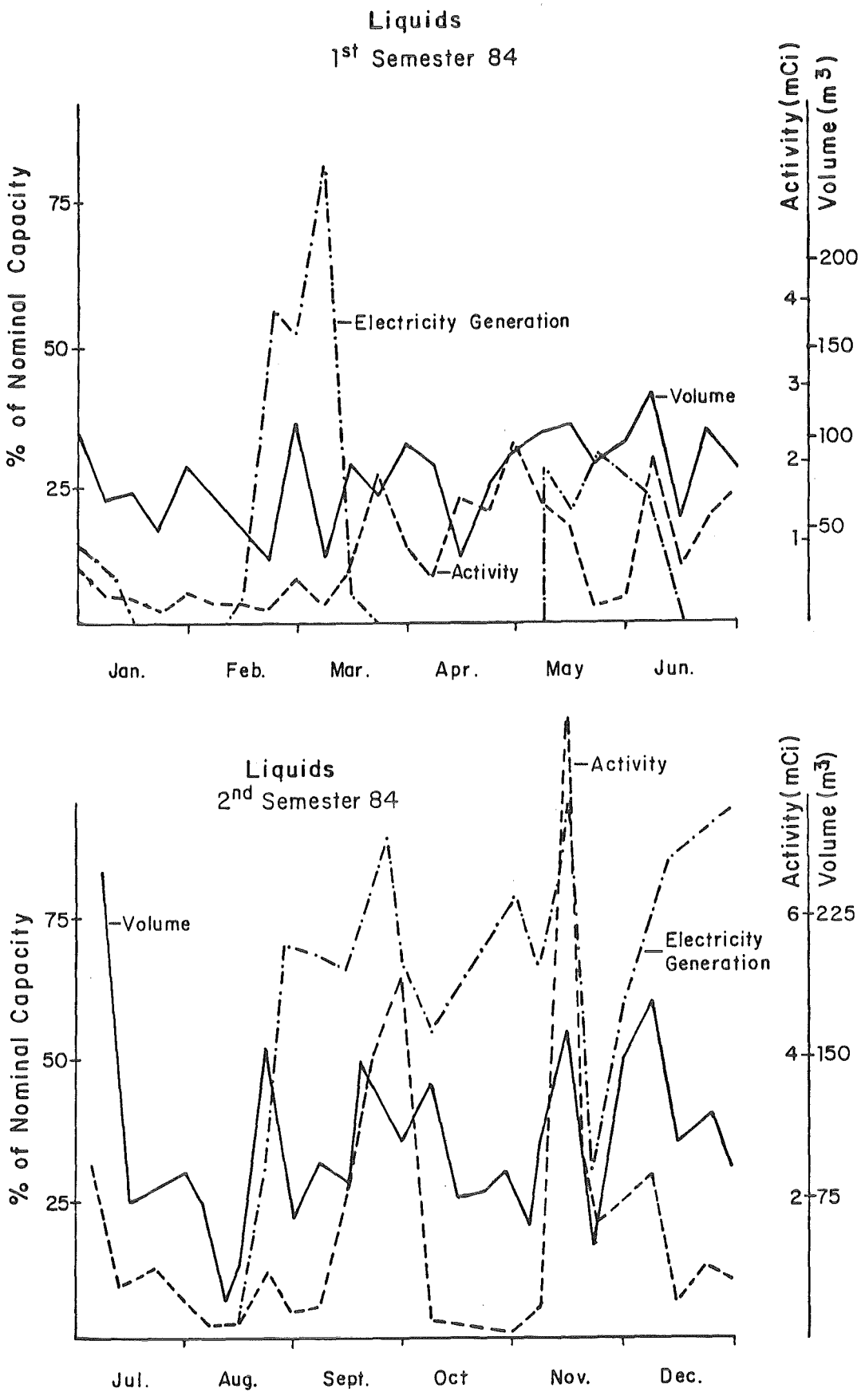

Fig. 2: Variations of power generation, volume and activities of liquid effluents in 1984.

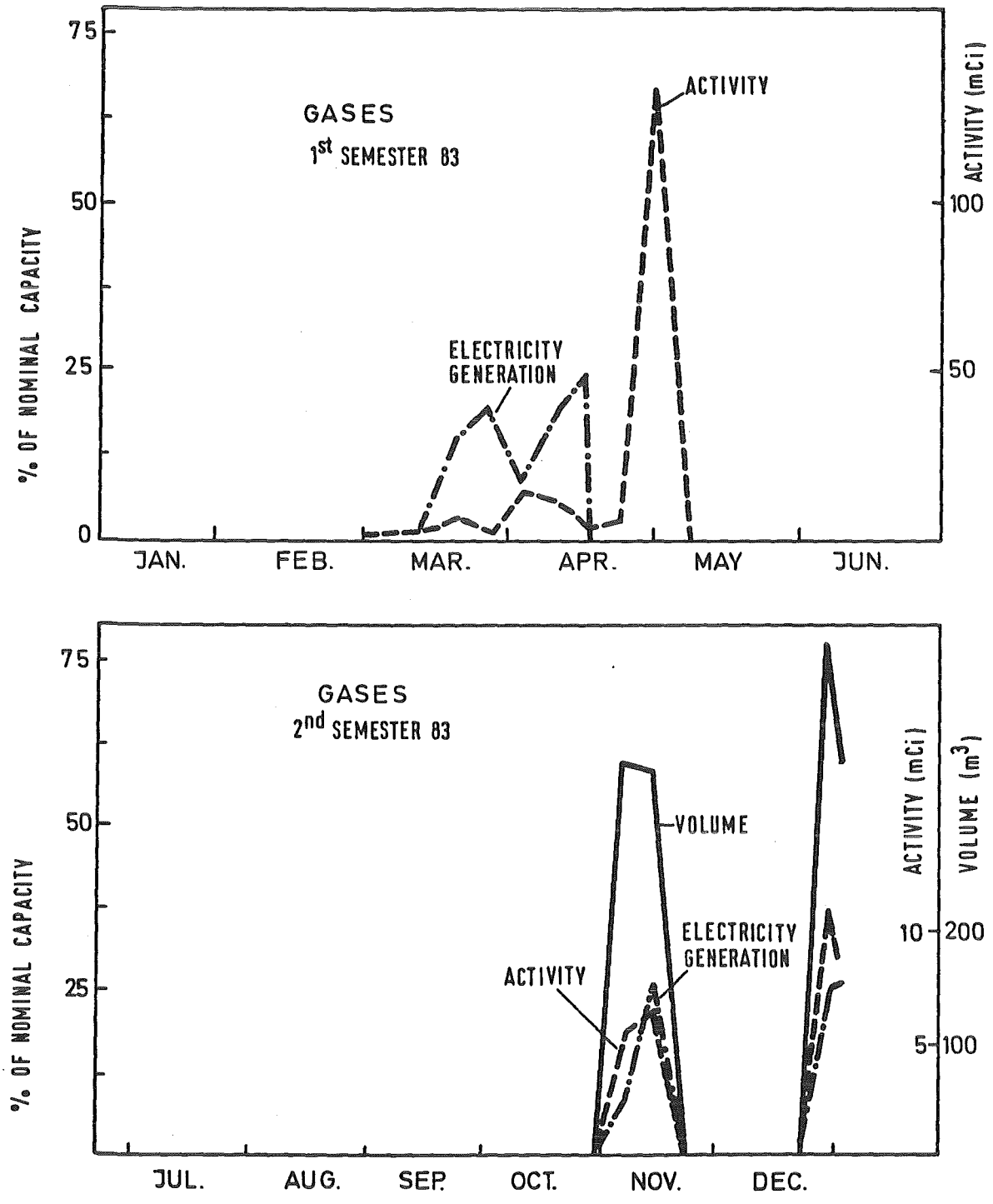

Fig. 3: Variations of power generation, volume and activities of gaseous effluents in 1983.

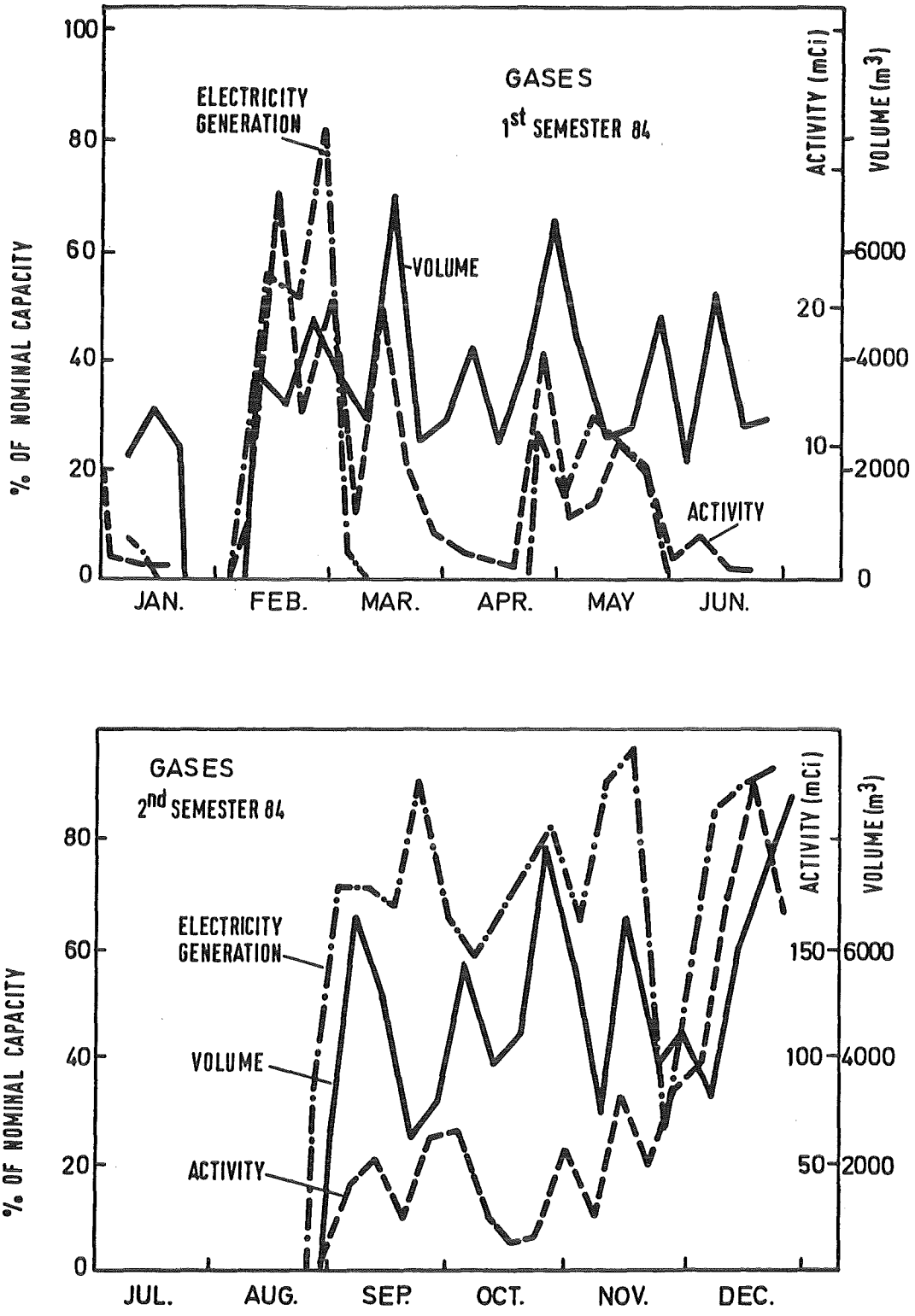

Fig. 4: Variations of power generation, volume and activities of gaseous effluents in 1984.

4. The Environmental Monitoring Program

4.1 The Program Established for the Operational Period of Unit 1

The media to be monitored, the sampling and measurement locations, the frequencies of monitoring, and the type of measurement to be performed were defined for the preoperational monitoring program. In formulating the program account was taken of the principal radionuclides likely to be emitted with the liquid and gaseous effluents of Unit 1. Two important pathways for human radiation exposure were identified for the liquid effluents: the ocean water - sea fish - man pathway and the direct radiation exposure paths by radionuclide deposition on beach sand. On the first pathway, "critical nuclides" are Cs-134 and Cs-137, while on the second the significant nuclides are Co-58 and Co-60. For the gaseous effluents the well known air - pasture - cow - milk - man pathway for radioiodine I-131 and the direct radiation exposure pathway of released radioactive noble gases were assumed to be of importance for monitoring.

After consideration of these pathways and of the preliminary site data (physical characteristics, predominant wind directions, local consumption habits and population distributions) the media to be monitored in addition to sampling and measurement locations and the frequencies of monitoring were specified.

Some adaptations introduced in the program for the operational period related only to the type of measurement and to the sampling locations. Tritium analysis in seawater and surface water was included. Some sampling lacations were left out because they were accessible temporarily only, others were included like sampling locations closer to the area of impact in the case of fish, crustaceans and mollusks.

The operational environmental program will be described in detail in a tabulated form (see p.12 - 21). Fig. 5 shows the TLD network and other measurement stations. The sampling locations are shown in Fig. 6.

Items of the monitoring program:

I. Direct Measurement of Radiation

I.1 Solid-state dosimeters
I.2 Ionization chambers

II. Radioactivity Measurements for the Air and Water Pathways

II.1 Aerosol
II.2 Radioiodine in air
II.3 Precipitation
II.4 Cow milk
II.5 Grass (pasture)
II.6 Surface water
II.7 Seawater
II.8 Sand
II.9 Sediment
II.10 Fish

III. Supplementary Radioactivity Measurements, Specifically Related to Terrestrial and Marine Food Chains

III.1 Soil
III.2 Bananas
III.3 Manioc (cassava)
III.4 Oranges
III.5 Seaweed
III.6 Crusteceans and mollusks

I. DIRECT MEASUREMENT OF RADIATION

Program Item	Monitoring Equipment Utilized	Measured Variables	Units Required	Values to be Reported	Number of Measurement Stations	Frequency of Measurements	Location of Measurement Stations	Remarks
I.1	Solid-state dosimeters	Local gamma dose H	mrem/a	Annual doses at individual stations	16	Quarterly	TLD control stations located along the boundary of the Angra NPP site: 1 station in the center of each of the diffusion sectors WNW, NNE and E.	These stations are adjacent to the operator's TLD measurement stations Nos. 1, 2 and 3.
							Control stations outside the Angra NPP site: 1) Ilha da Paquetá (ENE) 2) Ilha da Gipóia (ESE) 3) Ilha Sandri (SW) 4) Praia de Mambucaba (WSW) 5) Praia Brava (W) 6) Angra dos Reis Naval College (E) 7) Hotel do Praia (ENE) 8) Bracui (NE) 9) Tarituba (WSW) 10) Parati (SW)	Equivalent to operator's stations 8, 9, 10, 7 and 5, in this order.
							Additional stations 11) Hotel Frade (NNE) 12) Praia Frade (NNE) 13) Praia Piraquara de Dentro (SE)	
I.2	Ionization chambers	Local gamma dose rate $\dot{H}$	µrem/h		3	Continuous	Along the site boundary: 1) Diffusion sector WNW 2) Diffusion sector NNE 3) Diffusion sector E	Results to be sent to the supervisory authority by the NPP operator.

II. RADIOACTIVITY MEASUREMENTS FOR THE AIR AND WATER PATHWAYS

Program Item	Monitored Medium	Measured Variables	Units Required	Values to be Reported	Number of Sampling Locations	Frequency of Measurements and Samplings	Sampling Locations	Remarks
II.1	Aerosols	Long-lived specific alpha and beta gross activities (after about 7 days following the end of sampling)	fCi/m³	Single values	3	Quarterly (1 single filter from each station following a 2 weeks' collection period)	Along the site boundary: 1) Diffusion sector WNW 2) Diffusion sector NNE* 3) Diffusion sector E* *These stations were not operational during the pre-operational program.	The NPP operator was instructed to perform continuous air sampling for aerosols and to send the required samples to IRD, the supervisory authority.
		Specific activity of individual nuclides by gamma spectrometry	fCi/m³	Quarterly averaged values relative to the mid-period		Quarterly filter stack measured jointly		
II.2	Radioiodine in air (collected in activated charcoal cartridges)	Iodine-131 concentration in the atmosphere	fCi/m³	Single values	3	Quarterly (1 single cartridge from each station following a 2 weeks' collection period)	Same as program item II.1	Operator was instructed to send the required samples to the supervisory authority.
II.3	Precipitation	Long-lived alpha and beta gross activity concentration (after about 7 days following the end of sampling)	pCi/l	Monthly values and rainfall in mm/month	3	Quarterly (1 single sample from each station following the one month collection period)	Same as program item II.1	Operator was instructed to send all 9 samples for each quarter to the supervisory authority.
		Activity concentration of individual nuclides by gamma spectrometry	pCi/l					

II. RADIOACTIVITY MEASUREMENTS FOR THE AIR AND WATER PATHWAYS (CONTINUED)

Program Item	Monitored Medium	Measured Variables	Units Required	Values to be Reported	Number of Sampling locations	Frequency of Measurements and Samplings	Sampling Locations	Remarks
II.4	Cow milk	Iodine-131 concentration	pCi/l	Single values	3	Quarterly (1 single sample from one of the 3 locations)	1) Faz. Gratau (NNE) 2) Faz. Campo Alegre or Faz. Pedra Branca (ENE) 3) Fa. Milho Verde, near Mambucaba (WSW)	Rotation of sampling point every quarter. Samples originating from Faz. Milho Verde to be collected and sent to IRD by the NPP operator.
		Activity concentration of individual radionuclides determined by gamma spectrometry				Annually, (1 sample from each of the 3 locations)		
II.5	Grass (pasture)	Long-lived specific gross alpha and beta activities (after about 7 days following the end of sampling)	pCi/g dry matter	Single values	3	Quarterly (1 sample from each of the 3 locations)	Same as program item II.4	Samples originating from Faz. Milho Verde to be collected and sent to IRD by the NPP operator.
		Specific activity of individual radionuclides determined by gamma spectrometry				Annually, for each of the 3 locations		

II. RADIOACTIVITY MEASUREMENTS FOR THE AIR AND WATER PATHWAYS (CONTINUED)

Program Item	Monitored Medium	Measured Variables	Units Required	Values to be Reported	Number of Sampling Locations	Frequency of Measurements and Samplings	Sampling Locations	Remarks
II.6	Surface Water	Long-lived gross alpha and gross beta activity concentration (after about 7 days following sampling)	pCi/l	Single values	2	Semi-annual	1) Rio do Frade (NNE) 2) Córrego Cachoeiro Brava, water reservoir serving the Praia Brava settlement area (WNW) 3) Water reservoir serving the NPP site (NE)	Water at both Locations is used as drinking water
		K-40 activity concentration						
		Activity concentration of individual radionuclides by gamma spectrometry						
II.7	Seawater	Long-lived gross alpha and gross beta activity concentration (after about 7 days following sampling)	pCi/l	Single values	3	Quarterly (1 single sample from each location)	1) Saco do Piraquara de Fora, 100 m from point of cooling water discharge (ESE) 2) Itaorna Bay (location of NPP) (SW) 3) Tarituba Bay (WSW)	Seawater sampling at location 1 is performed continuously and the samples are split between FURNAS and IRD
		K-40 activity concentration						
		Activity concentration of individual radionuclides by gamma spectrometry						

II. RADIOACTIVITY MEASUREMENTS FOR THE AIR AND WATER PATHWAYS (CONTINUED)

Program Item	Monitored Medium	Measured Variables	Units Required	Values to be Reported	Number of Sampling Locations	Frequency of Measurements and Samplings	Sampling Locations	Remarks
II.8	Sand	Long-lived specific gross alpha and gross beta activities (after about 7 days following sampling)	pCi/g dry matter	Single values	4	Semi-annual	1) Praia Grande do Frade (NNE) 2) Praia de Piraquara de Dentro (SE) 3) Praia Brava (W) 4) Praia de Mambucaba (WSW)	
		Specific activity of the individual radionuclides determined by gamma spectrometry						
II.9	Sediment	Long-lived specific gross alpha and gross beta activities (after about 7 days following sampling)	pCi/g dry matter	Single values	4	Semi-annual	1) Saco do Frade (NNE) 2) Areas near Ilha de Paqueta (ENE) 3) Areas near Ilha do Brandão (ESE) 4) Bay of Tarituba (WSW)	The samples from points 1, 3 and 4 to be collected by the NPP operator and sent to IRD, the supervisory authority.
		Specific activity of the individual radionuclides determined by gamma spectrometry						

II. RADIOACTIVITY MEASUREMENTS FOR THE AIR AND WATER PATHWAYS (CONTINUED)

Program Item	Monitored Medium	Measured Variables	Units Required	Values to be Reported	Number of Sampling Locations	Frequency of Measurements and Samplings	Sampling Locations	Remarks
II.10	Fish, Sedentary and migratory	Long-lived specific gross alpha and gross beta activities (after 7 days following sampling)	pCi/g ash	Single values and weight ratio ash/ fresh matter	2	Semi-annual	1) Saco de Piraquara de Fora (ESE) 2) Tarituba Bay (WSW)	Due to time and material constraints fish samples were often bought from local fishermen after determining the fishing spots.
		Specific activity of the individual radionuclides determined by gamma spectrometry						

III. SUPPLEMENTARY RADIOACTIVITY MEASUREMENTS, SPECIFICALLY RELATED TO TERRESTRIAL AND MARINE FOOD CHAINS

Program Item	Monitored Medium	Measured Variables	Units Required	Values to be Reported	Number of Sampling Locations	Frequency of Measurements and Samplings	Sampling Locations	Remarks
III.1	Soil	Long-lived specific gross alpha and gross beta activities (after about 7 days following sampling)	pCi/g dry matter	Single values and weight ratio ash/ fresh matter	3	Annual	Same as program item II.4	Same as program item II.5
		Specific activity of the individual radionuclides determined by gamma spectrometry						
III.2	Bananas	Long-lived specific gross alpha and gross beta activities (after about 7 days following sampling	pCi/g ash	Single values	3	Semi-annual	1) Diffusion sector ENE, along the highway BR-101 "Rio Santos" close to NPP site 2) Cunhambebe (NNE) 3) Mambucaba (WSW)	
		Specific activity of the individual radionuclides determined by gamma spectrometry						

III. SUPPLEMENTARY RADIOACTIVITY MEASUREMENTS, SPECIFICALLY RELATED TO TERRESTRIAL AND MARINE FOOD CHAINS (CONT.)

Program Item	Monitored Medium	Measured Variables	Units Required	Values to be Reported	Number of Sampling Locations	Frequency of Measurements and Samplings	Sampling Locations	Remarks
III.3	Manioc (Cassava)	Long-lived specific gross alpha and gross beta activities (after about 7 days following sampling)	pCi/g ash	Single values and weight ratio ash/ fresh matter	1	Semi-annual	Farm near Mambucaba Beach (WSW)	
		Specific activity of the individual radionuclides determined by gamma spectrometry						
III.4	Oranges	Long-lived specific gross alpha and gross beta activities (after about 7 days following sampling)	pCi/g ash	Single values and weight ratio ash/ fresh matter	1	Twice per year at harvest time	Faz. Grataú (NNE)	
		Specific activity of the individual radionuclides determined by gamma spectrometry						

III. SUPPLEMENTARY RADIOACTIVITY MEASUREMENTS, SPECIFICALLY RELATED TO TERRESTRIAL AND MARINE FOOD CHAINS (CONT.)

Program Item	Monitored Medium	Measured Variables	Units Required	Values to be Reported	Number of Sampling Locations	Frequency of Measurements and Samplings	Sampling Locations	Remarks
III.5	**Seaweed**	Long-lived specific gross alpha and gross beta activities (after about 7 days following sampling)	pCi/g ash	Single values and weight ratio ash/ fresh matter	3	Semi-annual	1) Southern area of the Saco de Piraquara de Fora (ESE) 2) Pingo d'Agua Island (E) 3) Tarituba Bay (WSW)	Operator was instructed to send the samples from sampling location 3 to IRD, the supervisory authority.
		Specific K-40 activity						
		Specific activity of the individual radionuclides determined by gamma spectrometry						
III.6	Crustaceans and Mollusks	Long-lived specific gross alpha and gross beta activities (after about 7 days following sampling)	pCi/g ash	Single values and weight ratio ash/ fresh matter	2	Semi-annual	1) Southern area of the Saco de Piraquara de Fora (ESE) 2) Tarituba Bay (WSW)	The samples were purchased from local fishermen whenever the fishing spot could be determined.
		Specific K-40 activity						
		Specific activity of the individual radionuclides determined by gamma spectrometry						

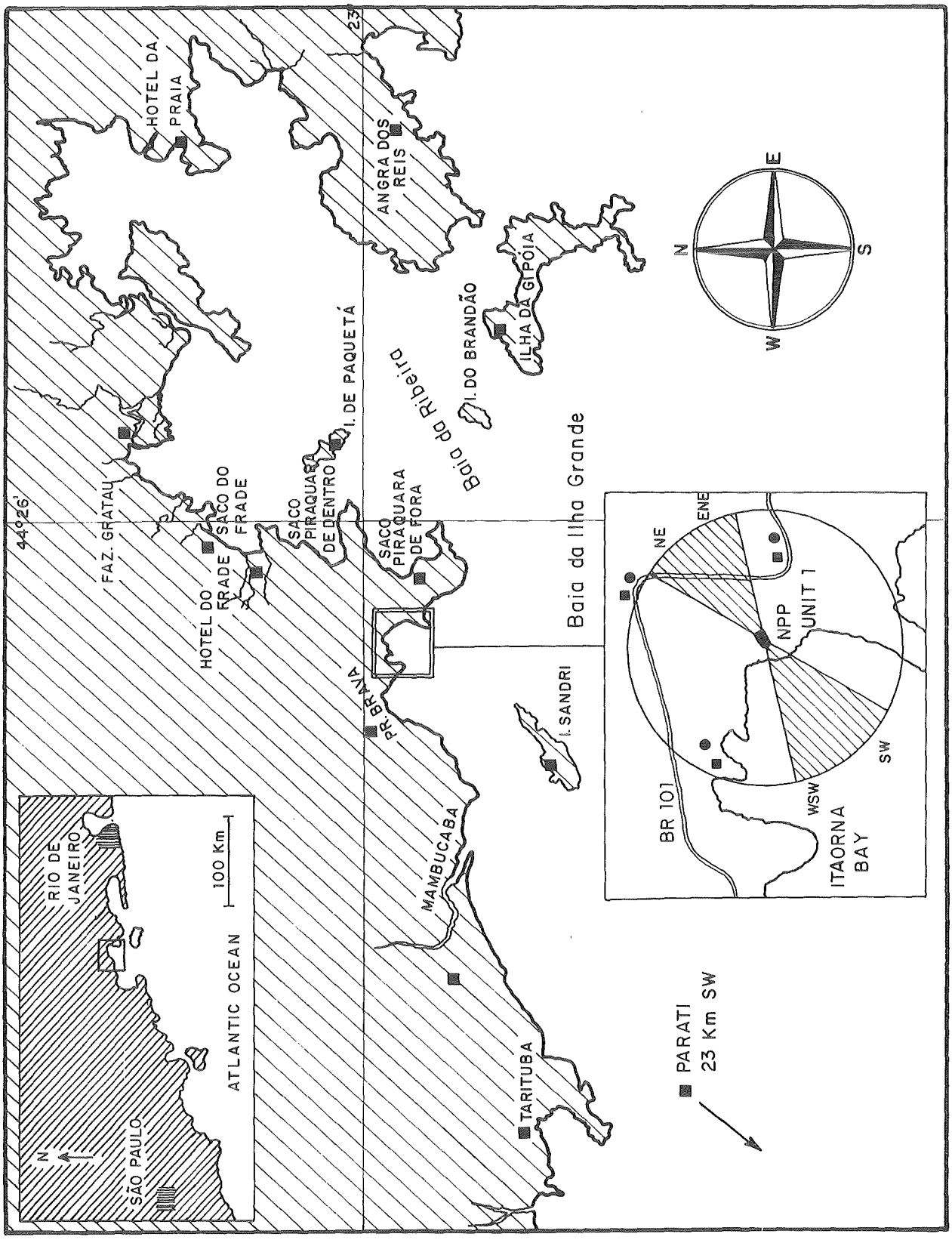

Fig. 5: Geographical location of the Angra Nuclear Power Plant Site and distribution of TLD (■) and ionization chamber (●) measurement stations.

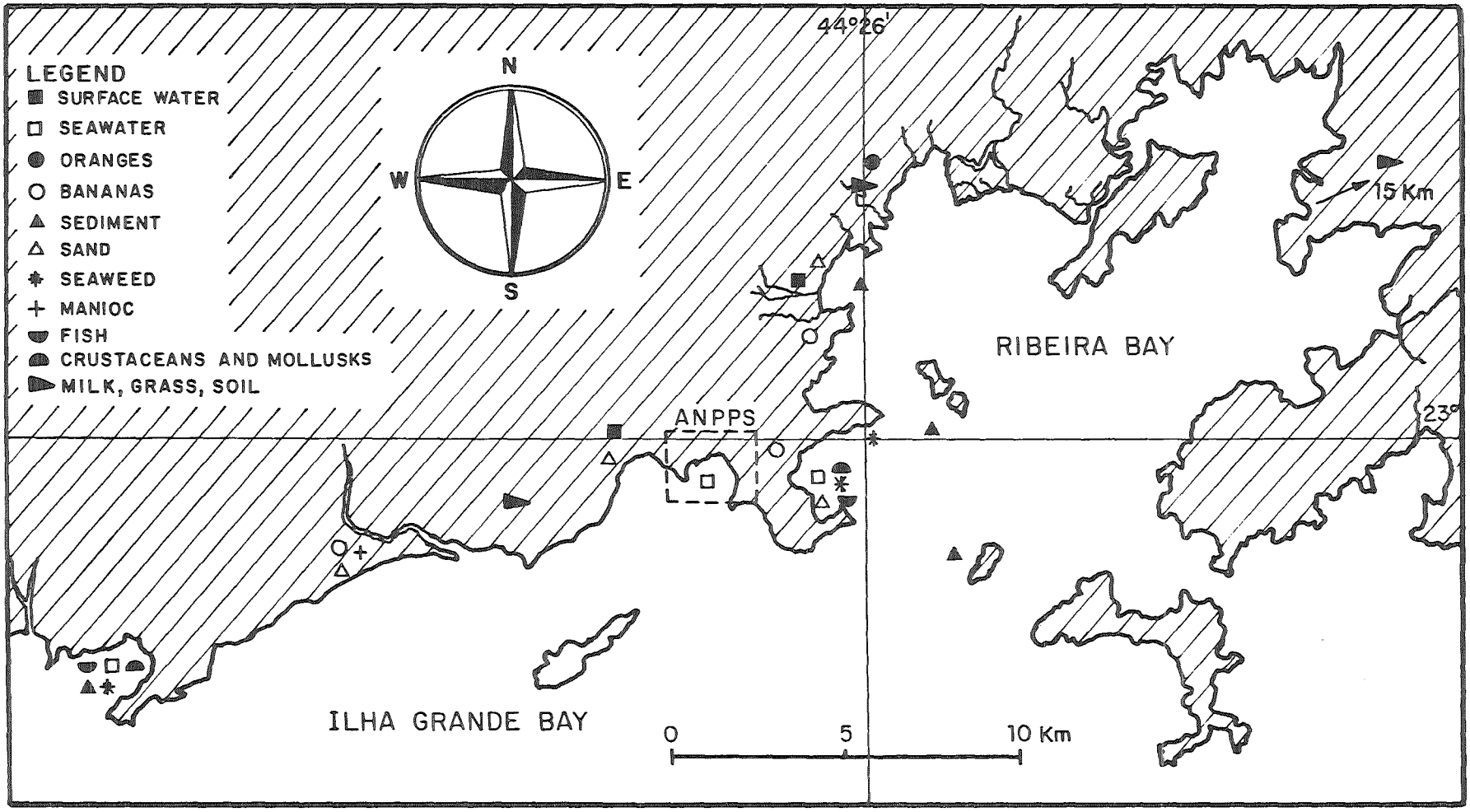

Fig. 6: Distribution of sampling locations around the Angra Nuclear Power Plant Site.

4.2 Program Modifications

The initial structure of the Operational Environmental Monitoring Programm was described in detail in Section 4.1. The changes, which were introduced later on, will be described here.

The main changes in the program were introduced, while it was being run, as a response to changing operator practices and to a changing environment and as a consequence of the acquired experience and information, especially those gathered from marine radioecological research carried out by the staff of the Department for Environmental Radiation Protection (DEPRA).

4.2.1 Soil, Pasture and Milk at Fazenda Milho Verde

As this sampling location is frequently in accessible, samples are taken and sent to IRD by the operator. However, Furnas had many difficulties to obtain milk and pasture samples because most of the cattle was sold and the pasture was burnt on several occasions. As a consequence, it was preferred to cancel this location from the program. Nevertheless, since Fazenda Milho Verde is located in one of the predominant wind diffusion sectors (WSE) the instruction to Furnas to send samples to IRD still holds. The last milk sample was received in January 1983.

As a result of these changes the sampling frequency for grass and milk was modified from quarterly to semi-annual.

4.2.2 Sediment

By the time the program was formulated, no detailed information was available on water and sediment transport patterns in Baia da Ribeira.

In the meantime, preliminary data obtained by the Geochemical Department of Universidade Federal Fluminense indicated that tidal currents cause alternating movements toward and from Baia da Ribeira. It was therefore considered to maintain the Paqueta and Frade locations since they provided information on the transport towards Baia da Ribeira. However, the Ilha do Brandão location was taken out of the program and substituted by Ponta Grossa (ESE) which, besides providing information on transport from Baia da Ribeira, is also closer to the impact area. Since, as already mentioned, Itaorna became a potential impact area for liquid effluents, sediment sampling supplementing the already existing seawater sampling was started at this location.

The controlled and uncontrolled liquid effluent discharges, which reached Itaorna on different occasions, justify the intensification of environmental monitoring at this location. An additional program item was therefore formulated for the annual sampling and spectrometric analysis of sediment and seawater in Itaorna Dike.

4.2.3 Fish and Shrimps

During the preoperational period, fish and shrimps were obtained from local fishermen. Because of the uncertainties concerning the fishing spots actually used by the fishermen, such sampling was performed during the operational program by IRD in cooperation with the operator, or by renting small fishing boats. Sedentary fish were caught by fish traps installed by divers and left overnight.

The work performed at DEPRA by Vetere [3] which comprised two years monitoring of the fish-fauna composition on the bottom of the sea, abundance and distribution at the bays of Piraquara de Fora and Piraquara de Dentro had shown marked differences between these two water bodies, despite their proximity. Therefore, both were included as fishing locations for non-sedentary fish in addition to Tarituba. Such

sampling effort was seldom worthwhile since no suitable fish or shrimp sample could be obtained at Tarituba, shrimp samples were occasionally obtained at Piraquara de Dentro, and fish sampling was succesful only at Piraquara de Dentro which confirms Vetere's data. Sedentary fish sampling at Piraquara de Fora was not successful either.

4.2.4 Seaweed

Sargassum and Acanthophora were the seaweeds which were initially sampled, the latter being collected only at Tarituba. However, both the sampling practice and the seaweed survey performed by Pedrini et al. [4] showed that Acantophora was very irregularly distributed over the year. A suitable Sargassum sampling location was therefore searched and found at Tarituba and Acanthophora sampling was discontinued. In this way a more reliable comparison of analytical results between the impact and control sampling location is now possible for this program item.

4.2.5 Mollusks

Sampling of mollusks was initially planned for Tarituba and Piraquara de Fora. However, an exhaustive survey by scuba divers and bottom sediment sampling showed that such organisms could not be obtained at these locations in quantities acceptable for the purposes of radiometric analysis. Dense mollusk populations are found only at Praia Grande do Frade (NNE) and Parati (SE), which were therefore included as sampling locations for the mollusk Anomalocardia.

4.2.6 Seawater

The large amount of the beta emitting K-40 occurring naturally in seawater makes rather difficult to detect any other beta-emitter, unless specific enrichment procedures are used. Since the only beta emitter expected in the liquid effluents of Unit 1 is Sr-90, gross beta activity measurements in seawater would be advantageouly replaced by radiochemical separation of Sr. Due to the frequent lack of a correlation between the K-40 specific activity and the gross-beta activity, and because of the great errors associated with it gross-beta activity measurements were discontinued in Spetember 1984.

5. Discussion of Summarized and Single Measurement Results

In this section, single and summarized measurement results are presented and discussed for each program item in the same sequence as used in the tabulated program description of section 4.1. The criteria used in data handling are described in the Annex.

The results for biological matrixes are given on an ash weight basis, but the average fresh weight to ash weight ratios obtained for each item during the monitoring period are listed in Table 40.

5.1 Solid-state Dosimeters

The thermoluminescent dosimeter (TLD) network established during the preoperational period was left essentially unchanged. Of a total of 18 TLD stations only two (Ponta de Caieirinha and Fazenda Gratañ) were taken out of the program because of inaccessability and/or frequent dosimeter losses or thefts.

The first TLD stations were installed in 1977. A selection of yearly results of the stations for which data are available from 1977 to 1984 is presented in graphic form in Fig. 7 to illustrate the geographic and temporal variations of direct radiation doses. The highest dose rates were observed for Mambucaba (up to 162 mrem/a) and Praia do Frade (up to 249 mrem/a) as expected from the presence of monazytic sand deposits at these locations. In the case of the Praia do Frade station, no satisfactory explanation can be given for the gradual decrease of the dose rates from 1977 to 1981 since no significant change had been observed in the vicinity of the station during these years.

Summarized $CaSO_4$-TLD data for the monitoring period are presented in Table 1. The average dose rate for all stations taken together was 113 mrem/a with a minimum of 64 mrem/a at Ilha de Paquetá and a maximum of 169 mrem/a at Praia do Frade. The general average for the preoperational monitoring period and for the same type of TLD was 118 mrem/a.

Yearly results for the 1982 - 1984 monitoring period are presented for all TLD stations in Tables 2, 4 and 6 ($CaSO_4$-TLD) and in Tables 3, 5 and 7 (LiF-TLD) and presented graphically in Fig. 8 and Fig. 9, respectively.

The year to year variations of the dose rates are within the 10 % measurement error, both for the stations located along the site fence and for the other stations. The higher dose rates at the NNE and E stations compared to the WNW station can be explained by their proximity to the basaltic rocks of the surrounding mountains.

When data were not available for some periods because of dosimeter loss or theft or when there were exposures over differing time intervals the doses were extrapolated or interpolated for the calendar year. The remark applies to all TLD data presented here.

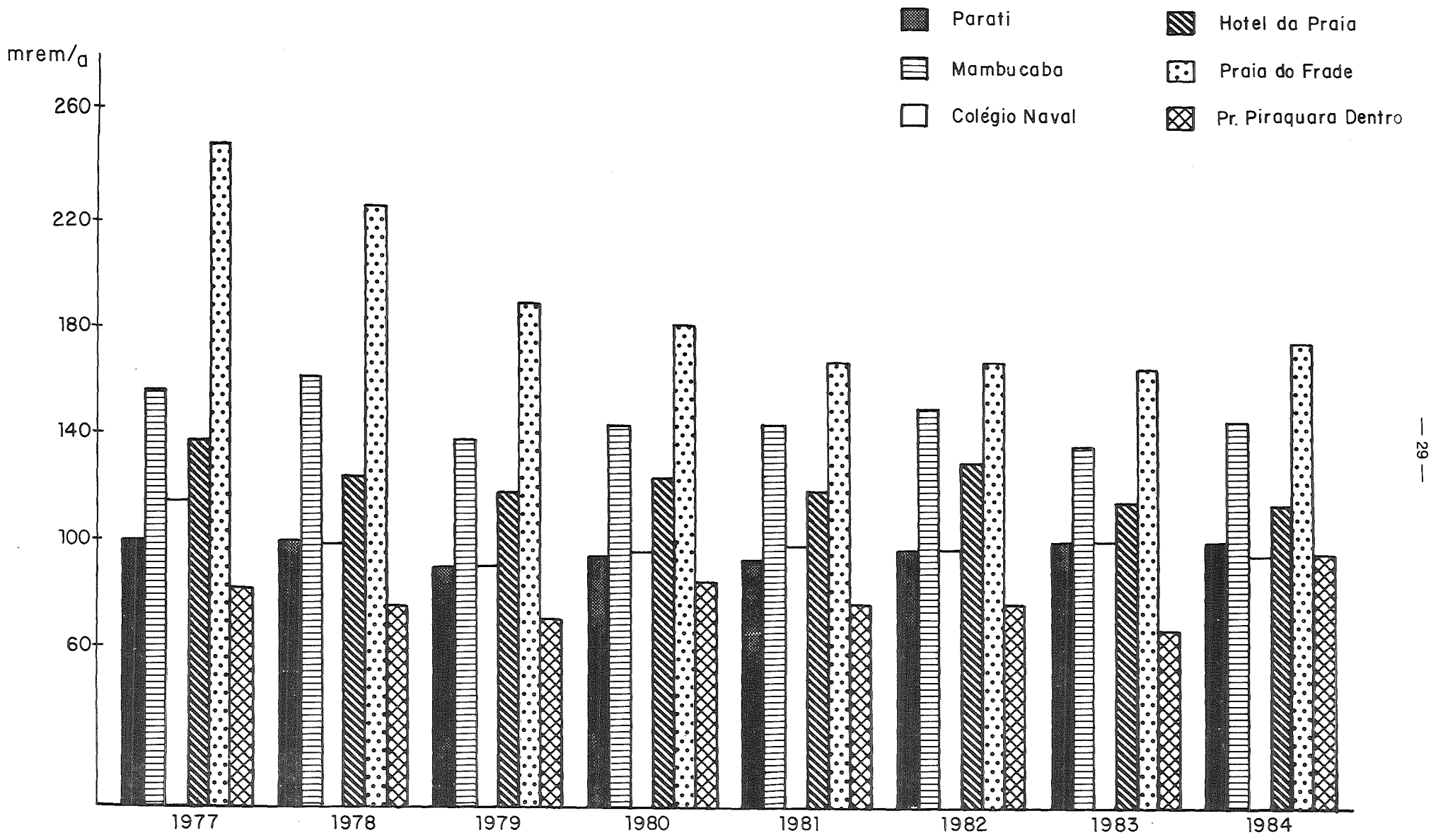

Fig.7 : Yearly $CaSO_4$-TLD results for six measurement stations from 1977 to 1984.

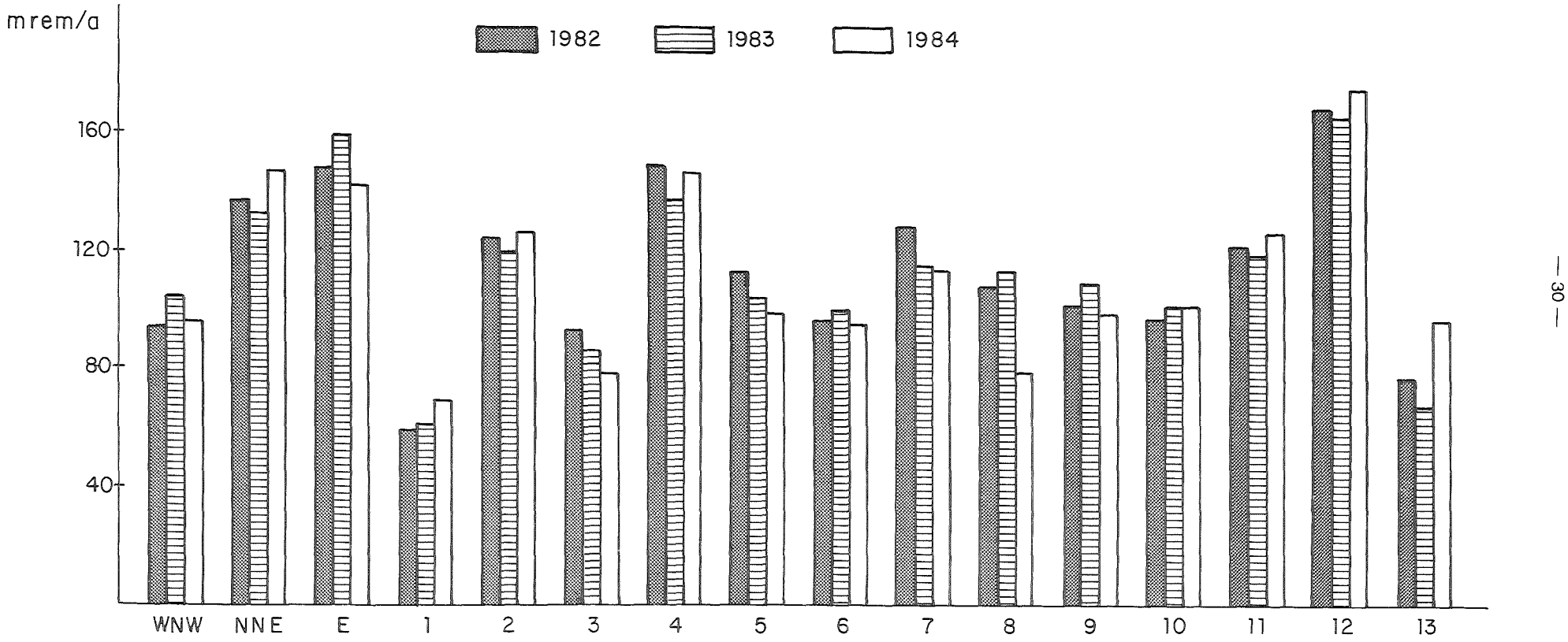

Fig. 8 : Yearly $CaSO_4$-TLD results for all measurement stations from 1982 to 1984. The stations are numbered according to the program description.

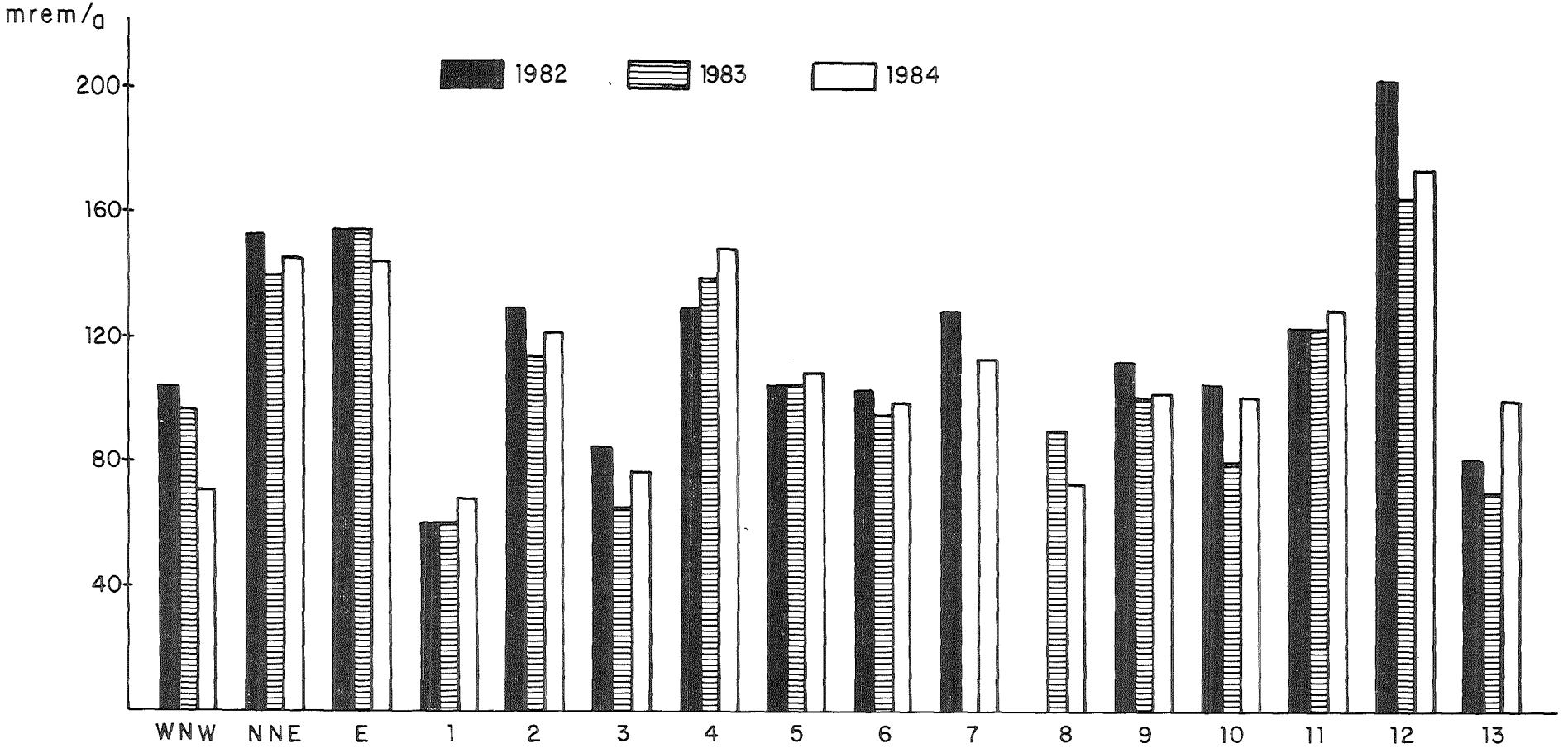

Fig. 9: Yearly LiF-TLD results for all measurement stations from 1982 to 1984. Stations are numbered according to the program description. No data were available for station 7 in 1983 and for station 8 in 1982.

Number of Measurement Stations		16
Total Exposure Time		519 months
Local Dose	Average	113 mrem/a
	Minimum	64 mrem/a
	Maximum	169 mrem/a
Corresponding Average Local Dose Rate		12.9 µrem/h

Table 1: $CaSO_4$-TLD measurement results for the monitoring period 1982 - 1984

Location of TLD Station	Diffusion Sector	Exposure Period in Months	Annual Local Dose mrem/a	Annual Local Dose µrem/h
At the Site Fence				
WNW	WNW	12	94± 6.0	10.7±0.7
NNE	NNE	12	137± 8.9	15.6±1.0
E	E	12	148± 9.5	16.9±1.1
Off-site				
1. Ilha de Paquetá	ENE	12	59± 3.9	6.7±0.4
2. Ilha da Gipoia	ESE	6	129±11.5	14.2±1.3
3. Ilha Sandri	SW	9	93± 5.9	10.6±0.7
4. Praia de Mambucaba	WSW	12	149± 9.6	17.0±1.1
5. Praia Brava	W	12	113± 7.1	12.9±0.8
6. Colégio Naval	E	12	97± 6.2	11.1±0.7
7. Hotel da Praia	ENE	12	128± 8.1	14.6±0.9
8. Bracuí	NE	9	108± 6.9	12.3±0.8
9. Tarituba	WSW	12	122± 6.5	11.6±0.7
10. Paratí	SW	9	97± 6.3	11.1±0.7
11. Hotel do Frade	NNE	12	121± 7.8	13.8±0.9
12. Praia do Frade	NNE	12	168±10.8	19.2±1.2
13. Praia Piraquara de Dentro (in the bay called Saco de Piraquara de Fora)	SE	12	77± 4.9	8.8±0.6
All Stations				
Total		177		
Mean Value			114±28	13.0±3.2

Table 2: Solid-state dosimeter data (program item I.1). Exposure periods and extrapolated annual local doses for $CaSO_4$-TLD in 1982.

Location of TLD Station	Diffusion Sector	Exposure Period in Months	Annual Local Dose mrem/a	Annual Local Dose µrem/h
At the Site Fence				
WNW	WNW	6	104± 6.7	11.9±0.8
NNE	NNE	6	153± 5.0	17.5±0.5
E	E	6	155± 4.8	17.7±0.5
Off-site				
1. Ilha de Paquetá	ENE	6	60± 4.9	6.8±0.6
2. Ilha da Gipoia	ESE	6	129± 6.4	14.7±0.7
3. Ilha Sandri	SW	6	84± 6.4	9.6±0.7
4. Praia de Mambucaba	WSW	6	129± 5.2	14.7±0.6
5. Praia Brava	W	6	105± 6.5	12.0±0.7
6. Colégio Naval	E	6	103± 6.5	11.8±0.7
7. Hotel da Praia	ENE	6	129± 7.1	14.7±0.8
8. Bracuí	NE	-		
9. Tarituba	WSW	6	112± 6.8	12.8±0.8
10. Paratí	SW	6	105± 6.8	12.0±0.8
11. Hotel do Frade	NNE	6	123± 6.2	14.0±0.7
12. Praia do Frade	NNE	6	203± 7.3	23.2±2.0
13. Praia Piraquara de Dentro (in the bay called Saco de Piraquara de Fora)	SE	6	81± 5.6	9.2±0.7
All Stations				
Total		90		
Mean Value			118±35	136 ±4.0

Table 3: Solid-state dosimeter data (program item I.1). Exposure periods and extrapolated annual local doses for LiF-TLD in 1982.

Location of TLD Station	Diffusion Sector	Exposure Period in Months	Annual Local Dose mrem/a	Annual Local Dose µrem/h
At the Site Fence				
WNW	WNW	12	105± 6.6	12.0±0.8
NNE	NNE	12	132± 8.8	15.1±1.0
E	E	9	159±10.5	18.2±1.2
Off-site				
1. Ilha de Paquetá	ENE	3	61± 8.0	7.0±0.9
2. Ilha da Gipoia	ESE	12	119± 7.9	13.6±0.9
3. Ilha Sandri	SW	3	86±11.3	9.8±1.3
4. Praia de Mambucaba	WSW	12	137± 9.1	15.6±1.0
5. Praia Brava	W	12	104± 6.9	11.9±0.8
6. Colégio Naval	E	12	100± 6.6	11.4±0.8
7. Hotel da Praia	ENE	6	115±10.6	13.1±1.2
8. Bracuí	NE	12	113± 7.4	12.9±0.8
9. Tarituba	WSW	12	109± 7.2	12.4±0.8
10. Paratí	SW	12	101± 6.8	11.5±0.8
11. Hotel do Frade	NNE	12	119± 7.8	13.6±0.9
12. Praia do Frade	NNE	12	165±10.4	18.8±1.2
13. Praia Piraquara de Dentro (in the bay called Saco de Piraquara de Fora)	SE	6	67± 6.0	7.6±0.7
All Stations				
Total		159		
Mean Value			112±28	12.8±3.2

Table 4: Solid-state dosimeter data (program item I.1). Exposure periods and extrapolated annual local doses for $CaSO_4$-TLD in 1983.

Location of TLD Station	Diffusion Sector	Exposure Period in Months	Annual Local Dose mrem/a	Annual Local Dose µrem/h
At the Site Fence				
WNW	WNW	12	97±10.4	11.1±1.2
NNE	NNE	12	140±15.0	16.0±1.7
E	E	12	155±16.5	17.7±1.9
Off-site				
1. Ilha de Paquetá	ENE	6	60± 9.1	6.8±1.0
2. Ilha da Gipoia	ESE	12	114±12.1	13.0±1.4
3. Ilha Sandri	SW	6	65± 9.8	7.4±1.1
4. Praia de Mambucaba	WSW	12	139±14.8	15.9±1.7
5. Praia Brava	W	12	105±11.3	12.0±1.3
6. Colégio Naval	E	12	95±10.1	10.8±1.2
7. Hotel da Praia	ENE	-		
8. Bracuí	NE	6	90±13.5	10.3±1.5
9. Tarituba	WSW	12	101±10.7	11.5±1.2
10. Paratí	SW	6	80±12.0	9.1±1.4
11. Hotel do Frade	NNE	12	123±13.1	14.0±1.5
12. Praia do Frade	NNE	12	165±17.5	18.8±2.0
13. Praia Piraquara de Dentro (in the bay called Saco de Piraquara de Fora)	SE	12	70± 7.4	8.0±0.8
All Stations				
Total		156		
Mean Value			107± 32	12.2± 3.7

Table 5: Solid-state dosimeter data (program item I.1). Exposure periods and extrapolated annual local doses for LiF-TLD in 1983.

Location of TLD Station	Diffusion Sector	Exposure Period in Months	Annual Local Dose mrem/a	Annual Local Dose µrem/h
At the Site Fence				
WNW	WNW	12	96± 6.3	10.9±0.7
NNE	NNE	12	147± 9.8	16.7±1.1
E	E	12	142± 9.4	16.2±1.1
Off-site				
1. Ilha de Paquetá	ENE	12	69± 4.6	7.9±0.5
2. Ilha da Gipoia	ESE	12	126± 8.3	14.3±0.9
3. Ilha Sandri	SW	12	78± 5.1	8.9±0.6
4. Praia de Mambucaba	WSW	12	147±10.2	16.7±1.2
5. Praia Brava	W	12	109± 7.2	12.4±0.8
6. Colégio Naval	E	12	95± 6.3	10.8±0.7
7. Hotel da Praia	ENE	9	114± 7.7	13.0±0.9
8. Bracuí	NE	6	79± 4.1	9.0±0.5
9. Tarituba	WSW	12	99± 6.6	11.3±0.8
10. Paratí	SW	12	101± 6.6	11.5±0.8
11. Hotel do Frade	NNE	12	126± 8.3	14.3±0.9
12. Praia do Frade	NNE	12	175±11.8	19.9±1.3
13. Praia Piraquara de Dentro (in the bay called Saco de Piraquara de Fora)	SE	12	96± 6.7	10.9±0.8
All Stations				
Total		183		
Mean Value			112±29	12.8±3.3

Table 6: Solid-state dosimeter data (program item I.1). Exposure periods and extrapolated annual local doses for $CaSO_4$-TLD in 1984.

Location of TLD Station	Diffusion Sector	Exposure Period in Months	Annual Local Dose mrem/a	Annual Local Dose µrem/h
At the Site Fence				
WNW	WNW	12	71± 8.3	8.1±0.9
NNE	NNE	12	145±15.4	16.5±1.8
E	E	12	144±15.4	16.4±1.8
Off-site				
1. Ilha de Paquetá	ENE	12	68± 7.3	7.7±0.8
2. Ilha da Gipoia	ESE	12	121±12.9	13.8±1.5
3. Ilha Sandri	SW	12	77± 8.3	8.8±0.9
4. Praia de Mambucaba	WSW	12	148± 9.4	16.8±1.1
5. Praia Brava	W	12	108±11.6	12.3±1.3
6. Colégio Naval	E	12	99±10.5	11.3±1.2
7. Hotel da Praia	ENE	6	113±17.0	12.9±1.9
8. Bracuí	NE	6	73±10.9	8.3±1.2
9. Tarituba	WSW	6	102±15.2	11.6±1.7
10. Paratí	SW	12	101±10.8	11.5±1.2
11. Hotel do Frade	NNE	12	129±13.9	14.7±1.6
12. Praia do Frade	NNE	12	174±19.1	19.8±2.2
13. Praia Piraquara de Dentro (in the bay called Saco de Piraquara de Fora)	SE	12	100±11.0	11.4±1.3
All Stations				
Total		174		
Mean Value			111±31	12.6±3.5

Table 7: Solid-state dosimeter data (program item I.1). Exposure periods and extrapolated annual local doses for LiF-TLD in 1984.

5.2 Ionization Chambers

See comments in section 6.2.

5.3 Aerosols

Single and summarized results for gross alpha and beta activity measurements are given in Tables 8 and 9. For both types of measurement the result in the WNW sector tend to be lower than those for the other sampling locations, NNE and E. The general average of 6.4 pCi/m^3 for gross beta activity is lower than the figure obtained during the preoperational period which was 18 fCi/m^3. This may be explained by the intense dust production on the site at the time of construction, and by the operation of a stone crushing mill on the site, which reduced its activity production during the last years. No comparison is possible with gross alpha activity results since such measurements were not reported for the preoperational period.

No artifical radionuclide was identified in aerosol samples by gamma spectrometry. The minimum detection limits for this type of measurement are given in Table 41.

Type of Radioactivity	Sampling Sector and Number of Sanples Analyzed *	Activity Concentration in fCi/m³			
		Average	Min.	Max.	General Average
Gross alpha	WNW 10	3.8 ± 0.7	1.9	9.3	
(related to	NNE 10	< 5.3 ± 1.3	< 1.7	16	< 5.0 ± 0.9
Am-241)	E 10	6.0 ± 0.7	1.6	8.8	
Gross beta	WNW 10	< 4.9 ± 1.5	< 1.1	14	
(related to	NNE 10	7.1 ± 1.1	< 2.1	12	< 6.4 ± 1.5
K-40)	E 10	< 7.1 ± 1.6	< 1.4	16	

* The number of samples refers to quarterly filter stacks measured jointly.

Table 8: Radioactivity in aerosols during the period December 1981 - September 1984.

Sampling Location	Collection Period	Long-lived Activity Concentration in fCi/m³	
		Gross alpha (related to Am-241)	Gross beta (related to K-40)
Sector WNW	30.11.81 - 25.02.82	2.0 ± 0.3	1.9 ± 0.2
	25.02.82 - 20.05.82	3.1 ± 0.6	1.9 ± 0.4
	20.05.82 - 16.08.82	1.9 ± 0.5	3.0 ± 0.5
	16.08.82 - 09.11.82	4.1 ± 0.7	< 1.3
	23.11.82 - 03.02.83	4.3 ± 4.5	5.6 ± 4.1
	29.04.83 - 29.07.83	9.3 ± 5.9	14.0 ± 5.6
	29.07.83 - 31.10.83	5.4 ± 1.4	12.0 ± 1.3
	29.12.83 - 28.03.84	2.0 ± 0.6	2.8 ± 0.5
	28.03.84 - 28.06.84	3.4 ± 0.6	5.4 ± 0.7
	28.06.84 - 27.09.84	2.7 ± 0.5	1.1 ± 0.4
Sector NNE	30.11.81 - 25.02.82	4.3 ± 0.8	7.4 ± 0.9
	25.02.82 - 20.05.82	5.7 ± 0.9	2.7 ± 0.6
	20.05.82 - 16.08.82	5.1 ± 0.8	8.4 ± 0.9
	16.08.82 - 09.11.82	4.9 ± 0.8	6.7 ± 0.8
	09.11.82 - 03.02.83	16.0 ± 7.1	11.0 ± 5.0
	29.04.83 - 29.07.83	< 4.3	11.0 ± 5.0
	29.07.83 - 01.11.83	5.7 ± 1.5	12.0 ± 1.3
	19.12.83 - 28.03.84	1.9 ± 0.8	3.1 ± 0.6
	28.03.84 - 28.06.84	3.0 ± 0.6	6.1 ± 0.7
	28.06.84 - 27.09.84	1.7 ± 0.5	2.1 ± 0.4
Sector E	30.11.81 - 25.02.82	8.0 ± 1.1	7.4 ± 0.8
	25.02.82 - 20.05.82	6.9 ± 0.9	2.5 ± 0.5
	20.05.82 - 16.08.82	3.6 ± 0.7	< 1.4
	16.08.82 - 09.11.82	6.3 ± 0.9	5.0 ± 0.7
	09.11.82 - 03.02.83	8.4 ± 5.3	9.6 ± 4.7
	29.04.83 - 29.07.83	8.8 ± 5.8	14.0 ± 5.6
	29.07.83 - 31.10.83	6.5 ± 1.5	16.0 ± 1.3
	29.12.83 - 28.03.84	4.1 ± 1.1	3.6 ± 0.7
	28.03.84 - 28.06.84	6.0 ± 1.0	9.6 ± 1.0
	28.06.84 - 13.09.84	1.6 ± 0.6	2.3 ± 0.5

Table 9: Radioactivity in aerosols (program item II.1) collected in the sectors WNW, NNE and E at the NPP fence.

5.4 Radioiodine in Air

The results of I-131 activity measurements on charcoal cartridges are given in Table 10. The results were always below the minimum detection limits, which ranged from 10 to 420 fCi/m^3 depending on the variable delays in the transportation of the filters to IRD. The minimum detection of 10 fCi/m^3 achieved when analysis closely followed sampling, was reached only once. At any rate, it was not expected to detect radioiodine because it has not occurred in Unit 1 gaseous effluents to date. Neither could it be expected that in the light of the small number of nuclear weapons' tests in the southern hemisphere and the short half-life of I-131 measurable concentrations of radioiodine in air occured.

Sampling Location	Collection Period	I-131-Activity Concentration in fCi/m³
Sector WNW	19.01.83 - 03.02.83	< 30
	17.03.83 - 31.03.83	< 70
	14.04.83 - 29.04.83	< 170
	31.05.83 - 15.06.83	< 420
	29.06.83 - 14.07.83	< 50
	15.08.83 - 30.08.83	< 200
	01.11.83 - 16.11.83	< 90
	30.11.83 - 15.12.83	< 50
	29.12.83 - 16.01.84	< 170
	07.03.84 - 14.03.84	< 20
	25.10.84 - 01.11.84	< 160
Sector NNE	07.02.83 - 17.02.83	NA
	03.03.83 - 17.03.83	< 90
	31.03.83 - 14.04.83	< 40
	16.05.83 - 31.05.83	< 60
	15.06.83 - 29.06.83	< 90
	14.07.83 - 29.07.83	< 260
	13.09.83 - 29.09.83	< 400
	18.04.84 - 25.04.84	< 30
	16.05.84 - 24.05.84	< 10
	25.10.84 - 05.11.84	< 50
	29.11.84 - 06.12.84	< 15
Sector E	29.04.83 - 16.05.83	< 50
	29.07.83 - 15.08.83	< 20
	30.08.83 - 15.09.83	< 50
	29.10.83 - 13.10.83	< 80
	30.01.84 - 15.02.84	< 40
	13.06.84 - 21.06.84	< 12
	12.07.84 - 19.07.84	< 10
	25.10.84 - 01.11.84	< 100

NA = Not analyzed

Table 10: Radioiodine in air (program item II.2) collected in activated charcoal cartridges in 3 sectors at the NPP fence.

5.5 Precipitation

Some of the precipitation samples sent to IRD by the operator were selcted for gross alpha and beta activity measurements. The summarized and single results are shown in Tables 11 and 12. The gross alpha activity was above the minimum detection limit in only 2 out of 49 analyzed samples collected in the NNE sector in Feb. 83 and Oct. 84. The gross beta activity, as a rule was close to or below the minimum detection limit. However, higher values were found in sectors NNE (18 pCi/l in February 1983) and E (26 pCi/l in April 1982). Nevertheless, these values are still lower than the average gross beta activity found in precipitations during the preoperational period which was 34.5 pCi/l. The activity concentrations of artificial gamma emitters were all below the minimum detection limits, which are listed in Table 42.

Type of Radio-activity	Sampling Sector and Number of Samples Analyzed		Activity Concentration in pCi/l Average	Min.	Max.	General Average
Gross alpha (related to Am-241)	WNW	18	< 1.3	< 0.7	< 4.2	
	NNE	13	< 1.8 ± 0.5	< 0.8	2.1	< 1.8 ± 0.3
	E	18	< 2.2	< 0.7	< 8.4	
Gross beta (related to K-40)	WNW	18	< 3.3 ± 0.4	< 2.0	4.8	
	NNE	13	< 4.5 ± 1.2	< 2.0	18	< 4.0 ± 1.0
	E	18	< 4.1 ± 1.2	< 2.1	26	

Table 11: Radioactivity in precipitations during the period March 1982 - December 1984.

Month of Collection	Precipitations in mm	Activity Concentration in pCi/l	
		Gross alpha (related to Am-241)	Gross beta (related to K-40)
March 82	289	< 1.0	< 2.0
April 82	90	< 1.1	< 2.1
June 82	53	< 1.0	< 6.8
August 82	127	< 1.6	< 8.2
September 82	164	< 1.0	< 3.2
October 82	153	< 1.0	3.5 ± 2.4
November 82	123	< 4.2	< 2.7
February 83	87	< 1.1	< 2.4
March 83	223	< 2.1	< 2.6
April 83	68	< 2.8	< 2.7
May 83	123	< 0.9	4.8 ± 2.8
June 83	100	< 0.8	3.5 ± 2.5
September 83	234	< 0.9	< 2.3
October 83	164	< 0.8	< 2.3
November 83	141	< 0.8	< 2.1
December 83	109	< 0.9	2.7 ± 2.4
August 84	73	< 0.9	3.3 ± 2.4
December 84	270	< 0.7	< 2.2

Table 12: Radioactivity in precipitations (program item II.3) collected in the WNW sector. Selection of data for the period March 1982 - December 1984

Month of Collection	Precipitations in mm	Activity Concentration in pCi/l	
		Gross alpha (related to Am-241)	Gross beta (related to K-40)
March 82	289	< 1.0	8.3 ± 3.0
April 82	90	< 1.0	< 2.0
June 82	53	< 1.0	3.7 ± 2.2
August 82	127	< 4.0	< 2.5
October 82	153	< 1.0	< 2.1
February 83	87	2.1 ± 1.1	18 ± 3.8
March 83	223	< 6.7	3.4 ± 3.1
April 83	68	< 1.1	3.3 ± 2.5
May 83	123	< 1.5	5.6 ± 3.8
September 83	234	< 0.8	< 2.2
August 84	73	< 0.9	< 2.2
October 84	126	1.0 ± 0.9	2.6 ± 2.4
December 84	270	< 0.8	< 2.2

Table 12 (cont.): Radioactivity in precipitations (program item II.3) collected in the NNE sector. Selection of data for the period March 1982 - December 1984.

Month of Collection	Precipitations in mm	Activity Concentration in pCi/l	
		Gross alpha (related to Am-241)	Gross beta (related to K-40)
March 82	289	< 7.1	< 3.0
April 82	90	< 6.1	26 ± 6
June 82	53	< 1.2	< 2.4
July 82	48	< 1.0	5.2 ± 2.4
August 82	127	< 8.4	10 ± 3.6
October 82	153	< 1.1	< 2.1
November 82	123	< 4.1	< 2.7
February 83	87	< 0.8	< 2.2
March 83	223	< 1.6	< 3.0
April 83	68	< 1.5	< 2.5
May 83	123	< 0.9	< 2.2
June 83	100	< 0.9	< 2.2
October 83	164	< 0.7	< 2.2
November 83	141	< 0.8	< 2.2
December 83	109	< 4.4	3.7 ± 2.9
August 84	73	< 0.7	< 2.2
October 84	121	< 0.8	< 2.2
December 84	270	< 0.8	< 2.2

Table 12 (cont.): Radioactivity in precipitations (program item II.3) collected in the E sector. Selection of data for the period March 1982 - December 1984

5.6 Cow Milk

Singles and summarized results of the I-131, K-40 and Cs-137 activity measurements are given in Tables 13 and 14. The radioiodine activity concentration was always below the minimum detection limits, which varied from 2.5 to 10 pCi/l. The minimum detection limit of 2.25 pCi/l was not reached because of the delays in sample transportation. Gamma spectrometry measurements of milk samples were made and besides K-40 activity Cs-137 was found at the three sampling locations and at different times within the monitoring period. The average of the detectable values was 14.6 pCi/l. No Cs-137 was found in milk samples during the preoperational period: the minimum detection limit at that time was 15 pCi/l, and it is now 6.2 pCi/l. The minimum detection limits for the other relevant gamma emitters are given in Table 42.

Type of Radio-activity	Sampling Location and Number of Samples Analyzed	Activity Concentration in pCi/l Average	Min.	Max.	General Average
I-131	Faz. Grataú 6	< 5.0	< 2.5	< 10	
	Faz. C. Alegre 6	< 5.0	< 2.7	< 11	< 5.4
	Faz. M. Verde 2	< 8.0	< 5.9	< 10	
K-40	Faz. Grataú 6	1180 ± 115	890	1714	
	Faz. C. Alegre 6	1480 ± 110	1140	1835	1340 ± 130
	Faz. M. Verde 4	1350 ± 160	1118	1817	
Cs-137	Faz. Grataú 6	< 13 ± 1.2	< 10	16	
	Faz. C. Alegre 6	< 11 ± 1.2	< 10	< 17	< 12.7 ± 1.5
	Faz. M. Verde 4	< 14 ± 2.0	< 10	17	

Table 13: Radioactivity in cow milk during the period March 1982 - September 1984.

Sampling Location	Sampling Date	Activity Concentration in pCi/l I-131	K-40	Cs-137
Faz. Gratau	11.03.82	< 10	1714 ± 435	16 ± 18
	04.06.82	NA	1038 ± 276	< 10
(Sector NNE)	09.09.82	NA	1189 ± 258	< 10
	08.12.82	NA	1126 ± 247	15 ± 11
	01.03.83	NA	1143 ± 254	15 ± 14
	08.06.83	< 4.3	NA	NA
	07.09.83	< 4.6	NA	NA
	06.12.83	< 4.5	NA	NA
	29.02.84	NA	891 ± 276	< 10
	07.06.84	< 2.5	NA	NA
	13.09.84	< 3.1	NA	NA
Faz. Campo Alegre	12.03.82	< 11	1743 ± 435	< 17
	04.06.82	NA	1835 ± 318	< 10
(Sector ENE)	10.09.82	NA	1381 ± 267	< 10
	08.12.82	NA	1307 ± 261	< 10
	03.03.83	NA	1467 ± 285	10 ± 14
	07.06.83	< 4.3	NA	NA
	07.09.83	< 5.0	NA	NA
	06.12.83	< 4.9	NA	NA
	29.02.84	NA	1140 ± 300	< 10
	07.06.84	< 2.7	NA	NA
	13.09.84	< 2.8	NA	NA
Faz. Milho Verde	02.03.82	< 9.5	1817 ± 483	< 17
	20.07.82	NA	1118 ± 258	< 10
(Sector WSW)	29.09.82	NA	1279 ± 267	< 10
	13.01.83	< 5.9	1203 ± 258	17 ± 16

NA = Not analyzed

Table 14: Radioactivity in cow milk (program item II.4)

5.7 Grass

Single and summarized results of K-40, gross alpha and beta activity measurements are presented in Tables 15 and 16 respectively. Results of gross beta activity (general average of 225 pCi/g ash) were comparable with those for K-40 (general average of 200 pCi/g ash) and more uniform than the results of gross alpha activity, which ranged from 3.1 to 18 pCi/g ash.

The only artifical radionuclide detected by gamma spectrometry was Cs-137, which was found in samples from Faz. Gratañ and Faz. Campo Alegre in February 1984. The Be-7 activity concentrations ranged from 26 to 40 pCi/g ash. The minimum detection limits for gamma spectrometric analysis of grass are given in Table 44.

Type of Radio-activity	Sampling Location and Number of Samples Analyzed	Specific Activity in pCi/g Ash			
		Average	Min.	Max.	General Average
Gross alpha (related to to Am-241)	Faz. Gratau 6	6.2±0.9	3.1	9.8	
	Faz. C. Alegre 5	< 7.9±2.6	< 3.2	18.0	< 12±1.6
	Faz. M. Verde 1	21±6.8	-	-	
Gross beta (related to K-40)	Faz. Gratau 6	240±27	139	337	
	Faz. C. Alegre 5	285±30	224	360	225±23
	Faz. M. Verde 1	147±30	-	-	
K-40	Faz. Gratau 4	200±45	97	292	
	Faz. C. Alegre 3	200±43	133	< 280	< 200±44
	Faz. M. Verde -	-	-	-	

Table 15: Radioactivity in grass during the period March 1982 - September 1984.

Sampling Location	Sampling Date	Specific Activity in pCi/g Ash			
		Gross alpha (related to Am-241)	Gross beta (related to K-40)	K-40	Cs-137
Faz. Gratau (Sector NNE)	11.03.1982	6.5 ± 4.0	260 ± 55	274 ± 35	< 0.18
	08.12.1982	6.2 ± 3.9	245 ± 41	292 ± 42	< 0.18
	08.06.1983	5.9 ± 3.5	216 ± 45	202 ± 34	< 0.18
	07.09.1983	5.7 ± 3.4	211 ± 45	NA	NA
	29.02.1984	9.8 ± 4.1	139 ± 30	97 ± 16	0.33 ± 0.39
	12.09.1984	3.1 ± 2.6	337 ± 72	NA	NA
Faz. C. Alegre (Sector ENE)	10.09.1982	< 3.2	246 ± 51	< 280	< 0.18
	07.06.1983	8.5 ± 3.9	224 ± 47	194 ± 28	< 0.18
	07.09.1983	4.8 ± 3.2	356 ± 76	NA	NA
	29.02.1984	18.0 ± 5.8	239 ± 54	133 ± 21	0.26 ± 0.33
	12.09.1984	5.2 ± 3.3	360 ± 76	NA	NA
Faz. M. Verde (Sector WSW)	18.05.1982	21.0 ± 6.0	147 ± 30	NA	NA

NA = Not analyzed

Table 16: Radioactivity in grass (program item II.5).

5.8 Surface Water

Single and summarized results for gross alpha and beta, K-40 and H-3 activity concentrations are given in Tables 17 and 18. The results for alpha activity were below the detection limits, which ranged from 0.7 to 6.1 pCi/l, with one exception measured at Rio do Frade in September 1982. No H-3 was detected during the monitoring period; the detection limits ranged from 620 to 1800 pCi/l. The results of gross beta activity were close to the minimum detection limits and higher than those obtained for K-40 which suggests that the values of gross beta activity detected in 1982 and 1983 were caused by analytical problems. No artifical radionuclide was detected by gamma spectrometry. The corresponding minimum detections are entered in Table 42.

Type of Radio-activity	Sampling Location and Number of Samples Analyzed	Activity Concentration in pCi/l Average	Min.	Max.	General Average
Gross alpha (related to Am-241)	R. Frade 5	< 2.3±0.7	< 0.8	< 4.5	< 2.0±0.5
	C. Brava 6	< 1.7	< 0.74	< 6.1	
Gross beta (related to K-40)	R. Frade 5	< 3.9±0.6	< 2.3	5.8	< 3.5±0.7
	C. Brava 6	< 3.2±0.8	< 2.0	7.2	
K-40	R. Frade 5	1.0±0.15	0.7	1.5	1.0±0.1
	C. Brava 5	1.1±0.04	1.0	1.2	

Table 17: Radioactivity in surface water during the period March 1982 - September 1984.

Sampling Location	Sampling Date	Activity Concentration in pCi/l Gross alpha (related to Am-241)	Gross beta (related to K-40)	K-40	H-3
Rio do Frade	10.03.1982	< 4.5	< 3.4	0.70 ± 0.05	< 1,800
(Sector NNE)	08.09.1982	1.2 ± 1.0	4.5 ± 2.2	0.75 ± 0.05	< 1,400
	01.03.1983	< 3.3	5.8 ± 2.8	1.5 ± 0.09	< 1,500
	07.09.1983	< 0.8	< 2.3	1.1 ± 0.09	< 1,700
	01.03.1984	< 1.8	< 3.5	0.81 ± 0.06	NA
	06.06.1984	NC	NC	NC	< 620
	12.09.1984	NA	NA	NA	< 760
Córrego Cachoeira	10.03.1982	< 6.1	7.2 ± 4.3	1.2 ± 0.06	< 1,800
Brava	08.09.1982	< 0.9	< 2.0	1.1 ± 0.06	< 1,400
(Sector WNW)	01.03.1983	< 0.9	3.4 ± 2.2	1.1 ± 0.06	< 1,500
	07.09.1983	< 0.7	< 2.2	1.1 ± 0.06	< 1,800
	29.02.1984	< 1.0	< 2.2	1.0 ± 0.06	NA
	07.06.1984	NC	NC	NC	< 670
	12.09.1984	< 0.8	< 2.1	NA	< 800

NC = Not collected. NA = Not analyzed.

Table 18: Radioactivity in surface water (program item II.6).

5.9 Seawater

Single and summarized results for gross beta, K-40 and H-3 activity measurements of seawater are shown in Tables 19 and 20. Of the 27 samples measured for gross alpha activity only one yielded a detectable value of 89 pCi/l, the remaining samples being below the minimum detection limits, which ranged from 50 to 123 pCi/l. Gross beta activity general averages were comparable to those obtained through atomic absorption K-40 measurements, though discrepant values were obtained for some samples. No H-3 was detected in seawater with the minimum detection limits varying from 600 to 1800 pCi/l. All the results of gamma spectrometric analyses were below the minimum detection limits given in Table 42. Some samples from Saco de Piraquara de Fora were not taken from the operator's continuous seawater sampler mentionned in the program description because of the frequent outages of this equipment.

Type of Radio-activity	Sampling Location and Number of Samples Analyzed		Activity Concentration in pCi/l Average	Min.	Max.	General Average
Gross alpha (related to Am-241)	S. P. Fora	9	< 87	< 64	< 106	
	Itaorna	9	< 88	< 58	< 123	< 87
	Tarituba	9	< 86	< 50	< 123	
Gross beta (related to K-40)	S. P. Fora	9	325± 23	186	402	
	Itaorna	9	317± 13	208	357	315±19
	Tarituba	9	303± 20	200	376	
K-40	S. P. Fora	10	310± 6	273	329	
	Itaorna	10	316± 16	264	386	300±11
	Tarituba	10	290± 10	224	328	

Table 19: Radioactivity in seawater during the period March 1982 - December 1984.

Sampling Location	Sampling Date	Activity Concentration in pCi/l Gross alpha (related to Am-241)	Gross beta (related to K-40)	K-40	H-3
Saco de Piraquara	09.03.1982	NA	NA	298 ± 18	NA
de Fora (100 m	02.06.1982	89 ± 44	186 ± 100	329 ± 21	NA
distance from	06.09.1982	NA	NA	323 ± 18	NA
cooling water	08.12.1982	NA	NA	295 ± 18	NA
discharge point)	09.03.1983	< 95	402 ± 133	328 ± 21	NA
(Sector ESE)	06.06.1983	NA	NA	313 ± 18	NA
	17.06.1983	< 98	359 ± 126	NA	NA
	06.09.1983	< 65	344 ± 121	273 ± 15	< 1,700
	01.11.-30.11.1983*	NA	NA	NA	< 1,600
	06.12.1983	< 64	249 ± 108	308 ± 18	NA
	28.02.1984	< 67	351 ± 123	327 ± 20	NA
	09.04.-03.05.1984*	NA	NA	NA	< 600
	05.06.1984	< 106	395 ± 129	NA	NA
	31.05.-02.07.1984*	< 100	344 ± 123	327 ± 21	< 800
	31.08.1984	NA	NA	NA	< 700
	01.11.-05.12.1984*	< 95	303 ± 117	NA	NA
Baia de	09.03.1982	NA	NA	322 ± 21	NA
Itaorna	02.06.1982	< 116	208 ± 100	293 ± 18	NA
(Sector SW)	08.09.1982	NA	NA	285 ± 18	NA
	08.12.1982	NA	NA	295 ± 18	NA
	02.03.1983	< 91	289 ± 116	386 ± 20	NA
	06.06.1983	< 72	351 ± 123	271 ± 15	NA
	06.09.1983	< 68	359 ± 123	264 ± 15	< 1,700
	06.12.1983	< 123	352 ± 125	301 ± 18	< 1,800
	28.02.1984	< 73	299 ± 120	322 ± 19	< 700
	05.06.1984	< 100	307 ± 117	310 ± 18	< 650
	13.09.1984	< 88	336 ± 121	NA	< 600
	05.12.1984	< 58	243 ± 107	NA	NA
Baia de	11.03.1982	NA	NA	259 ± 18	NA
Tarituba	01.06.1982	< 123	200 ± 96	288 ± 18	NA
(Sector WSW)	07.09.1982	NA	NA	269 ± 18	NA
	08.12.1982	NA	NA	271 ± 15	NA
	01.03.1983	< 89	327 ± 121	328 ± 21	NA
	08.06.1983	< 80	362 ± 125	224 ± 15	NA
	08.09.1983	< 79	300 ± 117	259 ± 15	< 1,800
	07.12.1983	< 88	376 ± 175	296 ± 18	< 1,800
	29.02.1984	< 50	240 ± 108	317 ± 19	< 700
	07.06.1984	< 110	331 ± 121	323 ± 21	NA
	12.09.1984	< 85	252 ± 111	NA	< 700
	05.12.1984	< 67	343 ± 122	NA	NA

*Refers to composite samples. NA = Not analyzed.

Table 20: Radioactivity in seawater (program item II.7).

5.10 Sand

Tables 21 and 22 show the single and summarized results of gross alpha and beta and K-40 activity measurements. The range of the alpha and beta activity results was narrower than in the preoperational monitoring period. As in the case of sediments, gross beta activity results are higher than those for K-40. This is due to the presence of natural radionuclides in sand. For details on these radionuclides and their specific activities in sand please refer to the Preoperational Report [1]. Such natural radionuclides are associated with monazytic sand deposits, especially at Praia Grande do Frade and Mambucaba: the highest value (8.8 pCi/g dry weight) for gross alpha activity was found at Mambucaba, and Praia Grande do Frade samples had a higher average of gross alpha activity than the other locations.

The specific activity of gamma emitters (with the exception of K-40) was lower than the minimum detection limits, which are shown in Table 50.

Type of Radio-activity	Sampling Location and Number of Samples Analyzed		Specific Activity in pCi/g Dry Material Average	Min.	Max.	General Average
Gross alpha (related to Am-241)	P. G. Frade	6	< 3.8±0.7	< 2.2	6.2	
	P. P. Dentro	6	< 3.4±0.5	< 2.2	5.9	< 3.3±0.5
	P. Brava	6	< 2.7±0.2	< 2.2	3.6	
	Mambucaba	6	< 3.2±0.5	< 2.2	8.8	
Gross beta (related to K-40)	P. G. Frade	6	53±4.5	41	65	
	P. P. Dentro	6	43±4.1	29	57	50±4.3
	P. Brava	6	48±5.7	35	70	
	P. Mambucaba	6	55±2.0	49	62	
K-40	P. G. Frade	6	23±2.0	18	32	
	P. P. Dentro	6	12±3.5	6.3	29	17±2.3
	P. Brava	6	18±1.8	13	26	
	P. Mambucaba	6	15±1.4	9.8	20	

Table 21: Radioactivity in sand during the period March 1982 - September 1984.

Sampling Location	Sampling Date	Specific Activity in pCi/g Dry Material Gross alpha (related to Am-241)	Gross beta (related to K-40)	K-40
Praia Grande do Frade (Sector NNE)	08.03.1982	6.2 ± 3.4	65 ± 14	32 ± 6.0
	07.09.1982	4.4 ± 4.0	44 ± 10	22 ± 2.9
	28.02.1983	4.9 ± 4.2	63 ± 14	18 ± 2.5
	08.09.1983	< 2.3	43 ± 10	22 ± 3.6
	29.02.1984	2.9 ± 2.7	41 ± 10	24 ± 3.9
	12.09.1984	< 2.2	62 ± 14	20 ± 3.2
Praia de Piraquara de Dentro (Sector SE)	09.03.1982	4.1 ± 3.0	46 ± 11	13 ± 3.0
	06.09.1982	< 3.1	33 ± 8	8 ± 1.8
	02.03.1983	< 2.6	45 ± 10	6 ± 1.6
	06.09.1983	< 2.6	46 ± 11	9 ± 2.2
	28.02.1984	< 2.2	57 ± 13	7 ± 1.5
	11.09.1984	5.9 ± 3.0	29 ± 8	29 ± 7.5
Praia Brava (Sector W)	10.03.1982	3.6 ± 3.2	43 ± 10	16 ± 1.0
	07.09.1982	< 3.1	41 ± 9	13 ± 2.2
	01.03.1983	< 2.6	62 ± 14	18 ± 2.9
	07.09.1983	< 2.6	35 ± 9	19 ± 3.5
	27.02.1984	< 2.2	70 ± 15	26 ± 4.2
	12.09.1984	2.3 ± 2.4	38 ± 9	16 ± 2.4
Praia de Mambucaba (Sector WSW)	10.03.1982	2.8 ± 4.0	58 ± 13	10 ± 2.1
	07.09.1982	4.6 ± 4.2	51 ± 12	16 ± 2.4
	01.03.1983	5.0 ± 3.3	62 ± 14	16 ± 2.3
	07.09.1983	< 2.2	49 ± 11	14 ± 2.4
	27.09.1984	2.5 ± 2.7	57 ± 13	14 ± 2.4
	12.09.1984	< 2.5	50 ± 13	20 ± 3.2

Table 22: Radioactivity in sand (program item II.8).

5.11 Sediment

Tables 23 and 24 show the summarized and single results of K-40 and gross alpha and beta activity measurements. The general average for gross alpha activity was 9.4 pCi/g dry weight but the average at Saco do Frade and Tarituba was 15 pCi/g. The same applies to the gross beta activity results, which are higher than the general average at these two locations. This is explained by the presence of natural radionuclides associated with monazytic sand desposits, as shown by the results of the preoperational monitoring program. This explanation also holds for the discrepancies in the results obtained for K-40 and gross beta activities, with general averages of 17 and 52 pCi/g, respectively. No artificial radionuclide was detected by gamma spectrometric analysis, and the minimum detection limits for these analyses are given in Table 43.

Type of Radio-activity	Sampling Location and Number of Samples Analyzed		Specific Activity in pCi/g Dry Material Average	Min.	Max.	General Average
Gross alpha (related to Am-241)	S. Frade	6	15±1.1	14	19	
	Paqueta	6	7.3±0.4	6.4	8.9	
	Brandão	3	5.1±1.0	3.4	5.0	< 9.4±1.3
	Tarituba	6	15±1.9	12	24	
	Pta. Grossa	4	< 2.8±0.3	< 2.2	6.9	
	B. Itaorna	4	11 ±2.0	7.1	16	
Gross beta (related to K-40)	S. Frade	6	66±4.1	50	77	
	Paqueta	6	41±5.7	23	59	
	Brandão	3	39±4.2	37	47	52± 4.3
	Tarituba	6	59±3.0	47	68	
	Pta. Grossa	4	41±4.4	33	54	
	B. Itaorna	4	56±4.0	46	64	
K-40	S. Frade	6	32±1.2	30	33	
	Paqueta	6	13±1.4	12	15	
	Brandão	3	9.8±2.1	7.3	11	16±1.8
	Tarituba	6	13±2.9	11	19	
	Pta. Grossa	3	8.5±0.8	7.3	9.3	
	B. Itaorna	4	18±1.9	15	19	

Table 23: Radioactivity in sediments during the period March 1982 - September 1984.

Sampling Location	Sampling Date	Specific Activity in pCi/g Dry Material Gross alpha (related to Am-241)	Gross beta (related to K-40)	K-40
Saco do Frade	08.03.1982	17 ± 6.0	77 ± 17	31 ± 3.0
(Sector NNE)	07.09.1982	11 ± 5.0	50 ± 11	30 ± 4.5
	28.02.1983	19 ± 6.5	68 ± 15	32 ± 4.2
	08.09.1983	14 ± 5.0	63 ± 14	33 ± 5.4
	29.02.1984	14 ± 4.8	75 ± 16	31 ± 5.0
	12.09.1984	14 ± 4.8	62 ± 14	33 ± 5.4
Vizinhança da	09.03.1982	8.9 ± 4.0	33 ± 8	14 ± 3.0
Ilha da Paquetá	08.09.1982	6.6 ± 4.0	36 ± 9	14 ± 3.0
(Sector ENE)	02.03.1983	7.1 ± 3.7	37 ± 9	13 ± 2.3
	06.09.1983	6.5 ± 3.7	55 ± 12	15 ± 3.8
	28.02.1984	6.4 ± 3.3	23 ± 6	11 ± 2.4
	11.09.1984	8.1 ± 3.6	59 ± 13	13 ± 2.4
Vizinhança da	09.03.1982	3.4 ± 3.5	47 ± 11	11 ± 3.0
Ilha do Brandão	08.09.1982	5.0 ± 4.0	37 ± 9	11 ± 2.2
(Sector ESE)	02.03.1983	6.9 ± 3.7	33 ± 8	7.3 ± 1.7
Ponta Grossa	06.06.1983	3.3 ± 3.1	38 ± 9	NA
(Sector ESE)	06.09.1983	< 2.9	35 ± 9	9.3 ± 2.4
	28.02.1984	< 2.2	37 ± 9	7.8 ± 2.1
	13.09.1984	2.6 ± 2.7	54 ± 12	8.4 ± 1.7
Baia de Itaorna	12.07.1983	7.9 ± 3.8	52 ± 12	17 ± 2.9
(Sector SW)	06.09.1983	11 ± 4.8	60 ± 13	19 ± 3.2
	28.02.1984	7.1 ± 3.5	46 ± 11	15 ± 2.4
	13.09.1984	16 ± 5.4	64 ± 14	19 ± 3.4
Baia de Tarituba	12.03.1982	12 ± 5.0	61 ± 13	13 ± 3.0
(Sector WSW)	07.09.1982	13 ± 5.0	47 ± 11	11 ± 2.1
	03.03.1983	24 ± 6.9	54 ± 12	12 ± 2.8
	08.09.1983	12 ± 4.6	63 ± 14	13 ± 3.0
	25.02.1984	17 ± 5.6	61 ± 14	12 ± 2.1
	12.09.1984	14 ± 4.8	68 ± 15	19 ± 2.4

NA = Not analayzed

Table 24: Radioactivity in sediments (program item II.9).

5.12 Fish

Groupers were caught as sedentary fish, and corvine and cocoroca (Haemulon steindachneri) were sampled as non-sedentary fish. Single and summarized K-40 and gross alpha and beta activity results are shown in Tables 25 and 26. Only 25 % of the gross alpha activity results were higher than the minimum detection limits, which ranged from 1.8 to 3.3 pCi/g ash. Gross beta activity results (general average of 116 pCi/g ash) were higher than those obtained for K-40 (general average of 60 pCi/g ash) as observed in the preoperational period. Cs-137 was the only artificial radionuclide found in fish by gamma spectrometric analysis in samples collected in June 1984 at the sampling locations of Saco de Piraquara de Fora and Baia de Tarituba. The minimum detection limits for the other relevant gamma emitters are given in Table 45.

Type of Radio-activity	Sampling Location and Number of Samples Analyzed		Specific Activity in pCi/g Ash Average	Min.	Max.	General Average
Gross alpha (related to Am-241)	P. Fora	5	< 2.4±0.03	< 2.3	2.5	
	P. Dentro	4	< 2.4	< 1.8	< 2.9	< 2.6
	Tarituba	8	< 2.8±0.2	< 2.2	3.3	
Gross beta (related to K-40)	P. Fora	5	115 ±8	94	135	
	P. Dentro	4	109 ±9	85	125	116± 9
	Tarituba	8	120 ±10	89	166	
K-40	P. Fora	4	54 ±5	43	63	
	P. Dentro	3	64 ±17	46	97	60±11
	Tarituba	8	56 ±7	37	95	

Table 25: Radioactivity in fish during the period March 1982 - December 1984.

Sampling Location	Sampling Date	Type of Fish (common names)	Specific Activity in pCi/g Ash			
			Gross alpha (related to Am-241)	Gross beta (related to K-40)	K-40	Cs-137
Saco de Piraquara de Fora (Sector ESE/E)	07.12.1983	grouper	< 2.3	133 ± 24	NA	NA
	29.02.1984	cocoroca	< 2.4	94 ± 20	43 ± 7	< 0.06
	01.03.1984	grouper	< 2.4	103 ± 21	61 ± 11	< 0.06
	07.06.1984	grouper	< 2.4	135 ± 29	63 ± 14	0.68±0.45
	11.09.1984	grouper	2.5 ± 2.4	131 ± 19	50 ± 9	< 0.06
Saco de Piraquara de Dentro (Sector NE/ENE)	01.03.1983	corvine	< 2.9	125 ± 25	97 ± 14	< 0.06
	08.09.1983	corvine	< 2.5	107 ± 23	49 ± 8	< 0.06
	07.12.1983	corvine	< 2.3	85 ± 17	NA	NA
	04.12.1984	corvine	< 1.8	120 ± 26	46 ± 8	< 0.06
Baia de Tarituba (Sector WSW)	12.03.1982	grouper	< 3.0	95 ± 20	46 ± 6	< 0.17
	12.03.1982	corvine	< 3.3	89 ± 19	48 ± 6	< 0.17
	09.09.1982	grouper	3.6 ± 3.6	144 ± 30	95 ± 14	< 0.06
	13.04.1983	grouper	< 2.5	166 ± 35	75 ± 12	< 0.06
	02.03.1984	grouper	< 2.9	102 ± 22	50 ± 8	0.07±0.06
	02.03,1984	corvine	< 2.4	94 ± 20	37 ± 6	< 0.06
	06.12.1984	grouper	2.2 ± 2.1	147 ± 31	47 ± 8	< 0.06
	06.12.1984	corvine	2.3 ± 2.2	126 ± 27	50 ± 8	< 0.06

NA = Not analyzed

Table 26: Radioactivity in fish (program item II.10).

5.13 Soil

Single and summarized results of gross alpha and beta, K-40 and Cs-137 activity measurements of soil are given in Tables 27 and 28. Relatively uniform results were obtained for gross alpha and beta activities. Gross beta activity measurement results were higher than those obtained for K-40, as was expected because of the presence in soil of natural radionuclides from the uranium and thorium decay series. For a detailed characterization of those radionuclides please refer to the preoperational report [1].

Cs-137 was found in three of the six soil samples analyzed, the average being 0.11 pCi/g dry weight. All the specific activities of the artifical radionuclides were below the minimum detection limits which are shown in Table 49.

Type of Radio-activity	Sampling Location and Number of Samples Analyzed	Specific Activity in pCi/g Dry Material			General Average
		Average	Min.	Max.	
Gross alpha (related to Am-241)	Faz. Gratau 3	7.5±1.1	5.3	8.7	9.8 ±1.3
	Faz. C. Alegre 3	12 ±1.5	9.4	14	
Gross beta (related to K-40)	Faz. Gratau 3	55 ±7	43	64	59 ±10
	Faz. C. Alegre 3	60 ±13	33	73	
K-40	Faz. Gratau 3	16 ±1.8	14	20	17 ±4
	Faz. C. Alegre 3	18 ±5.5	7.3	25	
Cs-137	Faz. Gratau 1	< 0.09	-	-	< 0.11±0.03
	Faz. C. Alegre 2	0.12± 0.04	0.07	0.16	

Table 27: Radioactivity in soil during the period December 1982 - February 1984

Sampling Location	Sampling Date	Specific Activity in pCi/g Dry Material Gross alpha (related to Am-241)	Gross beta (related to K-40)	K-40	Cs-137
Faz. Gratau	08.12.1982	8.7 ± 4.5	63 ± 14	14 ± 2.6	0.09 ± 0.09
(Sector NNE)	28.02.1983	5.3 ± 3.5	64 ± 14	15 ± 3.4	< 0.12
	29.02.1984	8.5 ± 3.7	43 ± 10	20 ± 3.5	< 0.05
Faz. C. Alegre	08.12.1982	9.4 ± 4.5	33 ± 8	7.3 ± 1.8	0.16 ± 0.09
(Sector ENE)	01.03.1983	14 ± 5.6	73 ± 16	25 ± 4.0	< 0.05
	29.02.1984	14 ± 4.8	73 ± 16	22 ± 3.6	0.07 ± 0.06

Table 28: Radioactivity in soil (program item III.1).

5.14 Bananas

Single and summarized results of activity measurements of bananas are given in Tables 29 and 30. Gross alpha activity results were close to or below the minimum detection limits with a general average of < 2.9 pCi/g ash. Gross beta activity results were comparable to those for K-40. Cs-137 was found only in the September 1982 sample at Mambucaba, with an activity concentration of 0.24 ± 0.33 pCi/g ash. The minimum detection limits for gamma spectrometric analysis of bananas are given in Table 47.

Type of Radio-activity	Sampling Location and Number of Samples Analyzed		Specific Activity in pCi/g Ash			
			Average	Min.	Max.	General Average
Gross alpha (related to Am-241)	Sector ENE	4	< 3.0±0.3	< 2.5	3.7	< 2.9± 0.2
	Cunhambebe	6	< 3.0±0.2	< 2.5	3.5	
	Mambucaba	6	< 2.8±0.1	< 2.4	3.2	
Gross beta (related to K-40)	Sector ENE	4	310±40	200	383	322±26
	Cunhambebe	6	337±18	290	398	
	Mambucaba	6	318±16	284	388	
K-40	Sector ENE	3	273±43	211	356	297±38
	Cunhambebe	5	323±45	221	457	
	Mambucaba	5	294±22	229	355	

Table 29: Radioactivity in bananas during the period March 1982 - September 1984

Sampling Location	Sampling Date	Specific Activity in pCi/g Ash Gross alpha (related to Am-241)	Gross beta (related to K-40)	K-40	Cs-137
Along the highway	10.03.1982	< 3.0	200 ± 42	252 ± 30	< 0.55
Br-101 Rio-Santos	03.03.1983	2.8 ± 3.0	383 ± 80	356 ± 46	< 0.11
close to NPP site	07.09.1983	< 2.5	337 ± 71	NA	NA
(Sector ENE)	29.02.1984	3.7 ± 3.1	318 ± 67	211 ± 33	< 0.11
Cunhambebe	11.03.1982	< 3.3	290 ± 61	221 ± 29	< 0.11
(Sector NNE)	09.09.1982	< 3.2	316 ± 66	375 ± 51	< 0.11
	03.03.1983	< 2.9	381 ± 80	457 ± 60	< 0.11
	09.09.1983	< 2.5	301 ± 65	NA	NA
	01.03.1984	< 2.6	333 ± 70	229 ± 36	< 0.11
	13.09.1984	3.5 ± 3.0	398 ± 84	333 ± 51	< 0.11
Mambucaba	10.03.1982	3.2 ± 3.3	287 ± 60	355 ± 45	< 0.55
(Sector WSW)	09.09.1982	< 3.1	284 ± 59	280 ± 36	0.24±0.33
	01.03.1983	< 2.9	294 ± 61	229 ± 29	< 0.11
	07.09.1983	< 2.4	314 ± 66	NA	NA
	29.02.1984	< 2.5	340 ± 72	279 ± 43	< 0.11
	12.09.1984	2.7 ± 2.4	388 ± 81	327 ± 54	< 0.11

NA = Not analyzed

Table 30: Radioactivity in bananas (program item III.2).

5.15 Manioc

Single and summarized results of K-40 and gross alpha and beta activity measurements are given in Tables 31 and 32. K-40 and gross beta activity measurements yielded quite uniform and coherent results, with respective averages of 356 and 333 pCi/g ash. Cs-137 was found in four of the six samples analyzed with an average of 0.76 pCi/g ash, while the average Cs-137 content of manioc during the preoperational phase was 1.15 pCi/g ash. No other artificial radionuclide was found in manioc by gamma spectrometry, the corresponding miniumum detection limits are given in Table 48.

Type of Radioactivity	Number of Samples Analyzed	Specific Activity in pCi/g Ash		
		Average	Min.	Max.
Gross alpha (related to Am-241)	6	< 3.7 ± 0.5	< 2.8	6.2
Gross beta (related to K-40)	6	333 ± 16	270	379
K-40	6	356 ± 16	301	401
Cs-137	6	< 0.76 ± 0.22	< 0.16	1.5

Table 31: Radioactivity in manioc during the period March 1982 - September 1984.

Sampling Location	Sampling Date	Specific Activity in pCi/g Ash			
		Gross alpha (related to Am-241)	Gross beta (related to K-40)	K-40	Cs-137
Farm near Mambucaba	10.03.1982	< 3.0	270 ± 54	371 ± 45	0.54 ± 0.51
	09.09.1982	< 3.2	313 ± 65	388 ± 49	0.80 ± 0.75
	01.03.1983	< 2.8	340 ± 71	301 ± 39	1.4 ± 0.5
	07.09.1983	3.4 ± 2.9	379 ± 80	347 ± 60	1.5 ± 1.6
	29.02.1984	6.2 ± 3.4	339 ± 72	327 ± 56	< 0.16
	12.09.1984	3.3 ± 2.5	355 ± 75	401 ± 62	< 0.16

Table 32: Radioactivity in manioc (program item III.3).

5.16 Oranges

Single and summarized results of gross alpha and beta, K-40 and Cs-137 activity measurement results are presented in Tables 33 and 34. Gross beta activity results were comparable to those for K-40. Cs-137 was detected at 0.23 pCi/g ash in one of the three samples analyzed. For all other artificial gamma emitters the specific activities were below the minimum detection limits, which are presented in Table 47.

Type of Radioactivity	Numbers of Samples Analyzed	Specific Activity in pCi/g Ash		
		Average	Min.	Max.
Gross alpha (related to Am-241)	3	3.8 ± 0.3	3.3	4.3
Gross beta (related to K-40)	3	233 ± 44	147	291
K-40	3	169 ± 41	88	214
Cs-137	3	< 0.19	< 0.11	0.23

Table 33: Radioactivity in oranges during the period September 1982 - June 1984.

Sampling Date	Specific Activity in pCi/g Ash Gross alpha (related to Am-241)	Gross beta (related to K-40)	K-40	Cs-137
09.09.82	3.7 ± 3.6	260 ± 52	206 ± 28	< 0.11
08.06.83	3.3 ± 3.1	147 ± 31	88 ± 13	< 0.23
07.06.84	4.3 ± 3.1	291 ± 62	214 ± 34	0.23 ± 0.3

Table 34: Radioactivity in oranges (program item III.4), samples taken from Fazenda Gratañ (sector NNE).

5.17 Seaweed

Single and summarized gross alpha, gross beta and K-40 specific activity results are presented in Tables 35 and 36. The gross alpha activity measurement results were more uniform, and gross beta results more coherent with K-40 results than in the preoperational period. Further improvements in terms of uniformity are expected because of standardization, among the different sampling locations, of the seaweed species collected.

In September 1984 Cs-137 was measured at 0.44 ± 0.27 pCi/g ash in a Sargassum sample from Piraquara de Fora (ESE). This was the only artifical radionuclide identified by gamma spectrometric analysis. The minimum detection limits for gamma emitters in seaweed samples are shown in Table 46.

Type of Radio-activity	Sampling Location and Number of Samples Analyzed	Specific Activity in pCi/g Ash			
		Average	Min.	Max.	General Average
Gross alpha (related to Am-241)	S. P. Fora 7	< 5.1±0.8	< 2.8	8.4	
	I. Pingo Agua 5	< 3.6±0.4	< 2.6	4.6	< 5.5±1.6
	Tarituba 5	7.9±2.6	2.4	17	
Gross beta (related to K-40)	S. P. Fora 7	141±11	98	187	
	I. Pingo Agua 5	125±24	62	203	137±17
	Tarituba 5	146±13	102	181	
K-40	S. P. Fora 7	118±17	60	179	
	I. Pingo Agua 5	112±24	60	204	117±20
	Tarituba 5	121±15	79	159	

Table 35: Radioactivity in seaweed during the period March 1982 - September 1984.

Sampling Location	Sampling Date	Species	Specific Activity in pCi/g Ash Gross alpha (related to Am-241)	Gross beta (related to K-40)	K-40
Southern area of the Saco de Piraquara de Fora (Sector ESE)	09.03.1982	Sargassum	4.0 ± 3.6	98 ± 21	60 ± 9
	06.09.1982	Sargassum	4.9 ± 3.7	133 ± 28	140 ± 20
	02.03.1983	Sargassum	< 2.9	115 ± 25	64 ± 10
	03.03.1983	Sargassum	< 2.8	187 ± 39	152 ± 20
	07.09.1983	Sargassum	4.9 ± 3.4	163 ± 34	179 ± 33
	28.03.1984	Sargassum	8.4 ± 3.9	132 ± 29	107 ± 20
	11.09.1984	Sargassum	7.5 ± 3.5	159 ± 34	126 ± 26
Ilha do Pingo d'Agua (Sector E)	06.09.1982	Sargassum	< 3.1	203 ± 42	204 ± 30
	02.03.1983	Sargassum	4.1 ± 3.2	116 ± 25	60 ± 9
	07.09.1983	Sargassum	3.4 ± 3.1	152 ± 32	105 ± 17
	28.03.1984	Sargassum	< 2.6	94 ± 20	93 ± 18
	13.09.1984	Sargassum	4.6 ± 2.7	62 ± 14	100 ± 21
Baia de Tarituba (Sector WSW)	12.03.1982	Acantophora	6.8 ± 4.3	155 ± 33	116 ± 18
	03.03.1983	Acantophora	9.7 ± 3.4	149 ± 31	100 ± 14
	08.09.1983	Acantophora	2.4 ± 2.7	181 ± 38	159 ± 26
	07.06.1984	Sargassum	3.8 ± 3.0	144 ± 31	152 ± 22
	12.09.1984	Sargassum	17.0 ± 5.4	102 ± 22	79 ± 15

Table 36: Radioactivity in seaweed (program item III.5).

5.18 Crustaceans and Mollusks

Table 39 presents the single results of crustacean and mollusk samples of gross alpha and beta, K-40 and Cs-137 activity measurements. Summarized results are presented in Table 37 for crustaceans (shrimps) and in Table 38 for mollusks (soft-bottom bivalves). Crustaceans like shrimps feed on detritus and the sampled bivalve (Anomalocardia brasiliana) is a suspension feeder, which may consequently ingest resuspended or suspended sediments. Sediment ingestion may explain the higher values of gross alpha activity in mollusks and also their variability (3 to 35 pCi/g ash). Surprisingly, however, the results for gross beta and K-40 activities in mollusks are comparable which is not true for crustaceans.

Fallout-Cs-137 was found in a shrimp sample collected in March 1983 with a specific activity of 0.19 pCi/g ash. The specific activities of all other artificial gamma emitters were below the minimum detection limits shown in Tables 46 (crustaceans) and 44 (mollusks).

Type of Radio-activity	Sampling Location and Number of Samples Analyzed		Specific Activity in pCi/g Ash			
			Average	Min.	Max.	General Average
Gross alpha (related to Am-241)	P. Dentro	1	6.4±3.8	-	-	< 6.4±2.8
	Tarituba	6	< 6.3±1.1	< 2.9	10	
Gross beta (related to K-40)	P. Dentro	1	122±26	-	-	101±21
	Tarituba	6	98±14	42	136	
K-40	P. Dentro	1	73±10	-	-	52±8
	Tarituba	6	48± 6	27	67	

Table 37: Radioactivity in crustaceans during the period March 1983 - September 1984.

Type of Radio-activity	Sampling Location and Number of Samples Analyzed	Specific Activity in pCi/g Ash			
		Average	Min.	Max.	General Average
Gross alpha (related to Am-241)	P. G. Frade 3	18± 7	6.6	30	18± 9.2
	Parati 2	19±11	3.0	35	
Gross beta (related to K-40)	P. G. Frade 3	71± 7	58	81	60±14
	Parati 2	43±19	24	62	
K-40	P. G. Frade 3	< 63±12	40	< 79	< 57± 9
	Parati 2	< 49± 3	46	< 51	

Table 38: Radioactivity in mollusks in 1984.

Sampling Location	Sampling Date	Species	Specific Activity in pCi/g Ash			
			Gross alpha (related to Am-241)	Gross beta (related to K-40)	K-40	Cs-137
Saco de Piraquara de Dentro	01.03.1983	shrimp	6.4 ± 3.8	122 ± 26	73 ± 10	-
Praia Grande	07.12.1983	mollusk	6.6 ± 3.5	74 ± 17	79 ± 27	-
do Frade	29.02.1984	mollusk	16.7 ± 5.4	58 ± 13	40 ± 11	-
(Sector ENE)	06.12.1984	mollusk	30.0 ± 8.1	81 ± 18	< 71	-
Baia de Tarituba	12.03.1982	shrimp	10.0 ± 5.0	128 ± 27	61 ± 9.0	< 0.25
(Sector WSW)	09.09.1982	shrimp	4.3 ± 3.7	91 ± 20	55 ± 8.4	-
	04.03.1983	shrimp	< 2.9	108 ± 23	67 ± 9.5	0.19±0.27
	09.09.1983	shrimp	5.9 ± 3.5	42 ± 10	27 ± 9.1	-
	29.02.1984	shrimp	9.0 ± 4.0	136 ± 29	45 ± 9.2	-
	13.09.1984	shrimp	5.4 ± 3.4	82 ± 18	35 ± 9.0	-
Parati	07.06.1984	mollusk	3.0 ± 2.9	62 ± 14	46 ± 15	-
(Sector SW)	07.12.1984	mollusk	35.0 ± 9.2	24 ± 7	< 51	-

Table 39: Radioactivity in crustaceans and mollusks (program item III.6).

6. Comments on Sampling and Measurement Procedures

6.1 Solid-state Dosimeters

The TLD crystal compositions adopted were $CaSO_4$: Dy (Teflon 0.4 mm thickness) from Teledyne Isotopes and LIF: Mg, Ti chips from Harshaw. LiF-TLDs were included because of their better response to low-energy gamma emitters and also in order to enable comparisons to be made of measurements and introduce a factor of redundance. Because of differences in sensitivity for these two types of TLDs, the dosimeter exchange frequencies were 3 months for $CaSO_4$-TLDs and 6 months for LiF-TLDs.

The dosimeters were shielded with a copper sheath of 3.5 mm thickness and enscapsulated in Nylon to protect them from moisture. The measurement error was estimated at ± 10 %. The dosimeters were exposed in the field at 1 m above ground level, and the stations were located away from buildings or rocks.

6.2 Ionization Chambers

During the preoperational period, in compliance with CNEN's request, FURANS had committed itself to instal fixed continuous gamma radiation measuring stations at the site fence in the sectors WNW, NNE and E. Later-on, when the operator had received the necessary equipment for these 3 measurement stations, it was agreed that two of them would be installed in the sectors NNE and E and the third at Praia Brava (W). The equipment was lost while being checked and tested, when a landslide destroyed FURNAS's Radioecology Laboratory. Gamma dose rate measurements have therefore been performed only discontinously by the operator and a second set of ionization chambers are being imported.

6.3 Aerosols

Aerosols were trapped on 6 cm dia. filter paper by a high volume air sampler (8500 m^3/h) operated at 1 m above ground level. Filters were replaced every 15 days, and for each sampling location the operator sent the quarterly filter stack to IRD. The filter stack was analyzed by gamma spectrometry. The stack was counted directly on an intrinsic Ge-detector for 1000 minutes. The minimum detection limits for gamma spectrometry measurements of aerosol samples are given in Table 41. The six filters of each stack were then arranged on a 20 cm dia. stainless steel planchet for gross alpha and beta activity measurements on a proportional counter. The counting time was 100 minutes.

6.4 Radioiodine in Air

Activated charcoal cartridges were used for radioiodine sampling in air, with a high-volume air sampler operated at 1 m above ground level. The cartridges were sent to IRD and counted for 1000 min. on an intrinsic Ge-detector of 30 % efficiency. The minimum detection limits for these analyses were variable, despending on the delays in transportation, and are shown in Table 12.

6.5 Gross Alpha and Beta Activity Measurements of Precipitations, Surface Water and Seawater.

One and a half liter of sample were filtered on 0.45 Millipore filters, acidified, and evaporated to 200 ml. This volume was then transferred to a 20 cm dia. stainless steel planchet and evaporated to dryness under infrared lamps. The activity was measured on a proportional counter for 100 minutes. The counting efficiency was 12 % for alpha-activity

measurements, and 45 % for beta-activity measurements.

6.6 K-40 and H-3 Specific Activity Measurements of Surface Water and Seawater.

The specific K-40-activity in surface water and seawater samples was calculated from the results of potassium determinations by atomic absorption spectrophotometry in order to avoid the greater errors and higher detection limits for K-40 measurements associated with gamma spectrometry.

The samples were filtered and acidified, diluted, when necessary, and directly aspirated on an atomic absorption spectrophotometer. The tritium concentrations were determined by liquid scintillation following sample distillation: 10 ml of filtered and non-acidified sample were distilled and homogenized with 12 ml of Instagel scintillation cocktail. The counting time was 50 minutes. The internal standard technique was used for quench correction. In this procedure, each sample is added a small amount of a tritium standard solution after counting. The samples are then counted again. The ratio between the pulse rate increment produced in this way and the known pulse rate of the internal standard furnishes the individual counting efficiency of a sample, which is necessary for calculating the sample activity. As can be seen in Table 20, the minimum detection limits ranged from 600 to 1800 pCi/l.

6.7 Radiochemical Determination of I-131 in Milk.

Immediately after milking, formalin was added to the sample at 5 ml/l. Four liters of milk were passed trough a volume of Dowex 1 X 8 resin equivalent to 100 ml at a rate of 40 ml/minute. The resin was then counted for 1000 minutes on a 30 % efficiency intrinsic Ge-detector. The

minimum detection limits varied from 2.5 to 10 pCi/l (Table 14) depending on the delays in transportation.

6.8 Gross Alpha and Gross Beta Activity Measurements of Sand, Soil, Sediment and Ashes of Biological Matrixes.

Sand, soil and sediment were dried at 100 °C to give a constant weight, and 1 g of sample was spread over a 20 cm dia. aluminium planchet.

The foodstuffs were prepared the way they usually are for human consumption, i. e. shrimps, oranges, manioc and bananas were peeled, fish had their head, fins and scales removed or not, depending on the fish size, and in the case of mollusks only the flesh was analyzed. These samples as well as grass and seaweeds were dried at 100 °C to give a constant weight and ashed at 450 °C. 1 g of sample was spread over a 20 cm dia. aluminimum planchet. Mean fresh weight to ash weight ratios are given in Table 40. The gross alpha and beta activities were measured for 100 minutes on a proportional counter, the counting efficiency being 12 % and 45 %, respectively.

Type and Number of Samples		Fresh Weight/Ash Weight
Grass	11	44.8
Manioc	31	124
Seaweed (Sargassum)	14	14.9
Seaweed (Acanthophora)	3	22.7
Oranges	4	236
Bananas	13	105
Fish (grouper)	8	27
Fish (corvine)	4	21.6
Fish (cocoroca)	1	18.7
Shrimp	7	31.6
Mollusk	4	58.8

Table 40: Fresh weight to ash weight ratios of biological matrixes, valid for the monitoring period 1982 - 1984.

6.9 Gamma Spectrometric Analysis

Precipitation, milk, surface and seawater were analyzed for gamma emitters in 3.5 l Marinelli flasks and counted for 1000 minutes on an intrinsicly Ge-detector. The minimum detection limits for gamma analyses of these items are shown in Table 42. Solid samples like dry soil, sediment and sand or ashes of biological matrixes were analyzed in plastic cups of 7 cm dia. and counted for 1000 minutes on intrinsic Ge-detectors of 10 - 30 % efficiency. The minimum detection limits for solid samples are given in Tables 43 (sediment), 44 (pasture and mollusks), 45 (fish), 46 (crustaceans and seaweeds), 47 (bananas and oranges), 48 (manioc), 49 (soil) and 50 (sand).

Nuclide	Specific Activity in pCi/m³	Measurement Conditions
Cr-51	6.9	Counting Time:
Mn-54	0.77	1,000 min
Co-57	0.52	
Co-58	0.75	
Fe-59	1.4	Detector:
Co-60	0.7	Germanium
Zn-65	1.5	
Zr-95	1.2	Geometry:
Nb-95	0.76	Six filters (dia. 5.5 cm)
Ru-103	0.88	piled up and counted
Ru-/Rb-106	7.5	directly on the detector.
Ag-110m	1.0	Typical total air volume:
Sb-124	0.74	8.500 m³.
Sb-125	2.2	
I-131	0.85	
Cs-134	0.95	
Cs-137	0.9	
Ba-140	3.3	
La-140	0.63	
Ce-141	1.1	
Ce-144	3.9	

Table 41: Minimum detection limits for gamma spectrometry measurements of aerosols (program item II.1)

Nuclide	Specific Activity in pCi/l	Measurement Conditions
Cr-51	51.0	Counting Time:
Mn-54	5.2	1,000 min
Co-57	4.3	
Co-58	5.0	
Fe-59	8.8	Detector:
Co-60	4.5	Germanium
Zn-65	1.0	
Zr-95	8.3	Geometry:
Nb-95	5.1	Liquids analyzed in
Ru-103	6.2	Marinelli flasks of 3.5 l
Ru-/Rb-106	52.0	volume.
Ag-110m	6.6	
Sb-124	5.1	Preparation
Sb-125	16.0	Direct measurement (no
I-131	6.2	enrichment).
Cs-134	6.3	
Cs-137	6.2	
Ba-140	23.0	
La-140	3.9	
Ce-141	8.8	
Ce-144	32.0	

Table 42: Minimum detection limits for gamma spectrometry measurements of milk (program item II.4), surface water (item II.6), seawater (item II.7) and precipitation (item II.3).

Nuclide	Specific Activity in pCi/g dry weight	Measurement Conditions
Cr-51	0.34	Counting Time:
Mn-54	0.034	1,000 min
Co-57	0.03	
Co-58	0.033	
Fe-59	0.06	Detector:
Co-60	0.03	Germanium
Zn-65	0.065	
Zr-95	0.06	Geometry:
Nb-95	0.034	Samples analyzed in
Ru-103	0.04	plastic cups (dia. 7 cm)
Ru-/Rb-106	0.34	filled to 3 cm height.
Ag-110m	0.044	Typical dry weight of
Sb-124	0.034	sample: 135 g.
Sb-125	0.11	
I-131	0.04	
Cs-134	0.04	
Cs-137	0.04	
Ba-140	0.15	
La-140	0.25	
Ce-141	0.06	
Ce-144	0.22	

Table 43: Minimum detection limits for gamma spectrometry measurements of sediments (program item II.9).

Nuclide	Specific Activity in pCi/g ash	Measurement Conditions
Cr-51	1.5	Counting Time:
Mn-54	0.15	1,000 min
Co-57	0.13	
Co-58	0.15	
Fe-59	0.26	Detector:
Co-60	0.13	Germanium
Zn-65	0.30	
Zr-95	0.24	Geometry:
Nb-95	0.15	Samples analyzed in
Ru-103	0.19	plastic cups (dia. 7 cm)
Ru-/Rb-106	1.5	filled to 3 cm height.
Ag-110m	0.2	Typical ash weight of
Sb-124	0.15	samples: 30 g.
Sb-125	0.48	
I-131	0.19	
Cs-134	0.19	
Cs-137	0.18	
Ba-140	0.70	
La-140	0.11	
Ce-141	0.28	
Ce-144	0.98	

Table 44: Minimum detection limits for gamma spectrometry measurements of pasture (program item II.5) and mollusks (item III.6)

Nuclide	Specific Activity in pCi/g ash	Measurement Conditions
Cr-51	0.46	Counting Time:
Mn-54	0.049	1,000 min
Co-57	0.04	
Co-58	0.044	
Fe-59	0.08	Detector:
Co-60	0.04	Germanium
Zn-65	0.09	
Zr-95	0.07	Geometry:
Nb-95	0.046	Samples analyzed in
Ru-103	0.06	plastic cups (dia. 7 cm)
Ru-/Rb-106	0.46	filled to 3 cm height.
Ag-110m	0.06	Typical ash weight of
Sb-124	0.046	samples: 100 g.
Sb-125	0.14	
I-131	0.056	
Cs-134	0.056	
Cs-137	0.055	
Ba-140	0.21	
La-140	0.034	
Ce-141	0.08	
Ce-144	0.3	

Table 45: Minimum detection limits for gamma spectrometry measurements of fish (program item II.10).

Nuclide	Specific Activity in pCi/g ash	Measurement Conditions
Cr-51	0.77	Counting Time:
Mn-54	0.077	1,000 min
Co-57	0.067	
Co-58	0.074	
Fe-59	0.13	Detector:
Co-60	0.066	Germanium
Zn-65	0.15	
Zr-95	0.12	Geometry:
Nb-95	0.076	Samples analyzed in
Ru-103	0.093	plastic cups (dia. 7 cm)
Ru-/Rb-106	0.77	filled to 3 cm height.
Ag-110m	0.098	Typical ash weight of
Sb-124	0.076	samples: 60 g.
Sb-125	0.24	
I-131	0.093	
Cs-134	0.094	
Cs-137	0.092	
Ba-140	0.35	
La-140	0.057	
Ce-141	0.14	
Ce-144	0.49	

Table 46: Minimum detection limits for gamma spectrometry measurements of crustaceans (program item III.6) and seaweeds (item III.5).

Nuclide	Specific Activity in pCi/g ash	Measurement Conditions
Cr-51	0.92	Counting Time:
Mn-54	0.1	1,000 min
Co-57	0.08	
Co-58	0.09	
Fe-59	0.16	Detector:
Co-60	0.08	Germanium
Zn-65	0.18	
Zr-95	0.14	Geometry:
Nb-95	0.09	Ash analyzed in
Ru-103	0.11	plastic cups (dia. 7 cm)
Ru-/Rb-106	0.93	filled to 3 cm height.
Ag-110m	0.12	Typical ash weight of
Sb-124	0.09	samples: 50 g.
Sb-125	0.3	
I-131	0.11	
Cs-134	0.11	
Cs-137	0.11	
Ba-140	0.42	
La-140	0.07	
Ce-141	0.16	
Ce-144	0.60	

Table 47: Minimum detection limits for gamma spectrometry measurements of bananas (program item III.2) and oranges (item III.4)

Nuclide	Specific Activity in pCi/g ash	Measurement Conditions
Cr-51	1.3	Counting Time:
Mn-54	0.13	1,000 min
Co-57	0.11	
Co-58	0.13	
Fe-59	0.22	Detector:
Co-60	0.11	Germanium
Zn-65	0.25	
Zr-95	0.21	Geometry:
Nb-95	0.13	Samples analyzed in
Ru-103	0.16	plastic cups (dia. 7 cm)
Ru-/Rb-106	1.33	filled to 3 cm height.
Ag-110m	0.17	Typical ash weight of
Sb-124	0.13	samples: 35 g.
Sb-125	0.41	
I-131	0.16	
Cs-134	0.16	
Cs-137	0.16	
Ba-140	0.60	
La-140	0.1	
Ce-141	0.23	
Ce-144	0.85	

Table 48: Minimum detection limits for gamma spectrometry measurements of manioc (program item III.3).

Nuclide	Specific Activity in pCi/g dry weight	Measurement Conditions
Cr-51	0.39	Counting Time:
Mn-54	0.039	1,000 min
Co-57	0.033	
Co-58	0.037	
Fe-59	0.065	Detector:
Co-60	0.033	Germanium
Zn-65	0.075	
Zr-95	0.06	Geometry:
Nb-95	0.038	Samples analyzed in
Ru-103	0.047	plastic cups (dia. 7 cm)
Ru-/Rb-106	0.39	filled to 3 cm height.
Ag-110m	0.049	Typical dry weight of
Sb-124	0.038	samples: 121 g.
Sb-125	0.12	
I-131	0.047	
Cs-134	0.047	
Cs-137	0.046	
Ba-140	0.18	
La-140	0.029	
Ce-141	0.07	
Ce-144	0.25	

Table 49: Minimum detection limits for gamma spectrometry measurements of soil (program item III.1).

Nuclide	Specific Activity in pCi/g dry weight	Measurement Conditions
Cr-51	0.26	Counting Time:
Mn-54	0.026	1,000 min
Co-57	0.022	
Co-58	0.025	
Fe-59	0.043	Detector:
Co-60	0.022	Germanium
Zn-65	0.05	
Zr-95	0.04	Geometry:
Nb-95	0.026	Samples analyzed in
Ru-103	0.031	plastic cups (dia. 7 cm)
Ru-/Rb-106	0.26	filled to 3 cm height.
Ag-110m	0.033	Typical dry weight of
Sb-124	0.025	samples: 180 g.
Sb-125	0.08	
I-131	0.031	
Cs-134	0.031	
Cs-137	0.031	
Ba-140	0.12	
La-140	0.019	
Ce-141	0.047	
Ce-144	0.16	

Table 50: Minimum detection limits for gamma spectrometry measurements of sand (program item II.8).

7. Results of Intercomparison Measurements

Besides a recently implanted internal quality control program - in which blank samples are included in the batches of environmental samples - IRD took part in many national and international intercomparison exercices during the monitoring period. The results of the exercices related to radioactivity measurements on environmental samples relevant to NPP monitoring are presented in Tables 51 - 54.

Type of Sample	Radionuclides	Specific Activity in Bq/kg Dry Material	
		WHO	IRD
Soil	Sr-90	5.4 ± 0.6	6.8 ± 0.6
	Cs-137	12.9 ± 1.3	16.2 ± 2.8
Total diet	Sr-90	0.41 ± 0.03	0.49 ± 0.1
	Cs-137	0.55 ± 0.05	< 0.74

Table 51: Intercomparison of Sr-90 and Cs-137 measurements made by WHO and IRD in 1982. The measurement were performed on reference samples sent by WHO.

WHO = World Health Organization, Geneva

Kind of Sample	Specific Alpha Activity in Bq/g Ash			Specific Gross Beta Activity in Bq/g Ash		
	IRD	UFF	IB/UFRJ	IRD	UFF	IB/UFRJ
Seaweed (Sargassum vulgare)	0.52 ± 0.19	0.63 ± 0.19	0.73 ± 0.12	3.9 ± 0.9	3.3 ± 0.9	3.4 ± 0.6
Seaweed (ulva fasciata)	< 0.13	0.053	NA	2.6 ± 0.6	2.0 ± 0.4	2.1 ± 0.2
Mollusk (Perna perna)	< 0.13	0.16 ± 0.06	0.20 ± 0.03	2.1 ± 0.5	1.7 ± 0.4	1.9 ± 0.3

NA = Not analyzed

Table 52: Intercomparison of specific gross alpha and beta activity measurements made in 1982 by IRD and by laboratories of Federal Universities in Rio des Janeiro. The measurements were performed on samples collected in the vicinity of Rio.

UFF = Universidade Federal Fluminense.
IB/UFRJ = Instituto de Biofisica da Universidade Federal do Rio de Janeiro.

Name of Agency and Kind of Sample	Type of Measurements	Results		Units
		IRD	Agency	
EPA Air filter	Gross alpha	14 ± 1 28 ± 1	13 ± 5 26 ± 6.5	pCi/filter
	Gross beta	70 ± 2 37 ± 1	68 ± 5 36 ± 5	
	Sr-90	9 ± 1 18 ± 2	10 ± 1.5 20 ± 1.5	
	Cs-137	36 ± 2 22 ± 2	27 ± 5 15 ± 5	
IAEA Soil	Cs-137 Sr-90	1654 ± 15 829 ± 24	1450 ± 60 820 ± 36	pCi/kg dry material
WHO Fish	Cs-137 Cs-137* Cs-134 Sr-90	172 ± 17 175 ± 7 16 ± 3 4.3 ± 0.6	155 ± 9 155 ± 9 18 ± 1.2 4.55 ± 0.23	pCi/kg fresh material

* gamma spectrometry after radiochemical separation

Table 53: Intercomparison of radiometric measurements made in 1983 by IRD and international agencies. The measurements were performed on reference samples sent by the agencies.

EPA = Environmental Protection Agency, Washington, USA

IAEA = International Atomic Energy Agency, Vienna

WHO = World Health Organization, Geneva

Name of Agency and Kind of Sample	Type of Measurements	Results		Units
		IRD	Agency	
EPA Air filter	Gross alpha	21.7 ± 0.67 15.7 ± 0.33	19 ± 2.89 15 ± 2.89	pCi/filter
	Gross beta	56.7 ± 1.2 53.3 ± 0.88	50 ± 2.89 51 ± 2.89	pCi/filter
	Sr-90	12.7 ± 0.67 8.3 ± 0.33	15 ± 0.86 21 ± 0.86	pCi/filter
	Cs-137	28.0 ± 1.0 14.3 ± 0.33	20 ± 2.89 10 ± 2.89	pCi/filter
EPA Water	Sr-89	35.7 ± 1.2 42.7 ± 2.2	36 ± 2.89 34 ± 2.89	pCi/l
	Sr-90	14.7 ± 0.33 12.7 ± 0.66	24 ± 0.87 19 ± 0.86	pCi/l
WHO Marine sediment	Mn-54 Co-60 Rh-106 Cs-137	20.6 ± 3.1 6.0 ± 1.2 189 ± 66 342 ± 20	21.3 ± 1.6 7.0 ± 1.0 229 ± 20 318 ± 18	Bq/kg dry material
WHO Rainwater Testwater	 H-3 H-3	 317 ± 49 33,100 ± 1,700	 165 ± 5 32,700 ± 700	 Bq/l Bq/l
PTB/BGA Air filter	Cr-51 Mn-54 Co-60 Zn-65 Cs-137	467 115 91,7 102 103	389 108 92,6 96 97	Bq/g dry material

Table 54: Intercomparison of radiometric measurements made in 1984 by IRD and international agencies. The measurements were performed on reference samples sent by the agencies.

EPA = Environmental Protection Agency, Washington, USA
WHO = World Health Organization, Geneva
PTB = Physikalisch Technische Bundesanstalt, Braunschweig, FRG
BGA = Bundesgesundheitsamt, Neuherberg, FRG

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Annex

Data Handling

The counting errors δx_i associated with single measurement results x_i are equivalent to three times the standard deviation.

The average value $\bar{x}_l = \frac{\sum_{i=1}^{n} x_{il}}{n}$ for a sampling location l is the arithmetic mean of all single results n available for that sampling location, and the associated error $\delta\bar{x}_l$ is the error of the mean $s/\sqrt{n}$, where s is the standard deviation.

When a single result x_i is below the Minimum Detection Limit (MDL), the MDL value itself is used to calculate the mean in a conservative approach. If one or more MDL values occur in a set of data for the sampling location l, the mean value $\bar{x}_l$ obtained from that set is presented as $< \bar{x}_l$. If such an average value is used in the calculation of a so-called general average $\bar{X}_m$ for all sampling locations of a program item due to the monitored medium m, this average is also preceded by the "less than" symbol.

The general average $\bar{X}_m$ for a monitored medium m and the associated error $\delta\bar{X}_m$ is obtained from the means $\bar{x}_l$ and from the associated errors $\delta\bar{x}_l$ of the L sampling locations of a program item according to the following equation:

$$\bar{X}_m = \frac{\sum_{l=1}^{L} \bar{x}_l}{L} \pm \sqrt{\frac{\sum_{l=1}^{L} (\delta\bar{x}_l)^2}{L}} \,.$$

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