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Preoperational Environmental Monitoring of the Angra Reactor Site

Program and Results

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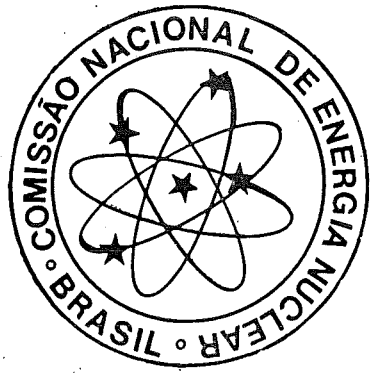

INSTITUTO DE RADIOPROTEÇÃO E DOSIMETRIA

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Preface

With the start of the energy crisis in the seventies, the Federative Republic of Brazil and the Federal Republic of Germany recognized that the utilization of nuclear energy for peaceful purposes would in time become an important factor for their peoples' technical, scientific and economic development. With this goal in mind, the two states signed an Agreement of Nuclear Cooperation on June 27, 1975.

Within the framework of this accord and an earlier agreement on scientific and technical cooperation reached in 1969, a special agreement providing for scientific 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 researchers that ensued between the Institute for Radioprotection and Dosimetry (IRD) of CNEN and KfK led to the definition in Brazil of a philosophy of environmental monitoring, monitoring techniques and programs for nuclear facilities.

A consequence of the cooperation between CNEN and KfK was the elaboration in 1979 of the Preoperational Environmental Monitoring Program for the Angra Nuclear Power Plant Site. During the following two years this program was carried out by IRD/CNEN. The results obtained will permit a distinction to be made between the operational impact, if any, resulting from the future operation of the nuclear power plant and the natural background activity found at the site. It is our conviction that this study will contribute to the radiation protection of the plant staff, to the general safety of the Brazilian public, and to the preservation of the ecosystem.

On behalf of CNEN and KfK we take great pleasure in presenting this joint report on the results of measurements in preoperational environmental monitoring recently completed. This program and its final report constitute an excellent example of successful international cooperation.

Dr. Rex Nazaré Alves

President of the Brazilian
National Nuclear Energy Commission,
Federative Republic of Brazil

Rio de Janeiro, February 1983

Prof. Dr. Rudolf Harde

Chairman of the Executive Board,
Karlsruhe Nuclear Research Center,
Federal Republic of Germany

Karlsruhe, February 1983

Summary

The Preoperational Environmental Monitoring Program for the Angra Nuclear Power Plant Site as well as the single and summarized results obtained under this Program are presented and discussed in this report. For clarity, a description is given of the Angra Site and of the program structure and a map of the region showing measurement and sampling locations is included. Preoperational monitoring was carried out over the period from September 1979 to September 1981. For direct measurements of background radiation levels a solid-state dosimeter network was used and the results were compared to measurements made with ionization chambers. Measurements were performed of natural and artificial radioactivity concentration levels in air, surface water, soil, grass, sea sediments, sea algae and various foodstuffs. Gross alpha and beta activity levels were determined as well as the concentration levels of individual natural radionuclides. The presence of cesium-137 originating from fallout was observed in manioc.

Minimum detection limits for fission and activated corrosion products which are of interest during the reactor operational period were defined and determined for the instrumentation and methods used at the Institute of Radioprotection and Dosimetry. These limits have been included in the tables.

Zusammenfassung

Im vorliegenden Bericht werden das Umgebungsüberwachungsprogramm für den Kernkraftwerksstandort Angra und die mit diesem Nullpegelmeßprogramm gewonnenen Einzeldaten und zusammengefaßten Ergebnisse dargestellt und diskutiert. Zum besseren Verständnis wird eine Beschreibung des Standortes Angra und der Programmstruktur gegeben. Eine Übersichtskarte der Region, aus der die Meß- und Probenahmeorte ersichtlich sind, wurde in den Bericht aufgenommen. Nullpegelmessungen wurden von September 1979 bis September 1981 durchgeführt. Zur Messung des Strahlungsnullpegels diente ein Netz von Festkörperdosimeter-Meßstellen. Die damit erzielten Ergebnisse wurden mit Messungen verglichen, die mit Hilfe von Ionisationskammern ausgeführt wurden. Ferner wurden Messungen des natürlichen und künstlichen Radioaktivitätsgehaltes in Luft, Oberflächenwasser, Boden, Gras, Meeressedimenten, Meeralgen und in verschiedenen Nahrungsmitteln vorgenommen. Bestimmt wurden die spezifische Alpha- und Beta-Gesamtaktivität und die spezifische Radioaktivität einzelner in der Natur vorkommenden Radionuklide. Cäsium-137 aus Fallout wurde in Maniokwurzeln nachgewiesen.

Für die während des Reaktorbetriebes interessierenden Spaltprodukte und aktivierten Korrosionsprodukte wurden untere Nachweisgrenzen definiert und für die im Institut für Strahlenschutz und Dosimetrie in Rio de Janeiro benutzten Geräte und Methoden bestimmt. Diese Nachweisgrenzen wurden in die Tabellen aufgenommen.

Table of Contents

		Page
1.	Introduction	1
2.	The Angra Nuclear Power Plant Site	2
2.1	Site Characteristics	2
2.2	Local Meteorology	4
2.3	Power Plants	4
2.4	Local Population	5
2.5	Use of Water and Land	5
3.	The Department for Environmental Radiation Protection of IRD	6
4.	The Preoperational Monitoring Program	10
4.1	General Remarks	10
4.2	The Program Structure	12
5.	Discussion of the Summarized Measurement Results and Conclusions	22
5.1	Direct Radiation Measurements	22
5.1.1	Solid-state Dosimeters	22
5.1.2	Ionization Chambers	24
5.2	Radioactivity Measurements for the Air and Water Pathways	25
5.2.1	Aerosol, Radioiodine and Precipitation	25
5.2.2	Cow Milk	27
5.2.3	Grass (Pasture)	29
5.2.4	Surface Water	30
5.2.5	Seawater	31
5.2.6	Sand	33
5.2.7	Sediment	35
5.2.8	Fish	37

Page

5.3 Supplementary Radioactivity Measurements Specifically Related to Terrestrial and Marine Food Chains 38

5.3.1 Soil 39

5.3.2 Bananas 40

5.3.3 Manioc 41

5.3.4 Oranges 43

5.3.5 Algae 44

5.3.6 Crustacea and Mollusks 46

6. Single Results of Measurements under the Preoperational Environmental Monitoring Program 48

7. References 89

Appendix 93

Acknowledgments 99

1. Introduction

The Angra Nuclear Power Plant, the first Brazilian nuclear installation, is being constructed close to the city of Angra dos Reis, State of Rio de Janeiro, Brazil. Unit I of this plant was completed in early 1982 and is currently in its testing phase preceding commercial operation. Units II and III are scheduled to go into operation in five and six years, respectively.

The Preoperational Environmental Monitoring Program carried out by the Institute of Radioprotection and Dosimetry of the Brazilian National Nuclear Energy Commission (IRD/CNEN) was started following preliminary studies in 1979, and run in addition to the operator's own program. The program of the supervisory authority was formulated with the advice and assistance provided by the Central Safety Department (Hauptabteilung Sicherheit HS) of the Karlsruhe Nuclear Research Center (KfK), Federal Republic of Germany. After the necessary technical infrastructure had been implanted by IRD in its Department for Environmental Radiation Protection (DEPRA), close collaboration between IRD/CNEN and HS/KfK led to measurement procedures and sample preparation techniques and to the selection of the media, samples and locations to be monitored. In conclusion of the preoperational period, the results obtained by IRD were analyzed and checked by IRD and KfK staff; they are published in this joint CNEN/KfK report.

The data of the environmental background radioactivity already available prior to the commissioning of Unit I are presented to show site specific radioactivity distribution patterns in the vicinity of the plant, to evaluate the adequacy of gaseous and liquid effluent emission control and to allow, in the course of future operation, an assessment to be made of the resulting environmental impact, if any.

2. The Angra Nuclear Power Plant Site

2.1 Site Characteristics

The Almirante Alvaro Alberto Nuclear Power Plant (CNAAA) is located on Itaorna Beach in the Municipality of Angra dos Reis, State of Rio de Janeiro, Brazil. It is 133 km distant from Rio de Janeiro, 216 km away from São Paulo, 15 km west from Angra dos Reis and 36 km northeast from the historical city of Parati.

The site was selected in 1970 following preliminary studies carried out by FURNAS Centrais Eléctricas, the plant owner and operator. In those studies, only coastal sites in the State of Rio de Janeiro had been considered. Site selection criteria had been based on meteorological and geological data, hypothesized construction difficulties, anticipated land purchases and costs of power transmission and transportation, as well as on local population density and practices of land use.

Itaorna Beach does not face the open sea. It is protected against adverse weather such as storms by two medium-sized islands, Ilha Grande and Ilha de Sandri, located in the Bay of Ilha Grande. The shoreline is oriented NNW to SSE with the Itaorna Bay to the west. In other directions there are hills rising to more than 600 meters (north), 290 meters (east) and 250 meters (south) within about 500 meters of the site center (see Fig. 1 and the site map in Chapter 4).

Access to the "bowl-shaped" site is possible by sea and by land. The Rio - Santos highway (BR-101) links the CNAAA to both Rio and Santos. A small on-site dock is capable of handling heavy equipment shipped by sea.

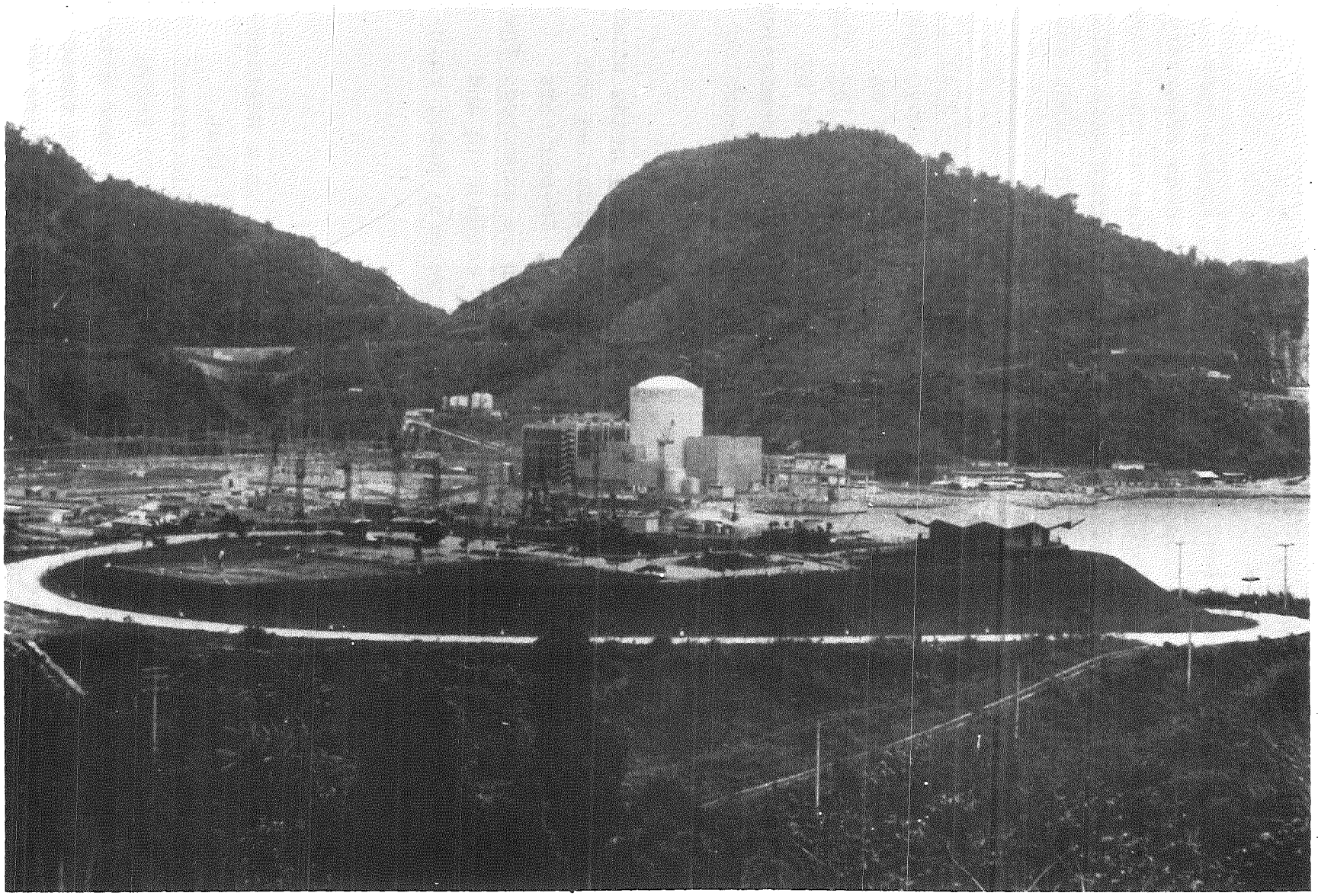

Fig. 1: The Angra Nuclear Power Plant Site.

2.2 Local Meteorology

In the early seventies, four meteorological towers were erected at the construction site to provide data necessary for the licensing procedure. It was determined at that time that the important atmospheric diffusion sectors were NNE, NE and ENE for the wind blowing from sea towards land, and WSW, SW for the wind heading seawards.

One of the four towers was refurbished several years ago. It is 100 m in height and stands about 50 meters above sea level. The meteorological instrumentation installed on three levels (15, 50 and 100 m) is computer controlled. The data collected are subjected to frequent evaluations by FURNAS and the Brazilian National Nuclear Energy Commission with a view to developing a more accurate micrometeorological model for the site.

The wind field at the site is complex and still being studied. In general, the sea breeze predominates during the day in a layer up to 80 m above sea level. Beyond this level, reversal in the wind direction can be expected. The temperature profile is often isothermal between 10 and 60 m, with strong inversions up to 100 meters. Heavy rainfalls occur several times a year.

2.3 Power Plants

The completed Unit I, also known as Angra I, is a Westinghouse designed pressurized water reactor (PWR) that reached criticality in March 1982. Its rated electrical output is 626 MW(e). Two other units, of the well known "Biblis" PWR type, are being constructed at the same site in cooperation with Kraftwerk Union (KWU). Each of these units will generate 1300 MW(e). All condenser cooling wa-

ter for the three units will be drawn from Itaorna Bay and discharged into Piraquara de Fora Bay.

2.4 Local Population

Presently, the major settlements near the plant are FURNAS residential villages on two beaches, Praia Brava and Praia de Mambucada, with about 5000 people in total. Angra dos Reis has about 100,000 inhabitants, Parati has approximately 10,000. Along the coastline are several small fishing villages with less than 5000 inhabitants. Weekend vacationers from Rio and São Paulo will continue to build homes along the picturesque shoreline, thus causing a different distribution, especially during the summer time.

2.5 Use of Water and Land

The local agricultural production is of minor importance and consists essentially of bananas, manioc (cassava root), beans, corn and citrus fruits. Livestock herds for meat and milk production mainly satisfy the proprietors' needs. Sports fishing in the sea or fishing for local consumption is practiced all over the year. While crustacea and mollusks are scarce in the region, shrimp are caught and marketed on a regular basis. It is to be noted that most staples of the local diet are bought from other production areas. The principal component of the local diet is fish caught in the region.

3. The Department for Environmental Radiation Protection of IRD

In December 1971, the Brazilian National Nuclear Energy Commission founded the Institute for Radioprotection and Dosimetry (IRD). As one of its five departments, the Department for Environmental Radiation Protection (DEPRA) was established to enable the supervisory authority to monitor the radioactive effluents into the environment from the new installations of the Brazilian nuclear fuel cycle and to assess the environmental impact of these emissions.

Currently, DEPRA executes preoperational and operational monitoring programs as well as effluent monitoring programs in the nuclear-fuel-cycle areas of mining, milling, fuel fabrication and nuclear power generation. Sporadically, the Department monitors the berths of foreign nuclear vessels docking at Brazilian harbors. Whenever requested, DEPRA provides its CNEN headquarters with technical expertise and support in licensing and inspection of nuclear installations.

Recently, DEPRA completed the Preoperational Environmental Monitoring Program for the Angra Nuclear Power Plant Site. It required the concerted efforts of about 30 persons, a quarter of them having Master's degrees or higher academic levels. Field and laboratory data were obtained using "current state-of-the-art" instrumentation: atomic absorption spectrometers, fluorimeters, multi-channel analyzers, Ge(Li) and intrinsic Ge-detectors, liquid-scintillation counters, solid-state dosimeters, ionization chambers, low-background GM-counters and large-area proportional counters (Figs. 2-5). Radiochemical procedures involving sample preparation and enrichment to determine the activity of ^{3}H, ^{14}C, $^{89}Sr/^{90}Sr$, ^{131}I, ^{137}Cs, etc., were implant-

Fig. 2: Determination of radium by the radon emanation method (DEPRA/IRD).

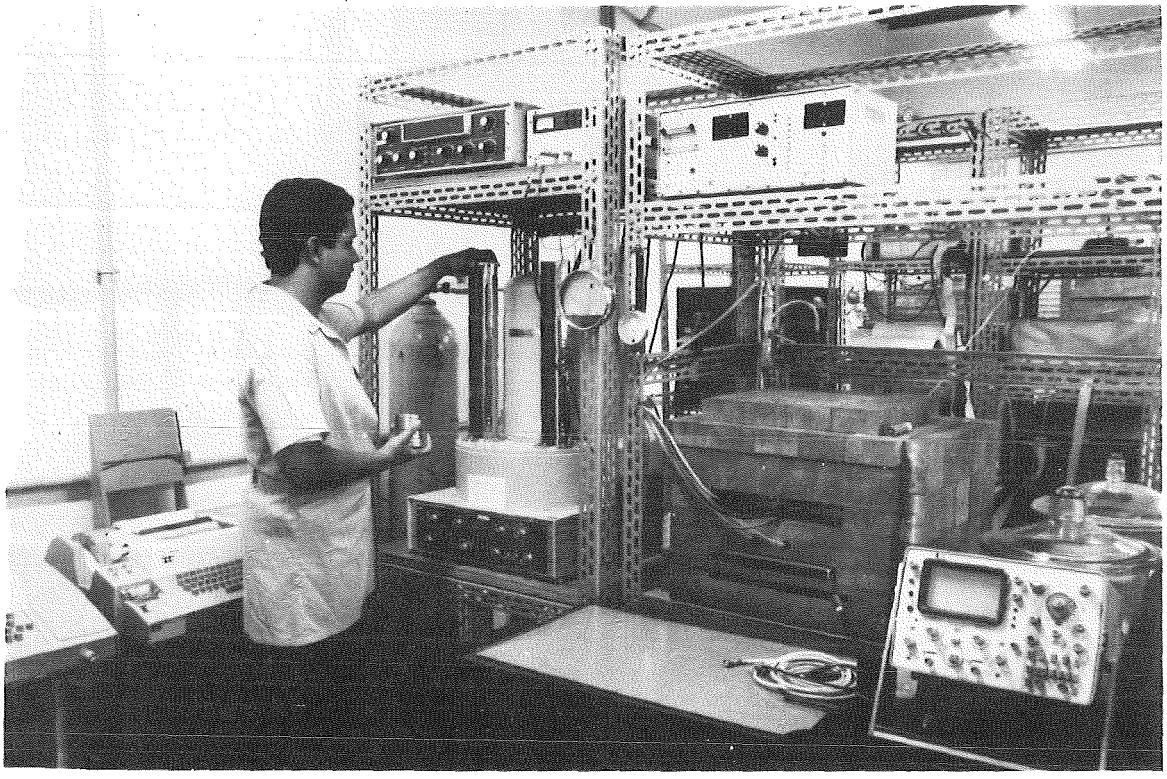

Fig. 3: Determination of alpha and beta activities in samples (DEPRA/IRD).

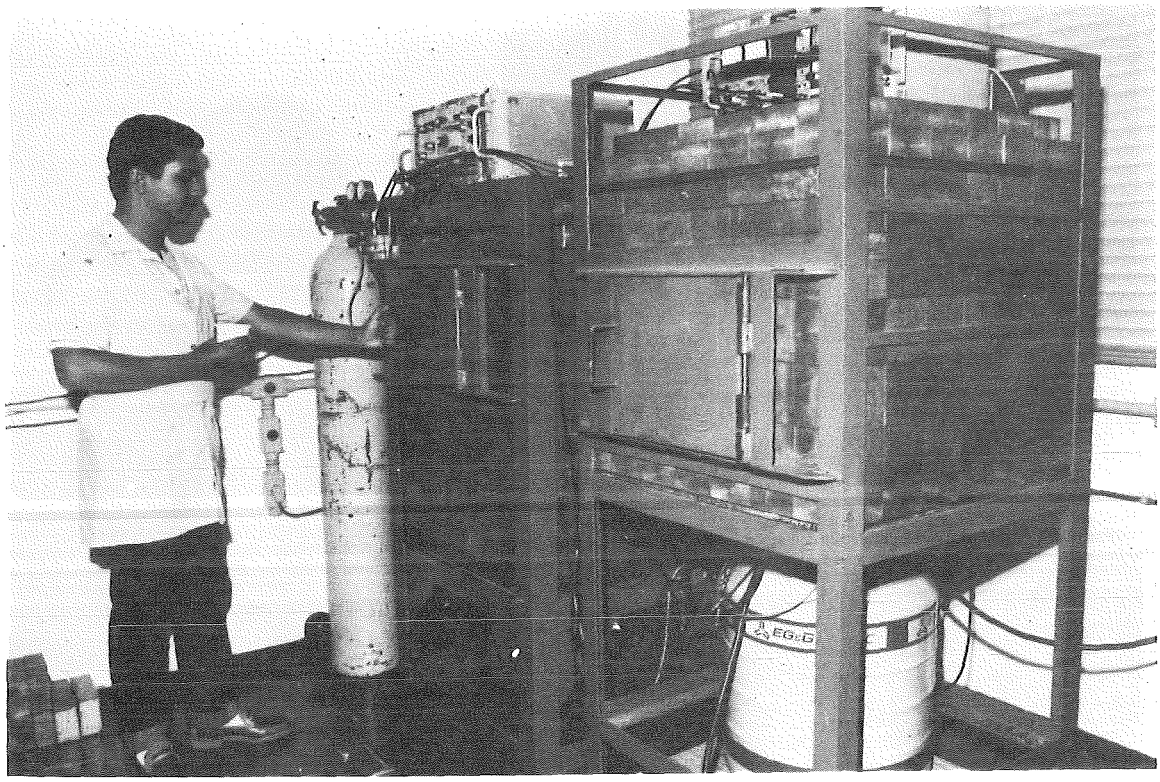

Fig. 4: Gamma spectrometry with solid state detectors (DEPRA/IRD).

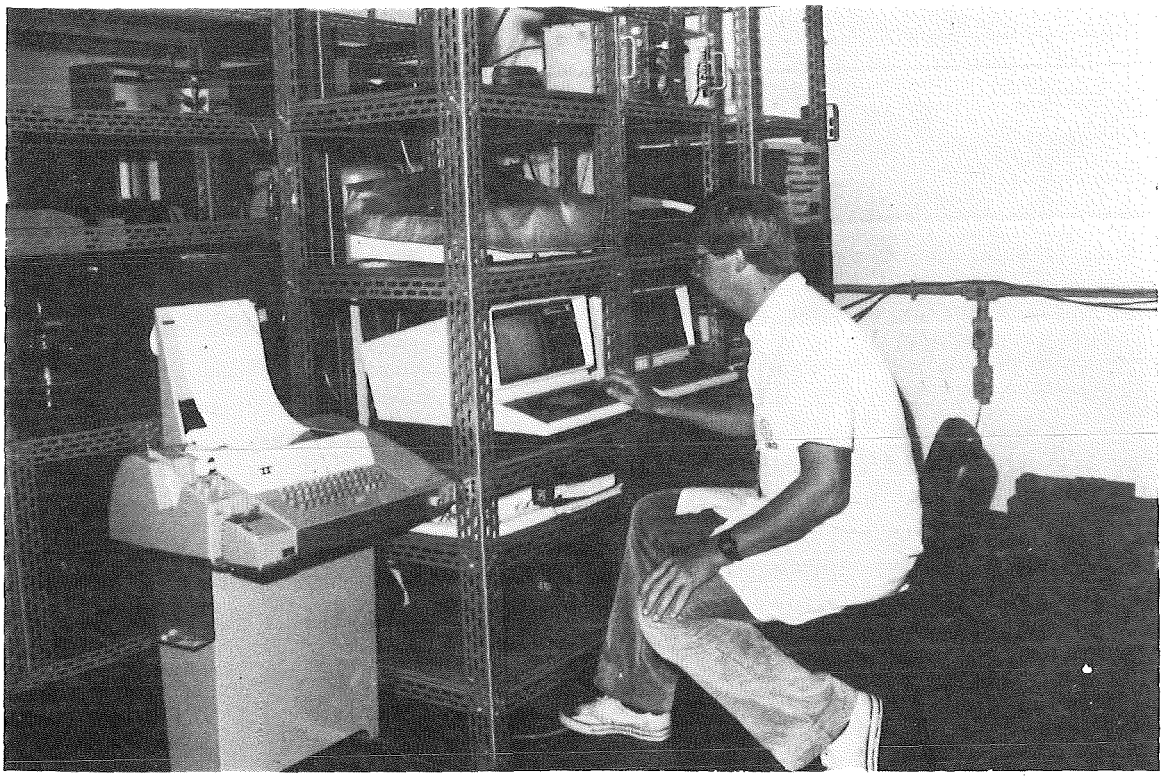

Fig. 5: Evaluation of gamma spectra with multi-channel analyzers (DEPRA/IRD).

ed and tested for reliability and accuracy. Furthermore, to supplement the sparse biological data base available for the nuclear site, the Biology Group of the Department initiated basic taxonomic studies of the aquatic fauna and flora to determine marine food chains and relationships between environmental parameters and population sizes of the species.

The execution of the Preoperational Environmental Program for the Angra Nuclear Power Plant Site was complemented by developing new analytical methods, tropical radioecological research and quality control studies. An internal quality assurance program was maintained to assure the validity of the data being gathered. International partners for intercomparison included the International Reference Center of the WHO, the IAEA, and the German Nuclear Research Center at Karlsruhe. National partners were selected among universities and nuclear measurement laboratories belonging to NUCLEBRAS and FURNAS Centrais Eléctricas S.A.. Usually, the results were in good to excellent agreement which confirms the quality of the environmental data generated (see Appendix).

4. The Preoperational Monitoring Program

4.1 General Remarks

The Preoperational Monitoring Program for the Angra Site became effective in September 1979. Its principal objectives were

- to determine the background levels and seasonal variations of direct external radiation doses and dose rates, within a radius of up to 15 km from the site center,
- to determine the natural and artificial (if any) concentration levels in air, soil, water, plants and foodstuffs,
- to train laboratory technicians in the processing and radiochemical/radiometric analysis of environmental samples,
- to train the DEPRA/IRD staff in statistical evaluation techniques to be applied to the environmental data generated in order to assess the future environmental impact,
- to evaluate the adequacy of procedures, techniques and instrumentation used,
- to furnish the basis for the establishment of the operational monitoring program that followed.

In formulating the program, account was taken of the principal radionuclides likely to be emitted with the liquid and gaseous effluents of PWRs. Two important pathways for human radiation exposure were identified for the liquid effluents: the ocean water → sea fish → human food chain

and the direct radiation exposure paths by radionuclide deposition on beach sand. On the first pathway, "critical nuclides" are ^{134}Cs and ^{137}Cs, while on the second the significant nuclides are ^{58}Co and ^{60}Co. For the gaseous effluents, the well known air → pasture → cow → milk → → man pathway for radioiodine ^{131}I 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. Details about the program are given in a tabulated form in Section 4.2. The map presented in the same section shows the network of the measurement and sampling locations around the nuclear power plant site.

The Preoperational Program was terminated in September of 1981, after roughly 200 samples had been taken and analyzed. Although the Program was sometimes not rigorously fulfilled due to inaccessibility of the sampling locations or due to instrument outages, the accumulated results provide a valuable basis for evaluating future environmental impacts on the Angra region.

4.2 The Program Structure

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 Gaseous 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 Algae
III.6 Crustacea 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	Semi-annual and annual doses at individual stations	15	Semi-annual	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 da Praia (ENE) 8) Ponta da Caieirinha (NE) 9) Bracui (NE) 10) Fazenda Grataú (NNE) 11) Tarituba (WSW) 12) Parati (SW)	Equivalent to operator's stations 8, 9, 10, 7 and 5, in this order.
							Additional stations: 13) Hotel Frade (NNE) 14) Praia Frade (NNE) 15) Praia Piraquara de Dentro (SE)	
I.2	Ionization chambers	Local gamma dose rate H	µrem/h		3	Intermittently performed for IRD by operator	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)	pCi/m^3	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	pCi/m^3	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	pCi/m^3	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 and nCi/m^2	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 and nCi/m^2					

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 K-40 activity						
		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	3	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)	Sampling at location 3 was discontinued after its waters were no longer 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 one of the 3 locations)	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)	Rotation of sampling every quarter. Samples to be taken by NPP operator and sent to IRD, the supervisory authority.
		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	6	Semi-annual	1) Praia Grande do Frade (NNE) 2) Praia do Sítio (ENE) 3) Praia de Piraquara de Dentro (SE) 4) Praia Brava (W) 5) Praia de Mambucaba (WSW) 6) Praia de Tarituba (WSW)	
		Specific K-40 activity						
		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	5	Semi-annual	1) Saco do Demo, Ilha Comprida (ENE) 2) Saco do Frade (NNE) 3) Areas near Ilha de Paquetá (ENE) 4) Areas near Ilha do Brandão (ESE) 5) 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 K-40 activity						
		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 fish	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) Frade (NNE) 2) Tarituba (WSW)	Due to time and material constraints fish samples were often bought from local fishermen after determining the fishing spots.
		Specific K-40 activity						
		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	
		Specific K-40 activity						
		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 K-40 activity						
		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 K-40 activity						
		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 K-40 activity						
		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	Algae	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	5	Semi-annual	1) Northern area of the Saco do Piraquara de Fora (E) 2) Southern area of the Saco do Piraquara de Fora (ESE) 3) Ilha do Brandão, southern part (ESE) 4) Marina located at the Saco do Piraquara de Fora (ESE) 5) Bay of Tarituba (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	Crustacea 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	1	Semi-annual	1) Bay of Tarituba (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						

5. Discussion of the Summarized Measurement Results and Conclusions

5.1 Direct Radiation Measurements

5.1.1 Solid-state Dosimeters

Measurements of direct radiation doses and dose rates were performed with thermoluminescent dosimeters (TLD) and ionization chambers (IC). Twelve TLD stations were located off-site near major settlements and towns within a radius of up to 36 km, but most of them within 10 km of the site center. Three additional TLD stations were sited along the site fence in the important atmospheric diffusion sectors W, NNE and E; however, they became operational as late as in December 1981. Summarized TLD data are presented in Table 1.

When the Preoperational Program was started there were substantial problems arising from the access to stations as well as from frequent dosimeter losses or thefts. These problems were resolved with time and a more regular frequency of exchange ensued. Whenever exposures could not be carried out over equal time intervals, dose extrapolation procedures were adopted. In calculating the average value of the direct radiation dose at each location, the true significance of the component values was taken into account by the use of weighting factors based on the length of the actual exposure period, as shown in Tables 17 and 18. Additional TLD data available from a preliminary small-scale study made in 1977-1978 have been included.

The TLD crystal compositions adopted were D-$CaSO_4$:Dy-0.4 and LiF: Mg,Ti from Teledyne Isotopes. Dosimeters were shielded with copper sheathing of 3.5 mm thickness to com-

pensate for over-sensitivity to the low-energy gamma dose, and encapsuled in nylon to protect them from moisture. Time integrated measurements were performed in the field 1 m above ground level. The postulated exchange frequencies were 3 and 6 months for the $CaSO_4$ and LiF TLDs, respectively. Measuring errors were estimated at ±10%. The global average TLD gamma dose for the Angra environment, obtained over a total exposure time of 340 months for all stations taken together, was 118 mrem/a. This figure is close to the accepted worldwide average. A maximum dose rate of 200 mrem/a was observed at Praia do Frade (NNE sector) and a minimum dose rate of 66 mrem/a was measured on Paquetá island (ENE sector).

Number of measurement stations		12
Total exposure time		340 months
Local dose	$\bar{H}$	118 mrem/a
	H_{min}	66 mrem/a
	H_{max}	200 mrem/a
Corresponding average local dose rate	$\bar{H}$	13.5 µrem/h

Table 1: TLD-measurements,
December 1976 - December 1980.

5.1.2 Ionization Chambers

The IC measurements were made every month by FURNAS Centrais Eléctricas S.A. on behalf of IRD (the supervisory authority); the readings covered one hour each. Portable Reuther-Stokes chambers were used with a sensitivity of 0.2 µrem/h. The measurement locations coincided with IRD-TLD stations located along the site boundary. The summarized results are contained in Table 2.

One measuring point at the site fence in the WNW sector lay 900 m distant from the nuclear reactor under construction, in the direction of FURNAS residential areas on Praia Brava and Praia de Mambucaba. These are the two largest settlements situated close to the nuclear power station. A second monitoring point was located 850 m from the reactor in the NNE sector and in the direction of the Cunhambebe region and the Grataú farm. The third and last station for IC measurements, 600 m away from the reactor building, was on the line connecting the NPP with the City of Angra dos Reis in the diffusion sector E.

It can be noted that the local gamma-dose rate measurements were made periodically and not continuously as first envisaged. In compliance with CNEN's request, FURNAS has committed itself to installing fixed continuous gamma radiation measuring stations at these points by the end of the reactor testing phase.

The lowest averaged external gamma radiation dose rate of about 13 µrem/h was observed at the WNW point. The highest rate, about 21 µrem/h, was found at location E. Probably, the near-surface underground granite foundations at point E were responsible for the higher rate. A variation in local natural-background gamma radiation of ±5% must be expected for each point.

Detailed values are given in Tables 19 and 20.

Number of measurement stations		3
Total exposure time		52 months
Local dose rate	$\bar{\dot{H}}$	17.3 µrem/h
	$\dot{H}_{min}$	12.3 µrem/h
	$\bar{\dot{H}}_{max}$	21.6 µrem/h
Corresponding average annual local dose	$\bar{H}$	152 mrem/a

Table 2: Discontinuous dose rate measurements with ionization chambers, March 1979 - December 1980.

5.2 Radioactivity Measurements for the Air and Water Pathways

5.2.1 Aerosol, Radioiodine and Precipitation

All samples corresponding to these program items had to be taken by FURNAS, the plant operator, and sent to IRD for analysis. However, for convenience the analyses were done by FURNAS and the results sent to IRD.

Measurements of the gross beta activity in aerosols trapped onto filters and collected by a high-volume air sampler operated at 1 m above ground level indicated that detectable values could be found next to the construction site (WNW sector). There, fine dust originating from rocks with some thorium and uranium content was given off by a quarry and a stone crushing mill.

Small fluctuations in gross beta activities were observed on aerosol filters during the period of monitoring. The highest value (0.1 pCi/m^3) was recorded for the WNW sector along the site fence in the second half of May 1980. The single results are indicated in Table 21 and the summarized results in Table 3.

Charcoal cartridges used for the determination of radioiodine in air were regularly analyzed (see Table 22). The filters were counted for ^{131}I gamma rays on Ge(Li) detectors over 10,000 seconds. No radioiodine originating from nuclear weapons tests was ever detected by direct gamma spectrometry. This result was expected because of the few nuclear bomb tests made in the Southern Hemisphere and the short half-life of ^{131}I of 8.04 days. The minimum detection limit of 10 fCi/m^3 was achieved when analysis followed sampling immediately.

Monthly precipitation indexes were kept by FURNAS which also performed gross beta activity measurements in rainwater. Dried water residues were counted during 300 minutes on small planchets with a 2" diameter proportional window counter. The results are shown in Table 23.

The gross beta activity fluctuations in precipitation were larger in magnitude than the fluctuations observed for aerosols. The maximum value (168 pCi/l) occurred during April 1980, the month before the maximum in aerosol activity was found. The average gross beta activity was 35 pCi/l, determined from 14 samples. The minimum gross beta activity was found to be 3.5 pCi/l. The average pluviometric index was 126 mm/month with a maximum of 253 mm/month and a minimum of 10 mm/month. The month of minimum precipitation, April 1980, coincided with the month of maximum aerosol activity. Please refer to Table 3 for the results.

Medium Monitored	Number of Samples Analyzed	Specific Gross Beta Activity (related to ^{40}K)			
		Average	Minimum	Maximum	Units
Aerosol	28	18	5	100	fCi/m^3
Precipitation	14	35.4 4.5	3.5 0.7	167.5 30.7	pCi/l nCi/m^2 per month
Pluviometric index		125.6	10.2	252.5	mm/month

Table 3: Aerosol and precipitation measurements during the period October 1979 - December 1980.

5.2.2 Cow Milk

Several difficulties associated with the sampling of this medium were encountered. At one time, the milk supply to the laboratory was interrupted because suppliers refused cooperation when the milk became scarce. Farms in the region usually had small herds of dairy cattle furnishing milk for home consumption only. Whenever there was heavy rainfall, the access to farms located off the major highway became impossible. Nevertheless, the sampling frequency was roughly observed.

The milk producing farms identified in the Program as Pedra Branca and Campo Alegre can be considered as a single monitoring point. They are located just one kilometer apart in the same ENE atmospheric diffusion sector.

Milk analyses for radioiodine were made. Radiochemical enrichment of ^{131}I on ion-exchange resin was followed by 1000 minutes of counting with a 4" x 4" planar NaI(Tl) detector, linked to an MCA. For direct counting on a Ge(Li) detector, Marinelli beakers of 3.5 l volume were used, the counting time being also 1000 minutes.

A minimum detection limit (MDL) of 2.24 pCi/l was attained for ^{131}I only if counting was started immediately after sampling. Often, due to delays in transportation and processing at the laboratory, this MDL was not achieved. However, the objective of training technicians in radioiodine analysis was attained.

Gamma spectrometry measurements were made of milk samples for the determination of activity concentrations of individual radionuclides and an MDL of 15 pCi/l was reached relative to ^{60}Co (see Tab. 25). Only ^{40}K-activity was found. The summarized results of milk analyses are shown in Table 4, and the single results in Table 24.

Number of Sampling Locations	Number of Samples Analyzed	Activity Concentration in pCi/l			
		^{40}K			^{131}I
		Average	Minimum	Maximum	MDL
4	9	1,045	603	1,545	< 2.24

Table 4: Radioactivity in cow milk during the period September 1979 - June 1981.

5.2.3 Grass (Pasture)

Grass samples were collected from the same farms and at the same dates when the milk samples were taken. The average ratio of fresh grass weight to dry grass weight was determined to be 5±2. The ratio of dry grass weight to ash weight was found to be 9±4. The drying of grass in ovens proceeded at 110 ^{o}C and ashing occurred at temperatures up to 450 ^{o}C.

Type of Radioactivity	Specific Activity in pCi/g ash		
	Average	Minimum	Maximum
Gross alpha (related to ^{241}Am)	7.7	2.0	21
Gross beta (related to ^{40}K)	172	102	288
^{40}K	154	63	239

Number of sampling locations:	6
Number of samples analyzed:	14

Table 5: Radioactivity in grass during the period September 1979 - June 1981.

The gross alpha activity, averaging 7.7 pCi/g ash, was always detectable. The gross beta activities for the samples were fairly uniform in value (average of 172 pCi/g ash)

and, with the measuring errors taken into consideration, directly comparable with the ^{40}K-activity (average of 154 pCi/g ash). These summarized results are entered in Table 5, while the single values are shown in Table 26.

Determinations of individual radionuclides by gamma spectrometric measurements were carried out and a lower limit of detection of 0.42 pCi/g ash relative to ^{60}Co was obtained. Further results are given in Table 27.

5.2.4 Surface Water

Surface water samples were collected once each semester. One surface water sampling point, Rio do Frade (NNE sector), was located near the Frade village next to a bridge over the river bearing the same name, on the Rio - Santos highway (BR-101). Another sampling point, at Córrego Cachoeira Brava (WNW), became the drinking water source for the construction workers at the site after clarification of the water at a treatment plant. While samples were taken from the drinking water source, the treated water itself was not sampled under the Preoperational Program as had been envisaged initially.

The analysis of surface water proceeded in a manner similar to that used for precipitation. More attention will be paid to this program item during the operational period because the minimum detection limits for alpha and beta gross activitiy concentrations obtained in the preoperational period were irregular. It was concluded that a better enrichment procedure will have to be adopted. The ^{40}K-activity concentrations in surface water were on the order of 1 pCi/l. The single results are presented in Table 28. Some results are missing on the table because samples got lost during mounting operations. The summarized results are shown in Table 6.

Type of Radioactivity	Specific Activity in pCi/l		
	Average	Minimum	Maximum
Gross alpha (related to ^{241}Am)	-	1.2	< 6
Gross beta (related to ^{40}K)	-	1.7	< 17
^{40}K	1.0	0.7	1.1

Number of sampling locations:	2
Number of samples analyzed:	10

Table 6: Radioactivity in surface water during the period September 1979 - March 1982.

No artificial radionuclides could be identified in surface water by gamma spectrometry. The minimum detection limits obtained for a selected set of relevant nuclides and a short description of the measurement conditions are presented in Table 25.

5.2.5 Seawater

Coastal seawater samples were taken once in a trimester, alternating among the three defined sampling locations. The sampling point chosen at the Saco Piraquara de Fora was 100 m downstream of the point of cooling water discharge. The other sampling point was located next to Ponta Fina in

Itaorna Bay, close to the cooling water intake. The third sampling point located in Tarituba Bay was the designated reference point.

Evaporation of 1 liter of coastal seawater samples from the Angra dos Reis region yielded about 35 g of dry salt. Gross beta and gross alpha activity measurements were made of the dried and crushed salt granules or of the dried residue from the evaporation of small seawater drops deposited on planchets. The beta activity measurement results initially obtained were questioned because they were much higher than the ^{40}K-activities found in these samples. Gamma spectrometry showed that natural activity could be measured but could not account for the observed difference. After lengthy experimentation using different sample preparation techniques, both IRD/CNEN and KfK obtained reasonable results which are reported in Table 29.

Potassium-40 was not identified in seawater using direct gamma spectrometry. Analysis of an enriched sample of residue (2 liters evaporated to dryness) yielded a ^{40}K-activity concentration of 260 pCi/l. Atomic absorption measurements on several coastal seawater samples from the Angra dos Reis region gave an average value of 315 pCi/l. Summarized alpha, beta and ^{40}K-results are shown in Table 7.

The gamma analysis of seawater samples revealed the presence of natural radionuclides resulting from the decay of uranium and thorium constituents: ^{208}Tl, ^{212}Pb, ^{212}Bi, ^{214}Pb, ^{214}Bi, ^{224}Ra and ^{228}Ac. No artificial radionuclides have been identified. The minimum detection limits obtained for nuclides which might occur during the operational period were already presented in Table 25.

Type of Radioactivity	Activity Concentration in pCi/l		
	Average	Minimum	Maximum
Gross alpha (related to ^{241}Am)	< 80	-	-
Gross beta (related to ^{40}K)	300	-	-
^{40}K	315	270	343

Number of sampling locations:	3
Number of samples analyzed:	6

Table 7: Radioactivity in seawater during the period November 1979 - September 1981.

5.2.6 Sand

Sand samples from six locations were evaluated for specific gross alpha, gross beta and ^{40}K-activities as well as for other natural radionuclides. Measurements of gross alpha and gross beta activities of 100 min duration were made with a large-area proportional counter using 1 g of sand evenly distributed over planchets 20 cm in diameter.

Great differences for gross alpha-activity levels can be noticed between samples from different beaches and even between those collected from the same beach. Sands taken from the Mambucaba and Grande do Frade Beaches exhibit higher than average alpha, beta and gamma values. The par-

ticular value depends on the exact sampling location. The wide range in specific activity values found at a single sampling point (see Table 30) is explained by the shifting of monazite sands with the tides. This was apparent from visual inspection of the color of the sand samples and verified by gamma spectrometry (see Table 31). The highest gross activity values were found in sand samples obtained on the Frade Beach (NNE). A higher than average specific

Type of Radioactivity	Specific Activity in pCi/g dry material		
	Average	Minimum	Maximum
Gross alpha (related to ^{241}Am)	< 7.7	< 2.2	67
Gross beta (related to ^{40}K)	49	27	155
^{40}K	12	< 2.0	24
^{208}Tl	-	< 0.2	60
^{212}Bi	-	< 1.5	60
^{214}Pb	-	< 0.2	34
^{214}Bi	-	< 0.2	29
^{228}Ac	-	< 0.3	68

Number of sampling locations:	6
Number of samples analyzed:	24

Table 8: Radioactivity in sand during the period September 1979 - March 1981.

^{40}K-activity was observed at this location as well. In general, the specific gross beta activity was higher than the specific ^{40}K-activity. The results are summarized in Table 8.

No artificial radionuclides were identified in sand samples with gamma spectrometry. The minimum detection limits obtained for a selected set of relevant nuclides are presented in Table 32 together with a short description of the measurement conditions.

5.2.7 Sediment

Sediment, a medium susceptible to contamination over long periods due to the deposition of radionuclides from effluents released from the reactor, was analyzed for base-line radioactivity levels in a manner similar to that used for the analysis of sand and soil samples.

The sampling point in Tarituba Bay which was designated as the reference point happened to yield sediments with the highest alpha, beta and ^{40}K-activities of all. A place originally in the program, Mambucaba Bay, was dropped when no sediment had been found there.

A large range (6 to 29 pCi/g dry material) in specific gross alpha activities can be noted for this medium (see Table 33 for single alpha, beta and ^{40}K-results). Higher specific gross beta activity levels than the ^{40}K-activity values were found. As expected, this can be attributed to the presence of daughter nuclides of the uranium and thorium decay chains. Refer to Table 34 for natural radionuclide activity determined by gamma spectrometry for the Saco do Frade (NNE) and Baia de Tarituba (WSW) sampling locations. The summarized results are given in Table 9.

Artificial radionuclides have not been identified in sediments by gamma spectrometry. For a selected set of pertinent radionuclides, the minimum detection limits achieved are presented in Table 35. In this table a short description of the measurement conditions has been included.

Type of Radioactivity	Specific Activity in pCi/g dry material		
	Average	Minimum	Maximum
Gross alpha (related to ^{241}Am)	14	5.6	29
Gross beta (related to ^{40}K)	60	36	77
^{40}K	20	7	32
^{208}Tl	< 2.0	0.7	3.6
^{212}Bi	< 2.5	1.5	3.3
^{214}Pb	1.5	0.9	2.5
^{214}Bi	1.3	0.8	2.2
^{228}Ac	2.1	0.9	3.4

Number of sampling locations:	5
Number of samples analyzed:	14

Table 9: Radioactivity in sediment during the period November 1979 - April 1981.

5.2.8 Fish

Fish from the Angra dos Reis region was caught by the FURNAS Radioecology Group or bought by IRD at fish markets in the villages. Generally, the fish came from the Frade and Tarituba areas. Gross alpha, gross beta and ^{40}K-specific activities were determined for sedentary and migratory fish and a distinction was made between meat and bone. Gamma spectrometry measurements were also carried out.

For analyzing purposes, "total fish" was defined to be edible fish meat, including the spines (bones) but excluding the viscera, scales and fins. Separate analyses of the fish meat, the spines and the fish as a whole were carried out. There was some difficulty in separating meat from spine in smaller fish samples. A range of ratios of 20 to 60 was found between meat weight and meat ash weight.

It was observed that the principal specific activity resides in the meat and is due predominantly to the ^{40}K-activity. Specific alpha activities on the order of a few pCi/g ash were found in both bone and meat but usually they were below the minimum detection limit. No significant difference in specific radioactivities was found among the fish species, nor among sedentary and migratory fish. The single data on activities determined in fish are presented in Table 36 and the summarized values are given in Table 10.

Gamma spectrometry measurements made on fish samples revealed no activity above the minimum detection limits for a selected set of relevant artificial radionuclides. These limits are given in Table 37 together with a short description of the measurement conditions.

Type of Radioactivity	Specific Activity in pCi/g ash		
	Average	Minimum	Maximum
Gross alpha (related to ^{241}Am)	< 2.5	< 1.0	< 6.2
Gross beta (related to ^{40}K)	81	34	217
^{40}K	54	16	166

Number of sampling locations:	2
Number of samples analyzed:	20

Table 10: Radioactivity in fish during the period September 1979 - March 1981.

5.3 Supplementary Radioactivity Measurements Specifically Related to Terrestrial and Marine Food Chains

Supplementary measurements of radioactivity levels in typical agricultural produces of the Angra area were made under the Preoperational Monitoring Program. The foodstuffs investigated were bananas, oranges, manioc (cassava root), crustacea and mollusks. Soil was also considered.

5.3.1 Soil

Samples of soil, a medium expected to be a future integrator and indicator of airborne radionuclide deposition, were evaluated with a view to the presence of natural (see Table 39) or artificial (see Table 40) radionuclides, alpha and beta gross activity and ^{40}K-activity levels. The summarized results are presented in Table 11.

Type of Radioactivity	Specific Activity in pCi/g dry material		
	Average	Minimum	Maximum
Gross alpha (related to ^{241}Am)	14	7.3	20
Gross beta (related to ^{40}K)	55	32	79
^{40}K	8.4	< 2	14
^{208}Tl	< 2.3	0.3	5.9
^{212}Bi	< 2.9	< 1.7	5.7
^{214}Pb	1.6	0.3	3.5
^{214}Bi	1.4	0.4	3.0
^{228}Ac	< 2.5	< 0.5	5.7

Number of sampling locations:	4
Number of samples analyzed:	8

Table 11: Radioactivity in soil during the period September 1979 - June 1981.

The soil samples were taken annually at the same farms where milk and pasture samples were obtained. As can be seen from Table 38, the alpha activities were fairly uniform, averaging 14 pCi/g dry material. Beta activities were consistently higher than ^{40}K-concentration levels. Once again, as with similar media, these results are explained by the presence of beta emitting natural radionuclides from the thorium-uranium decay series. By gamma spectrometry, no relevant artificial radionuclides were determined for soil samples above the minimum detection limits. The limits for the selected set of relevant artificial radionuclides, together with a description of the adopted measurement conditions, are given in Table 40.

5.3.2 Bananas

During the program implementation the stipulated sampling point in the NE diffusion sector close to Ponta do Caioba was transferred to Cunhambebe in the NNE sector because of the significant banana production there. A third sampling point situated close to Mambucaba village in the WSW sector was included in the program, since this also was an area of commercial banana production.

The single results shown in Table 41 indicate that specific alpha activities were consistently below the minimum detection limit of 2.4 pCi/g ash. Comparison of gross beta activity and ^{40}K-activity indicates nearly identical values, leading to the conclusion that ^{40}K is the source of most of the activity to be found in bananas. No significant difference in activity was discovered between the two species considered (bananas prata and d'água). The summarized results of the specific activities are shown (in pCi/g ash) in Table 12. The banana fresh weight to ash weight ratio averaged 120.

Type of Radioactivity	Specific Activity in pCi/g ash		
	Average	Minimum	Maximum
Gross alpha (related to ^{241}Am)	< 2.1	< 0.9	< 2.8
Gross beta (related to ^{40}K)	300	248	391
^{40}K	300	158	387

Number of sampling locations:	4
Number of samples analyzed:	13

Table 12: Radioactivity in bananas during the period September 1979 - March 1981.

For banana samples, gamma spectrometry measurements made for a selected set of relevant artificial radionuclides showed no activity above the lower limits of detection. These limits are shown in Table 42 including a short description of the measurement conditions.

5.3.3 Manioc

Manioc plantations are not predominant in the near vicinity of the Angra Site. Therefore, samples were obtained biannually mainly from the Mambucaba area in the WSW sector.

The specific alpha activities in manioc were usually below the minimum detection limit and no significant difference was found between the specific gross beta and ^{40}K-activities. This is evident from Table 43. The ratio of manioc fresh weight to ash weight was 135 on average.

Type of Radioactivity	Specific Activity in pCi/g ash		
	Average	Minimum	Maximum
Gross alpha (related to ^{241}Am)	< 2.8	< 0.9	4.1
Gross beta (related to ^{40}K)	329	247	387
^{40}K	290	215	331
^{137}Cs	< 1.0	< 0.54	1.4

Number of sampling locations:	1
Number of samples analyzed:	4

Table 13: Radioactivity in manioc during the period September 1979 - March 1981.

Cesium-137 fallout from nuclear weapons tests was detected in manioc samples by gamma spectrometry with small values of about 1 pCi/g ash. As a consequence, a careful analysis of manioc is being undertaken in the operational monitoring phase. Specifically, comparisons of ^{137}Cs levels in different sorts of manioc will be made. The influence of

soil type on the ^{137}Cs levels in the manioc (cassava) roots is also being studied. It is expected that after the cesium activity levels in the soils have been determined the coefficient of the soil to root transfer can be calculated. The summarized data on activity levels in manioc are presented in Table 13.

Except for ^{137}Cs, no other relevant artificial nuclides were determined above the minimum detection limits for manioc by gamma spectrometry measurements. The limits for this selected set of nuclides are given in Table 44 in addition to a short description of the measurement conditions.

5.3.4 Oranges

Two orange species (lima and pera) were sampled at the Gratafi farm in the NNE sector beginning in March 1980, during the local harvest seasons.

No difference was found in the activity levels between the two species studied. Considering the measurement errors the gross beta and ^{40}K-activities are comparable (see Table 45). The average ratio of fresh orange weight to orange ash weight was found to be about 180. The summarized data are presented in Table 14.

No fission nuclides have been identified for oranges by gamma spectrometry. The selected set of pertinent aritificial radionuclides and their detection limits are presented in Table 46. A short description of the measurement conditions is also given in this table.

Type of Radioactivity	Specific Activity in pCi/g ash		
	Average	Minimum	Maximum
Gross alpha (related to ^{241}Am)	< 4.6	< 2.2	7.1
Gross beta (related to ^{40}K)	239	202	292
^{40}K	241	155	312

Number of sampling locations:	1
Number of samples analyzed:	4

Table 14: Radioactivity in oranges during the period March 1980 - June 1981.

5.3.5 Algae

The study and monitoring of algae was initiated on account of their suitability as bio-indicators of coastal seawater contamination due to liquid effluents from nuclear power plants. They are useful because of the bio-concentration properties of particular species. Studies are in progress to find the most suitable species to serve as bio-indicators.

The Mambucaba Bay sampling location was dropped from the program because no algae have been found in this bay. It was replaced by a new place in the Saco de Piraquara de Fora Bay, close to the outlet of the condenser cooling water discharge channel. The reference point was located in Tarituba Bay (WSW).

The data base for algae is presented in Table 47. The specific alpha activity of algae varied between less than the MDL of 1.0 pCi/g ash and 18 pCi/g. The specific gross beta activities were fairly uniform among the predominant species investigated, averaging 106 pCi/g ash. The average specific beta activity of Sargassum algae was comparable to that of Acantophora algae. Considering this single fact there would no longer be a need to distinguish between the algae species; however, the reconcentration factors may be species dependent. Potassium-40 levels fluctuated greatly between 23 pCi/g ash and 146 pCi/g ash, with an average value of 69 pCi/g ash. Refinements in the method for "cleaning" algae of attached sediments are proceeding and in the future should lead to more uniform specific activity values. The fresh algae weight to ash-weight ratio varied between 10 and 20. The summarized results are presented in Table 15.

Gamma spectrometry measurement results for a typical algae sample are presented in Table 48. There, the minimum detection limits for a selected and relevant set of artificial radionuclides are given together with a short description of the measurement conditions.

Type of Radioactivity	Specific Activity in pCi/g ash		
	Average	Minimum	Maximum
Gross alpha (related to ^{241}Am)	< 5.8	< 1.0	18
Gross beta (related to ^{40}K)	106	63	165
^{40}K	69	23	146

Number of sampling locations:	5
Number of samples analyzed:	19

Table 15: Radioactivity in algae during the period November 1979 - March 1981.

5.3.6 Crustacea and Mollusks

No crustacea or mollusks are caught commercially in the Saco de Piraquara de Fora Bay and at Brandão Island because fishing regulations prohibit commercial harvesting within small bays. The shrimp that IRD obtained by purchase in Tarituba camefrom areas outside the Tarituba Bay. No specimens in the mollusks and crustacea class other than shrimp were analyzed due to their scarcity in the mud-free bays.

The specific alpha activity levels found in shrimp were generally below the MDL of about 2.8 pCi/g ash. Specific beta activities were fairly uniform considering the measurement errors, and averaged 74 pCi/g ash. The ^{40}K activity concentrations fluctuated between 18 and 60 pCi/g ash. These single results are presented in Table 49, while the summarized data are found in Table 16. It was determined that the ratio of fresh shrimp weight to ash weight varied between 26 and 34.

Type of Radioactivity	Specific Activity in pCi/g ash		
	Average	Minimum	Maximum
Gross alpha (related to ^{241}Am)	< 4.8	< 2.6	9
Gross beta (related to ^{40}K)	74	61	83
^{40}K	41	18	60

Number of sampling locations:	1
Number of samples analyzed:	3

Table 16: Radioactivity in crustacea and mollusks during the period March 1980 - March 1981.

No artificial radionuclides were found above the minimum detection limits for shrimp samples by gamma spectrometry. Typical minimum detection limits are given in Table 50 in addition to a short description of the measurement conditions.

At the start of the operational program, IRD and FURNAS obtained an exemption from the state ordinance prohibiting fishing in the bays close to the nuclear site. Fish species, consumption habits and the number of population in the immediate vicinity of the NPP are presently being studied by the IRD Biology Group. The bays around the nuclear power plant are known as an area of potential environmental impact and therefore warrant continuous attention. It is obvious that maintaining the Tarituba reference point will continue to be useful for assessing the impact on the Angra dos Reis coastal region resulting from the operation of the Angra Nuclear Power Plant.

6. Single Results of Measurements under the Preoperational Environmental Monitoring Program

This chapter is made up of Tables 17 through 50. It is a documentation of all measured single results obtained under the Preoperational Monitoring Program and already presented as summarized results in Chapter 5. In the discussion of the results of measurements reference has always been made to the respective tables in Chapter 6. To facilitate the assignment of Tables 17 through 50 to the Monitoring Program, the corresponding program items (see Chapter 4.2) have been indicated in all legends of the tables.

Location of TLD Stations	Diffusion Sector	1977		1978	
		Annual Local Dose in mrem/a	Exposure Period in months	Annual Local Dose in mrem/a	Exposure Period in months
AT THE SITE FENCE					
WNW	WNW	-	-	-	-
NNE	NNE	-	-	-	-
E	E	-	-	-	-
OFF-SITE					
1. I. Paquetá	ENE	77 ± 8	5	62 ± 6	9
2. I. Gipóia	ESE	-	-	-	-
3. I. Sandri (a)	SW	175 ± 18	5	117 ± 12	9
I. Sandri (b)	SW	117 ± 12	5	139 ± 14	9
I. Sandri (c)	SW	99 ± 10	10	113 ± 11	3
4. P. Mambucaba	WSW	157 ± 16	10	162 ± 16	9
5. P. Brava	W	-	-	-	-
6. Angra, C. Naval	E	115 ± 12	5	98 ± 10	9
7. Hotel Praia	ENE	138 ± 14	10	124 ± 12	9
8. Pta. Caieirinha	NE	-	-	-	-
9. Bracuí	NE	-	-	-	-
10. Faz. Grataú	NNE	-	-	-	-
11. Tarituba	WSW	-	-	-	-
12. Parati	SW	101 ± 10	8	99 ± 10	9
ADDITIONAL STATIONS					
13. Hotel Frade	NNE	93 ± 9	8	98 ± 10	9
14. P. Frade	NNE	249 ± 25	7	207 ± 21	9
15. Piraquara de Dentro (a)*	SE	82 ± 8	10	76 ± 8	9
Piraquara de Dentro (b)*	SE	114 ± 11	5	104 ± 10	3

- = Station was not operational.

* = Beach located in the bay called Saco de Piraquara de Fora, not to be confused with the beach of the same name located in the bay named Saco de Piraquara de Dentro.

Table 17: Solid-state dosimeter data (program item I.1), exposure periods and extrapolated annual local doses for 1977 and 1978.

Location of TLD Stations	Diffusion Sector	1979		1980	
		Annual Local Dose in mrem/a	Exposure Period in months	Annual Local Dose in mrem/a	Exposure Period in months
AT THE SITE FENCE					
WNW	WNW	-	-	-	-
NNE	NNE	-	-	-	-
E	E	-	-	-	-
OFF-SITE					
1. I. Paquetá	ENE	65 ± 7	9	-	-
2. I. Gipóia	ESE	-	-	-	-
3. I. Sandri (a)	SW	91 ± 9	4	-	-
I. Sandri (b)	SW	131 ± 13	4	-	-
I. Sandri (c)	SW	-	-	-	-
4. P. Mambucaba	WSW	138 ± 14	12	143 ± 14	12
5. P. Brava	W	-	-	-	-
6. Angra, C. Naval	E	91 ± 9	9	96 ± 10	8
7. Hotel Praia	ENE	118 ± 12	9	124 ± 12	8
8. Pta. Caieirinha	NE	-	-	-	-
9. Bracuí	NE	-	-	-	-
10. Faz. Grataú	NNE	-	-	-	-
11. Tarituba	WSW	-	-	-	-
12. Parati	SW	91 ± 9	12	94 ± 9	12
ADDITIONAL STATIONS					
13. Hotel Frade	NNE	105 ± 11	9	-	-
14. P. Frade	NNE	190 ± 19	12	182 ± 17	12
15. Piraquara de Dentro (a)*	SE	71 ± 7	9	85 ± 9	3
Piraquara de Dentro (b)*	SE	83 ± 8	12	-	-

- = Station was not operational.

* = Beach located in the bay called Saco de Piraquara de Fora, not to be confused with the beach of the same name located in the bay named Saco de Piraquara de Dentro.

Table 17: Solid-state dosimeter data (cont.), exposure periods and extrapolated annual local doses for 1979 and 1980.

Location of TLD Stations	Diffusion Sector	Total Exposure Time in months	Average Local Dose Rate During the Total Exposure Time in mrem/a	in µrem/h
AT THE SITE FENCE				
WNW	WNW	-	-	-
NNE	NNE	-	-	-
E	E	-	-	-
OFF-SITE				
1. I. Paquetá	ENE	23	66	7.5
2. I. Gipóia	ESE	-	-	-
3. I. Sandri (a)	SW	18	127	14.5
I. Sandri (b)	SW	18	131	15.0
I. Sandri (c)	SW	13	102	11.7
4. P. Mambucaba	WSW	43	149	17.0
5. P. Brava	W	-	-	-
6. Angra, C. Naval	E	31	98	11.2
7. Hotel Praia	ENE	36	126	14.4
8. Pta. Caieirinha	NE	-	-	-
9. Bracuí	NE	-	-	-
10. Faz. Grataú	NNE	-	-	-
11. Tarituba	WSW	-	-	-
12. Parati	SW	41	96	10.9
ADDITIONAL STATIONS				
13. Hotel Frade	NNE	26	99	11.3
14. P. Frade	NNE	40	199	22.7
15. Piraquara de Dentro (a)	SE	31	77	8.8
Piraquara de Dentro (b)	SE	20	94	10.7
ALL STATIONS				
Sum-total		340	-	-
Mean value		-	118	13.5

- = Station was not operational.

Table 18: Solid-state dosimeter data (program item I.1), average dose values during the exposure period 1977 - 1980.

1979	Along the Fence in Sector	Local Dose Rate $\dot{H}$ in µrem/h		
		$\bar{\dot{H}}$	$\dot{H}_{min}$	$\dot{H}_{max}$
January	WNW NNE E	-	-	-
February	WNW NNE E	-	-	-
March	WNW NNE E	-	-	-
April	WNW NNE E	-	-	-
May	WNW NNE E	12.8 18.8 20.3	* * *	* * *
June	WNW NNE E	12.6 19.2 20.5	* * *	* * *
July	WNW NNE E	* * *	* * *	* * *
August	WNW NNE E	12.9 20.1 20.3	* * *	* * *
September	WNW NNE E	12.6 18.9 *	* * *	* * *
October	WNW NNE E	13.2 19.2 20.8	* * *	* * *
November	WNW NNE E	13.1 10.2 *	* * *	* * *
December	WNW NNE E	12.9 19.6 20.1	12.4 ± 0.2 18.7 ± 0.3 19.9 ± 0.2	13.3 ± 0.2 20.2 ± 0.2 20.2 ± 0.2

* = Data not reported by NPP operator.

Table 19: Ionization chamber readings (program item I.2), local dose rates along the NPP fence 1979.

1980	Along the Fence in Sector	Local Dose Rate $\dot{H}$ in µrem/h		
		$\bar{\dot{H}}$	$\dot{H}_{min}$	$\dot{H}_{max}$
January	WNW	12.4	12.3 ± 0.2	12.5 ± 0.1
	NNE	20.2	19.6 ± 0.4	20.2 ± 0.1
	E	20.2	20.1 ± 0.1	20.3 ± 0.2
February	WNW	12.5	12.4 ± 0.2	13.3 ± 0.1
	NNE	19.5	19.1 ± 0.1	20.1 ± 0.1
	E	20.1	20.0 ± 0.1	20.3 ± 0.2
March	WNW	13.4	12.8 ± 0.2	14.1 ± 0.2
	NNE	20.1	19.1 ± 0.1	21.1 ± 0.1
	E	20.5	20.1 ± 0.1	21.2 ± 0.2
April	WNW	12.9	12.4 ± 0.2	13.4 ± 0.2
	NNE	20.1	19.9 ± 0.2	20.2 ± 0.1
	E	*	* *	* *
May	WNW	13.2	12.9 ± 0.2	13.5 ± 0.2
	NNE	20.8	20.2 ± 0.1	21.3 ± 0.2
	E	20.8	20.3 ± 0.2	21.2 ± 0.1
June	WNW	13.3	13.2 ± 0.1	13.3 ± 0.2
	NNE	20.7	20.7 ± 0.1	20.7 ± 0.1
	E	21.5	21.5 ± 0.2	21.6 ± 0.2
July	WNW	13.2	13.1 ± 0.2	13.3 ± 0.1
	NNE	20.8	20.6 ± 0.2	21.0 ± 0.1
	E	21.0	21.0 ± 0.1	21.1 ± 0.1
August	WNW	13.2	12.9 ± 0.2	13.5 ± 0.2
	NNE	19.8	19.3 ± 0.2	20.3 ± 0.2
	E	20.7	20.5 ± 0.2	20.9 ± 0.2
September	WNW	12.9	12.7 ± 0.2	13.2 ± 0.1
	NNE	*	* *	* *
	E	20.6	20.4 ± 0.2	20.8 ± 0.2
October	WNW	12.7	12.5 ± 0.2	12.9 ± 0.1
	NNE	19.9	19.7 ± 0.2	20.1 ± 0.1
	E	20.5	20.4 ± 0.2	20.8 ± 0.3
November	WNW	12.9	12.7 ± 0.1	13.1 ± 0.1
	NNE	18.7	18.2 ± 0.1	19.1 ± 0.2
	E	20.5	20.2 ± 0.1	20.6 ± 0.2
December	WNW	13.1	13.0 ± 0.2	13.1 ± 0.3
	NNE	19.8	18.5 ± 0.2	19.9 ± 0.3
	E	*	* *	* *

* = Data not furnished by the NPP operator.

Table 19: Ionization chamber readings (cont.), local dose rates along the NPP fence 1980.

Along the NPP Fence in Sector	Exposure Period in months	Local Dose Rate $\dot{H}$			
		$\bar{\dot{H}}$		$\dot{H}_{min}$	$\dot{H}_{max}$
		mrem/a	µrem/h	µrem/h	µrem/h
WNW	19	113	12.9	12.3	14.1
NNE	18	169	19.3	18.2	21.3
E	15	181	20.6	18.5	21.6
Sum-total	52	-	-	-	-
Mean value	-	152	17.3	-	-

Note: The $\dot{H}_{min}$ and $\dot{H}_{max}$ values were determined for a period seven months shorter than the one used for $\bar{\dot{H}}$.

Table 20: Ionization chamber readings (program item I.2), minimum, maximum and mean values of the local dose rate along the NPP boundary in the period 1979/1980.

Collection Period	Month	Long-lived Beta Activity Concentration (related to ^{40}K) in fCi/m^3
04.10. - 19.10. 19.10. - 02.11.	October 1979	5.0 ± 1.0 12.0 ± 0.9
05.11. - 19.11. 19.11. - 03.12.	November 1979	11.0 ± 1.4 8.9 ± 1.0
05.12. - 19.12.	December 1979	16.0 ± 0.9
08.01. - 23.01. 23.01. - 07.02.	January 1980	8.9 ± 1.0 8.9 ± 1.0
07.02. - 22.02.	February 1980	1.3 ± 1.1
22.02. - 08.03. 08.03. - 24.03. 24.03. - 08.04.	March 1980	14.0 ± 1.2 18.0 ± 8.2 24.0 ± 1.2
08.04. - 23.04. 23.04. - 07.05.	April 1980	12.0 ± 0.8 15.0 ± 0.9
07.05. - 22.05. 22.05. - 06.06.	May 1980	10.0 ± 1.9 15.0 ± 1.0
06.06. - 20.06.	June 1980	10.0 ± 1.0
27.06. - 12.07. 12.07. - 28.07.	July 1980	20.0 ± 1.3 18.0 ± 0.9
28.07. - 12.08. 12.08. - 27.08.	August 1980	16.0 ± 1.0 27.0 ± 1.0
27.08. - 11.09. 11.09. - 26.09.	September 1980	14.0 ± 1.0 17.0 ± 1.1
26.09. - 10.10. 10.10. - 27.10.	October 1980	9.7 ± 0.9 11.0 ± 0.8
27.10. - 11.11. 11.11. - 25.11.	November 1980	35.0 ± 0.8 17.0 ± 0.9
25.11. - 11.12. 11.12. - 29.12.	December 1980	20.0 ± 0.8 50.0 ± 0.8

Table 21: Radioactivity in aerosols (program item II.1), collected in sector WNW at the NPP fence.

Collection Period	Month	^{131}I-Activity Concentration in fCi/m^3
04.10. - 19.10. 19.10. - 02.11.	October 1979	< 10 < 10
05.11. - 19.11. 19.11. - 03.12.	November 1979	< 10 < 10
05.12. - 19.12.	December 1979	< 10
08.01. - 23.01. 23.01. - 07.02.	January 1980	< 10 < 10
07.02. - 22.02.	February 1980	< 10
22.02. - 08.03. 08.03. - 24.03. 24.03. - 08.04.	March 1980	< 10 < 10 < 10
08.04. - 23.04. 23.04. - 07.05.	April 1980	< 10 < 10
07.05. - 22.05. 22.05. - 06.06.	May 1980	< 10 < 10
06.06. - 20.06.	June 1980	< 10
27.06. - 12.07. 12.07. - 28.07.	July 1980	< 10 < 10
28.07. - 12.08. 12.08. - 27.08.	August 1980	< 10 < 10
27.08. - 11.09. 11.09. - 26.09.	September 1980	< 10 < 10
26.09. - 10.10. 10.10. - 27.10.	October 1980	< 10 < 10
27.10. - 11.11. 11.11. - 25.11.	November 1980	< 10 < 10
25.11. - 11.12. 11.12. - 29.12.	December 1980	< 10 < 10

Table 22: Radioiodine in air (program item II.2), collected in activated charcoal cartridges in sector WNW at the NPP fence.

Collection Period 1979/1980	Precipitation in mm	Long-lived Gross Beta Activity (related to ^{40}K) in nCi/m²	in pCi/l
02. - 30. October	80.5	2.7 ± 0.2	33.8 ± 2.1
05. - 30. November	205.7	0.7 ± 0.04	3.5 ± 0.2
03. - 28. December	174.8	0.9 ± 0.05	5.2 ± 0.3
02. - 30. January	252.5	1.2 ± 0.08	4.6 ± 0.3
01. - 29. February	203.0	3.8 ± 0.22	18.9 ± 1.1
03. - 30. March	62.0	3.6 ± 0.13	57.6 ± 2.1
01. - 30. April	183.1	30.7 ± 0.6	167.5 ± 3.2
02. - 30. May	10.2	0.7 ± 0.02	66.3 ± 2.1
02. - 30. June	52.8	2.1 ± 0.11	40.0 ± 2.1
01. - 30. July	43.9	3.1 ± 0.09	70.5 ± 2.1
01. - 30. August	106.7	3.9 ± 0.22	36.8 ± 2.1
01. - 30. September	57.9	1.7 ± 0.12	29.5 ± 2.1
01. - 30. October	159.5	4.9 ± 0.33	30.5 ± 2.1
01. - 28. November	166.1	2.1 ± 0.35	13.7 ± 2.1
Oct. 1979 - Sum: Nov. 1980 (14 months) Mean value:	1,758.7 125.6	62.3 4.45	- 35.4

Table 23: Radioactivity in precipitation (program item II.3), collected in sector WNW at the NPP fence.

Sampling Location	Sampling Date	Activity Concentration in pCi/l	
		^{131}I	^{40}K
1. Faz. Grataú (NNE)	07.11.1979	$< 2 \times 10^{+5}$	603 ± 311
	18.09.1980	NA	1,083 ± 317
	10.06.1981	< 10	986 ± 314
2a. Faz. Pedra Branca (ENE)	14.09.1979	$< 3 \times 10^{+6}$	1,316 ± 341
	07.11.1979	$< 1.7 \times 10^{+5}$	1,033 ± 327
2b. Faz. Campo Alegre (ENE)	09.07.1980	$< 8.6 \times 10^{+6}$	877 ± 315
	19.03.1981	$< 1.3 \times 10^{+4}$	928 ± 310
3. Fa. Milho Verde (WSW)	14.09.1979	NA	1,545 ± 355
	05.12.1980	$< 1.8 \times 10^{+5}$	1,033 ± 326

Note: The lower limit of detection is 2.3 pCi/l, when sample is analyzed immediately following sampling.
NA = Not analyzed.

Table 24: Radioactivity in cow milk (program item II.4).

Nuclide	Activity Concentration in pCi/l	Measurement Conditions
^{51}Cr	< 159	Counting time:
^{54}Mn	< 14	1,000 min
^{57}Co	< 13	
^{58}Co	< 13	Detector:
^{59}Fe	< 28	Ge(Li)
^{60}Co	< 15	
^{65}Zn	< 36	Geometry:
^{95}Zr	< 28	Liquids analyzed
^{95}Nb	< 14	in Marinelli
^{103}Ru	< 15	flasks of 3.5 l
$^{106}Ru/Rh$	< 80	volume
^{110m}Ag	< 15	
^{124}Sb	< 16	
^{125}Sb	< 43	Preparation:
^{131}I	< 17	Direct measure-
^{134}Cs	< 15	ment without
^{137}Cs	< 17	enrichment
^{140}Ba	< 38	procedure
^{140}La	< 18	
^{141}Ce	< 29	
^{144}Ce	< 112	

Table 25: Minimum detection limits for γ-spectrometry measurements of milk (program item II.4), surface water (II.6) and sea water (II.7).

Sampling Location	Sampling Date	Specific Activity in pCi/g ash		
		Gross Alpha (related to ^{241}Am)	Gross Beta (related to ^{40}K)	^{40}K
1. Faz. Grataú (NNE)	12.09.1979	2.4 ± 1.1	198 ± 41	212 ± 29
	06.11.1979	5.0 ± 1.4	195 ± 40	203 ± 27
	17.09.1980	9.0 ± 3.9	186 ± 39	115 ± 24
	10.06.1981	4.9 ± 3.2	288 ± 60	239 ± 32
2a. Faz. Pedra Branca (ENE)	14.09.1979	20.8 ± 4.2	120 ± 25	91 ± 15
	06.11.1979	9.1 ± 2.1	158 ± 33	172 ± 24
2b. Faz. Campo Alegre (ENE)	09.07.1980	3.5 ± 2.6	170 ± 37	183 ± 24
	17.03.1981	5.6 ± 3.2	227 ± 47	191 ± 27
3. Faz. Milho Verde (WSW)	27.09.1979	4.5 ± 1.4	225 ± 46	198 ± 31
	08.11.1979	9.5 ± 4.0	180 ± 38	203 ± 54
EXTRA:				
1. P. do Tunel, Sul de Piraquara de Fora	09.1979	12.9 ± 2.8	104 ± 20	87 ± 27
	11.1979	10.8 ± 2.4	102 ± 20	79 ± 17
	11.1979	8.1 ± 1.9	124 ± 25	63 ± 18
2. P. do Sitio, Norte de Piraquara de Fora	09.1979	2.0 ± 1.1	135 ± 29	117 ± 27

Table 26: Radioactivity in grass (program item II.5).

Nuclide	Specific Activity in pCi/g ash	Measurement Conditions
^{51}Cr	< 3.8	Counting time:
^{54}Mn	< 0.37	1,000 min
^{57}Co	< 0.30	
^{58}Co	< 0.35	Detector:
^{59}Fe	< 0.75	Ge(Li)
^{60}Co	< 0.42	
^{65}Zn	< 0.96	Geometry:
^{95}Zr	< 0.73	Ash analyzed in
^{95}Nb	< 0.37	plastic cups of
^{103}Ru	< 0.39	7 cm diameter
$^{106}Ru/Rh$	< 2.0	filled to 3 cm
^{110m}Ag	< 0.37	height
^{124}Sb	< 0.39	
^{125}Sb	< 1.1	
^{131}I	< 0.41	
^{134}Cs	< 0.39	
^{137}Cs	< 0.42	
^{140}Ba	< 1.1	
^{140}La	< 0.48	
^{141}Ce	< 0.60	
^{144}Ce	< 2.5	

Table 27: Minimum detection limits for γ-spectrometry measurements of grass (program item II.5).

Sampling Location	Sampling Date	Activity Concentration in pCi/l		
		Gross Alpha (related to ^{241}Am)	Gross Beta (related to ^{40}K)	^{40}K
1. Rio do Frade	12.09.1979	1.20 ± 0.60	1.7 ± 1.0	NA
(NNE)	17.09.1980	NA	NA	0.69 ± 0.02
	17.03.1981	< 6.0	< 17.3	NA
	14.09.1981	< 1.0	< 2.2	NA
	10.03.1982	< 4.5	< 3.4	NA
2. Córrego Cachoeira	13.09.1979	NA	NA	1.07 ± 0.04
Brava	28.03.1980	NA	NA	1.11 ± 0.03
(WNW)	17.09.1980	NA	NA	1.10 ± 0.03
	18.03.1981	< 6.0	< 17.3	NA
	14.09.1981	< 0.8	< 2.1	NA

NA = Not analyzed.

Table 28: Radioactivity in surface water (program item II.6).

Sampling Location	Sampling Date	Activity Concentration in pCi/l		
		Gross Alpha (related to ^{241}Am)	Gross Beta (related to ^{40}K)	^{40}K
1. Saco Piraquara de Fora (100 m distance from cooling water discharge point) (ESE)	March 1980	NA	NA	332 ± 6
	04.12.1980	< 80	NC	NA
	18.03.1981	< 80	NC	NA
	17.09.1981	< 130	320 ± 120	343 ± 5
	09.03.1982*	< 30	275 ± 75	270 ± 10
2. Baia de Itaorna (SW)	Nov. 1979	NA	NA	327 ± 9
	18.09.1980	< 80	NC	NA
	09.06.1981	< 80	NC	NA
3. Baia de Tarituba (WSW)	Nov. 1979	NA	NA	284 ± 5
	July 1980	NA	NA	332 ± 6
	01.04.1981	< 80	NC	NA

NA = Not analyzed.
NC = Result proven not correct.
* = Sample measured at KfK.

Table 29: Radioactivity in seawater (program item II.7).

Sampling Location	Sampling Date	Specific Activity in pCi/g dry material		
		Gross Alpha (related to ^{241}Am)	Gross Beta (related to ^{40}K)	^{40}K
1. Pr. Grande Frade (NNE)	12.09.1979	14.5 ± 5.2	67 ± 15	14.7 ± 3.0
	26.03.1980	9.4 ± 4.0	37 ± 9	24.1 ± 3.9
	18.09.1980	3.9 ± 2.8	54 ± 12	23.9 ± 3.9
	17.03.1981	5.9 ± 3.5	62 ± 14	20.9 ± 3.2
2. Pr. do Sitio (ENE)	11.09.1979	5.0 ± 3.3	42 ± 10	7.7 ± 2.4
	26.03.1980	< 2.6	27 ± 7	8.6 ± 2.3
	18.09.1980	< 2.5	42 ± 10	8.8 ± 2.3
	18.03.1981	< 2.6	45 ± 10	5.9 ± 1.7
3. Pr. de Piraquara de Dentro (SE)	11.09.1979	< 2.6	43 ± 10	5.9 ± 2.2
	26.03.1980	< 2.5	33 ± 8	17.1 ± 3.0
	18.09.1980	< 2.4	48 ± 11	10.2 ± 2.4
	18.03.1981	3.1 ± 9	41 ± 9	11.8 ± 2.2
4. Pr. Brava (W)	13.09.1979	< 3.2	52 ± 12	12.2 ± 2.7
	27.03.1980	< 2.5	38 ± 9	21.9 ± 1.5
	17.09.1980	< 2.2	39 ± 9	15.9 ± 2.9
	18.03.1981	< 2.6	34 ± 8	2.9 ± 1.5

Table 30: Radioactivity in sand (program item II.8).

Sampling Location	Sampling Date	Specific Activity in pCi/g dry material		
		Gross Alpha (related to ^{241}Am)	Gross Beta (related to ^{40}K)	^{40}K
5. Pr. de Mambucaba (WSW)	12.09.1979	7.2 ± 3.6	28 ± 7	7.6 ± 2.4
	27.03.1980	4.5 ± 3.2	46 ± 11	10.3 ± 3.3
	17.09.1980	(67.0 ± 20)*	(155 ± 41)*	3.1 ± 2.4
	19.03.1981	13.9 ± 4.7	64 ± 14	6.2 ± 2.4
6. Pr. de Tarituba (WSW)	12.09.1979	< 3.2	30 ± 8	8.4 ± 2.4
	27.03.1980	4.7 ± 3.5	54 ± 12	9.4 ± 2.4
	04.09.1980	< 3.0	42 ± 10	< 2.0
	19.03.1981	< 2.2	42 ± 9	NA

* = Value attributed to high Monazite sand portions.

NA = Not analyzed.

Table 30: Radioactivity in sand (cont.).

Sampling Location	Sampling Date	Specific Activity in pCi/g dry material						
		^{208}Tl	^{212}Pb	^{212}Bi	^{214}Pb	^{214}Bi	^{224}Ra	^{228}Ac
1. Praia Grande do Frade (NNE)	12.09.1979	1.93±0.75	< 2.7	2.8±2.1	1.87±0.42	1.26±0.48	10.0± 8.6	2.70±0.66
	26.03.1980	1.28±0.48	< 2.7	< 1.5	0.77±0.30	0.90±0.33	< 8.0	1.84±0.60
	18.09.1980	0.99±0.48	< 2.7	< 1.5	0.45±0.42	0.47±0.27	< 2.6	0.95±0.69
	17.03.1981	0.44±0.21	< 1.7	1.7±1.7	0.76±0.21	0.69±0.24	< 8.0	1.49±0.48
2. Praia do Sîtio (ENE)	11.09.1979	< 0.33	< 2.7	< 1.5	< 0.22	< 0.19	< 2.6	< 0.45
	08.11.1979	< 0.33	< 2.7	< 1.5	< 0.22	< 0.19	< 2.6	< 0.45
	26.03.1980	< 0.33	< 2.7	< 1.5	< 0.22	< 0.19	< 2.6	< 0.45
	18.09.1980	< 0.33	< 2.7	< 1.5	< 0.22	< 0.19	4.2± 3.8	0.60±0.60
	18.03.1981	< 0.20	< 1.7	< 0.74	< 0.22	< 0.19	< 1.6	< 0.28
3. Praia Piraquara de Dentro (SE)	11.09.1979	< 0.33	< 2.7	< 1.5	< 0.22	< 0.19	< 2.6	< 0.45
	26.03.1980	0.46±0.33	< 2.7	< 1.5	< 0.22	< 0.19	< 2.6	0.70±0.42
	18.09.1980	< 0.33	< 2.7	< 1.5	< 0.22	< 0.19	< 2.6	< 0.45
	18.03.1981	0.37±0.24	< 1.7	< 0.74	0.30±0.21	0.23±0.18	< 2.6	0.49±0.36

Table 31: Natural radioactivity in sand (program item II.8).

Sampling Location	Sampling Date	Specific Activity in pCi/g dry material						
		^{208}Tl	^{212}Pb	^{212}Bi	^{214}Pb	^{214}Bi	^{224}Ra	^{228}Ac
4. Praia Brava	13.09.1979	< 0.33	< 2.7	< 1.5	< 0.22	< 0.19	< 2.6	< 0.45
(W)	08.11.1979	NA	NA	NA	NA	NA	NA	NA
	27.03.1980	< 0.33	< 2.7	< 1.5	0.73±0.54	< 0.19	< 2.6	< 0.45
	17.09.1980	< 0.33	< 2.7	< 1.5	< 0.23	0.37±0.27	NA	< 0.57
	18.03.1981	< 0.20	< 1.7	< 0.74	< 0.14	< 0.12	< 1.6	< 0.28
5. Praia de	12.09.1979	2.3±1.5	< 2.7	3.6±2.4	1.54±0.39	1.38±0.36	< 8.4	2.8 ±1.3
Mambucaba	07.11.1979	NA	NA	NA	NA	NA	NA	NA
(WSW)	27.03.1980	< 1.1	< 2.7	< 1.5	0.67±0.42	0.54±0.33	< 2.6	0.81±0.75
	17.09.1980*	60.1 ±7.3	NA	59.6±8.1	33.9 ±4.1	28.8 ±3.5	237±141	67.9 ±8.3
	19.03.1981*	30.8 ±4.0	NA	32.5±5.7	17.9 ±2.4	14.3 ±1.9	90± 89	33.9 ±3.2
6. Praia de Tarituba	12.09.1979	0.93±0.45	< 2.7	< 1.5	0.32±0.27	0.45±0.27	< 2.6	1.04±0.69
(WSW)	07.11.1979	NA	NA	NA	NA	NA	NA	NA
	27.03.1980	< 0.69	< 2.7	< 1.5	0.46±0.27	0.27±0.21	NA	0.65±0.51
	04.09.1980	< 0.33	< 2.7	< 1.5	< 0.22	< 0.19	< 2.6	< 0.45
	19.03.1981	NA	NA	NA	NA	NA	NA	NA

NA = Not analyzed.
* = Value attributed to high Monazite sand portions.

Table 31: Natural radioactivity in sand (cont.).

Nuclide	Specific Activity in pCi/g dry material	Measurement Conditions
^{51}Cr	< 0.98	Counting time:
^{54}Mn	< 0.096	1,000 min
^{57}Co	< 0.074	
^{58}Co	< 0.091	Detector:
^{59}Fe	< 0.20	Ge(Li)
^{60}Co	< 0.11	
^{65}Zn	< 0.26	Geometry:
^{95}Zr	< 0.19	Dry material analyzed
^{95}Nb	< 0.096	in plastic cups of
^{103}Ru	< 0.10	7 cm diameter filled
$^{106}Ru/Rh$	< 0.52	to 3 cm height
^{110m}Ag	< 0.097	
^{124}Sb	< 0.10	
^{125}Sb	< 0.28	
^{131}I	< 0.11	
^{134}Cs	< 0.10	
^{137}Cs	< 0.11	
^{140}Ba	< 0.28	
^{140}La	< 0.13	
^{141}Ce	< 0.15	
^{144}Ce	< 0.63	

Table 32: Minimum detection limits for γ-spectrometry measurements of sand (program item II.8).

Sampling Location	Sampling Date	Specific activity in pCi/g dry material		
		Gross Alpha (related to ^{241}Am)	Gross Beta (related to ^{40}K)	^{40}K
1. Saco do Demo, Ilha Comprida (ENE)	06.11.1979	12.0 ± 4.9	67 ± 15	NA
	01.04.1981	7.7 ± 3.5	49 ± 11	NA
2. Saco do Frade (NNE)	06.11.1979	8.9 ± 2.1	36 ± 7	8.1 ± 7.3
	26.03.1980	17.8 ± 5.8	77 ± 17	29.2 ± 4.7
	18.09.1980	13.9 ± 4.7	57 ± 12	31.8 ± 5.0
	17.03.1981	12.4 ± 4.0	78 ± 17	26.7 ± 4.1
3. Ilha de Paquetá (ENE)	07.05.1980	8.1 ± 4.4	53 ± 12	NA
	01.04.1981	5.9 ± 3.5	55 ± 12	NA
4. Ilha do Brandão (ESE)	07.05.1980	7.3 ± 4.3	43 ± 10	NA
	01.04.1981	5.6 ± 3.5	43 ± 10	NA
5. Baia de Tarituba (WSW)	07.11.1979	29.0 ± 7.5	61 ± 14	18.8 ± 4.2
	27.03.1980	28.7 ± 7.6	77 ± 17	24.0 ± 17.0
	04.09.1980	23.0 ± 7.0	72 ± 16	7.0 ± 3.5
	18.03.1981	16.3 ± 5.2	65 ± 14	11.1 ± 2.5

NA = Not analyzed.

Table 33: Radioactivity in sediment (program item II.9).

Sampling Location	Sampling Date	Specific Activity in pCi/g dry material						
		^{208}Tl	^{212}Pb	^{212}Bi	^{214}Pb	^{214}Bi	^{224}Ra	^{228}Ac
2. Saco do Frade	06.11.1979	< 1.4	< 13	< 6.0	< 1.1	< 0.88	< 13	< 2.1
(NNE)	26.03.1980	2.0 ±1.1	< 3.7	2.7±2.0	1.56±0.45	1.31±0.36	< 3.6	1.89±0.72
	18.09.1980	2.14±0.63	< 3.7	< 2.6	1.29±0.51	1.37±0.42	< 3.6	2.67±0.90
	17.03.1981	0.72±0.27	< 2.1	1.5±1.5	1.63±0.42	1.29±0.33	NA	1.83±0.54
5. Baia de Tarituba	07.11.1979	2.67±0.81	< 3.7	3.3±2.8	2.03±0.54	1.84±0.45	< 13	2.5 ±1.1
(WSW)	26.03.1980	3.6 ±1.7	< 3.7	< 1.7	2.54±0.69	2.16±0.66	< 3.6	3.4 ±1.1
	04.09.1980	2.4 ±1.1	< 3.7	< 1.7	1.39±0.48	1.07±0.42	NA	1.93±0.78
	19.03.1981	1.92±0.69	< 2.1	< 1.7	1.21±0.48	1.09±0.30	< 3.6	1.60±0.54
EXTRA								
Bracui	07.08.1980	1.25±0.72	< 2.1	< 1.7	0.89±0.45	0.81±0.39	< 3.6	0.90±0.87
(NE)								

NA = Not analyzed.

Table 34: Natural radioactivity in sediment (program item II.9).

Nuclide	Specific Activity in pCi/g dry material	Measurement Conditions
^{51}Cr	< 1.5	Counting time:
^{54}Mn	< 0.14	1,000 min
^{57}Co	< 0.11	
^{58}Co	< 0.14	Detector:
^{59}Fe	< 0.30	Ge(Li)
^{60}Co	< 0.17	
^{65}Zn	< 0.38	Geometry:
^{95}Zr	< 0.29	Dry material analyzed
^{95}Nb	< 0.14	in plastic cups of
^{103}Ru	< 0.15	7 cm diameter filled
$^{106}Ru/Rh$	< 0.76	to 3 cm height
^{110m}Ag	< 0.15	
^{124}Sb	< 0.15	
^{125}Sb	< 0.41	
^{131}I	< 0.16	
^{134}Cs	< 0.15	
^{137}Cs	< 0.16	
^{140}Ba	< 0.40	
^{140}La	< 0.19	
^{141}Ce	< 0.22	
^{144}Ce	< 0.93	

Table 35: Minimum detection limits for γ-spectrometry measurements of sediment (program item II.9).

Sampling Location	Sampling Date	Species (common name)	Part of Fish	Specific Activity in pCi/g ash		
				Gross Alpha (related to ^{241}Am)	Gross Beta (related to ^{40}K)	^{40}K
1. Frade (NNE)	14.09.1979	Parati (m)	total	< 1.0	63 ± 13	48.1 ± 7.0
	14.09.1979	Espada (m)	total	< 1.0	96 ± 20	67.7 ± 9.5
	14.09.1979	Sardinha (m)	total	< 1.0	74 ± 15	58.7 ± 8.4
	09.11.1979	Cocoroca (s)	meat	< 2.6	207 ± 43	201 ± 28
			bone	4.8 ± 3.9	52 ± 12	11.9 ± 4.0
	09.11.1979	Carapicu (s)	meat	< 3.3	123 ± 26	91 ± 14
			bone	6.8 ± 4.2	52 ± 12	< 4.1
	28.03.1980	Mira (s)	meat	< 3.3	49 ± 11	NA
			bone	< 2.8	52 ± 12	NA
	18.09.1979	Corvina (m)	total	< 2.4	78 ± 17	36.6 ± 5.7
2. Tarituba (WSW)	12.09.1979	Corvina (m)	total	< 1.0	42 ± 9	26.8 ± 5.1
	12.09.1979	Robalo (s)	total	< 1.0	71 ± 15	33.4 ± 5.3
	07.11.1979	Corvina (m)	meat	10.9 ± 2.4	172 ± 36	130 ± 20
			bone	< 3.3	27 ± 7	< 5.5

(m) = Migratory fish.
(s) = Sedentary fish.

Table 36: Radioactivity in fish (program item II.10).

Sampling Location	Sampling Date	Species (common name)	Part of Fish	Specific Activity in pCi/g ash		
				Gross Alpha (related to ^{241}Am)	Gross Beta (related to ^{40}K)	^{40}K
Tarituba (cont.)	23.03.1980	Garoupa (s)	meat	3.3 ± 3.0	140 ± 29	57 ± 29
			bone	< 2.5	28 ± 7	10.0 ± 4.2
	27.03.1980	Corvina (m)	meat	< 2.5	173 ± 36	82.3 ± 33
			bone	< 2.5	42 ± 10	8.3 ± 4.2
	18.09.1980	Corvina (m)	total	< 2.2	62 ± 15	38.4 ± 5.9
	18.09.1980	Pescadinha (m)	total	< 3.3	116 ± 28	60.2 ± 8.9
	18.09.1980	Cação (m)	total	< 2.2	217 ± 46	165.7 ± 24
	04.12.1980	Garoupa (s)	total	< 2.2	58 ± 13	34.7 ± 6.1
	04.12.1980	Robalo (s)	total	< 2.1	93 ± 20	63.5 ± 9.3
	04.12.1980	Linguado (s)	total	< 2.3	44 ± 10	54.7 ± 7.9
	18.03.1981	Corvina (m)	total	< 2.6	34 ± 8	48.9 ± 7.3
	18.03.1981	Garoupa (s)	total	< 2.6	68 ± 15	43.1 ± 6.9

(m) = Migratory fish.
(s) = Sedentary fish.

Table 36: Radioactivity in fish (cont.).

Nuclide	Specific Activity in pCi/g ash	Measurement Conditions
^{51}Cr	< 1.6	Counting time:
^{54}Mn	< 0.15	1,000 min
^{57}Co	< 0.12	
^{58}Co	< 0.14	Detector:
^{59}Fe	< 0.31	Ge(Li)
^{60}Co	< 0.18	
^{65}Zn	< 0.40	Geometry:
^{95}Zr	< 0.30	Ash analyzed in
^{95}Nb	< 0.15	plastic cups of 7 cm
^{103}Ru	< 0.16	diameter filled to
$^{106}Ru/Rh$	< 0.80	3 cm height
^{110m}Ag	< 0.15	
^{124}Sb	< 0.16	
^{125}Sb	< 0.43	
^{131}I	< 0.17	
^{134}Cs	< 0.16	
^{137}Cs	< 0.17	
^{140}Ba	< 0.43	
^{140}La	< 0.20	
^{141}Ce	< 0.24	
^{144}Ce	< 0.98	

Table 37: Minimum detection limits for γ-spectrometry measurements of fish (program item II.10).

Sampling Location	Sampling Date	Specific Activity in pCi/g dry material		
		Gross Alpha (related to ^{241}Am)	Gross Beta (related to ^{40}K)	^{40}K
1. Faz. Grataú (NNE)	12.09.1979	17.8 ± 5.4	79 ± 17	13.4 ± 3.4
	17.09.1980	10.3 ± 4.1	56 ± 12	11.0 ± 3.7
	10.06.1981	19.4 ± 6.2	44 ± 10	7.8 ± 2.6
2a. Faz. Pedra Branca (ENE)	14.09.1979	13.6 ± 4.7	32 ± 8	< 1.9
2b. Faz. Campo Alegre (ENE)	Sept. 1980	16.2 ± 5.4	74 ± 17	13.9 ± 3.1
	17.03.1981	20.3 ± 6.2	61 ± 13	8.4 ± 2.4
3. Faz. Milho Verde (WSW)	27.09.1979	9.1 ± 4.0	47 ± 11	< 1.9
	Sept. 1980	7.3 ± 3.5	49 ± 11	9.0 ± 3.6

Table 38: Radioactivity in soil (program item III.1).

Sampling Location	Sampling Date	Specific Activity in pCi/g dry material						
		^{208}Tl	^{212}Pb	^{212}Bi	^{214}Pb	^{214}Bi	^{224}Ra	^{228}Ac
1. Faz. Grataú (NNE)	12.09.1979	2.3 ±1.5	< 3.1	3.3± 2.2	1.61±0.42	1.39±0.42	< 12	3.0 ±1.1
	06.11.1979	NA	NA	NA	NA	NA	NA	NA
	17.09.1980	< 0.38	< 3.1	< 1.7	1.25±0.48	1.07±0.45	< 3.0	< 0.52
	10.06.1981	0.30±0.18	< 3.1	< 1.7	0.61±0.33	0.65±0.33	< 3.0	< 0.52
2a. Faz. Pedra Branca (ENE)	14.09.1979	3.37±0.66	< 3.1	2.8± 1.7	1.76±0.39	1.58±0.33	10.9± 9.8	3.36±0.66
	06.11.1979	NA	NA	NA	NA	NA	NA	NA
2b. Faz. Campo Alegre (ENE)	17.09.1980	2.95±0.84	< 3.1	2.8± 2.2	2.18±0.54	1.74±0.42	NA	3.86±0.90
	17.03.1981	3.38±0.81	< 2.1	3.3± 2.1	2.02±0.45	1.57±0.39	16 ±12	3.62±0.78
3. Faz. Milho Verde (WSW)	27.09.1979	< 1.10	< 3.1	< 2.0	0.34±0.33	0.44±0.27	< 3.0	0.95±0.75
	04.12.1980	1.12±0.72	< 3.1	< 3.5	1.11±0.45	1.06±0.48	< 3.0	1.34±0.81
EXTRA Faz. near Mambucaba (WSW)	19.03.1981	5.9 ±1.1	< 2.1	5.7± 2.4	3.45±0.66	3.04±0.57	< 30	5.73±0.90

NA = Not analyzed.

Table 39: Natural radioactivity in soil (program item III.1).

Nuclide	Specific Activity in pCi/g dry material	Measurement Conditions
^{51}Cr	< 0.96	Counting time:
^{54}Mn	< 0.094	1,000 min
^{57}Co	< 0.073	
^{58}Co	< 0.084	Detector:
^{59}Fe	< 0.20	Ge(Li)
^{60}Co	< 0.11	
^{65}Zn	< 0.25	Geometry:
^{95}Zr	< 0.19	Dry material analyzed
^{95}Nb	< 0.093	in plastic cups of
^{103}Ru	< 0.098	7 cm diameter filled
$^{106}Ru/Rh$	< 0.51	to 3 cm height
^{110m}Ag	< 0.095	
^{124}Sb	< 0.10	
^{125}Sb	< 0.28	
^{131}I	< 0.11	
^{134}Cs	< 0.098	
^{137}Cs	< 0.11	
^{140}Ba	< 0.27	
^{140}La	< 0.13	
^{141}Ce	< 0.15	
^{144}Ce	< 0.62	

Table 40: Minimum detection limits for γ-spectrometry measurements of soil (program item III.1).

Sampling Location	Sampling Date (species)	Specific Activity in pCi/g ash		
		Gross Alpha (related to ^{241}Am)	Gross Beta (related to ^{40}K)	^{40}K
1. Along the highway BR-101 "Rio Santos", close to NPP site (ENE)	12.09.1979	< 0.9	304 ± 82	355 ± 44
	28.03.1980 (prata)	< 2.8	352 ± 72	332 ± 41
	17.09.1980 (prata)	< 2.4	290 ± 60	319 ± 39
	20.03.1981 (prata)	< 2.2	293 ± 61	300 ± 38
2. Cunhambebe (NNE)	28.03.1980 (prata)	< 2.4	309 ± 64	255 ± 32
	17.09.1980 (prata)	< 2.2	273 ± 57	287 ± 39
	18.03.1981 (prata)	< 2.2	295 ± 61	298 ± 38
3. Mambucaba (WSW)	07.11.1979	< 0.9	248 ± 51	307 ± 38
	09.07.1980 (d'água)	< 3.1	262 ± 55	313 ± 40
	17.09.1980 (d'água)	< 2.3	252 ± 53	158 ± 21
	17.09.1980 (prata)	< 2.2	295 ± 62	301 ± 38
	19.03.1981 (d'água)	< 2.4	338 ± 70	308 ± 39
EXTRA Saco Grande do Frade (NNE)	Sept. 1979	< 0.9	391 ± 79	387 ± 45

Table 41: Radioactivity in bananas (program item III.2).

Nuclide	Specific Activity in pCi/g ash	Measurement Conditions
^{51}Cr	< 4.78	Counting time:
^{54}Mn	< 0.47	1,000 min
^{57}Co	< 0.36	
^{58}Co	< 0.44	Detector:
^{59}Fe	< 0.96	Ge(Li)
^{60}Co	< 0.53	
^{65}Zn	< 1.24	Geometry:
^{95}Zr	< 0.94	Ash analyzed in
^{95}Nb	< 0.46	plastic cups of 7 cm
^{103}Ru	< 0.49	diameter filled to
$^{106}Ru/Rh$	< 2.52	3 cm height
^{110m}Ag	< 0.48	
^{124}Sb	< 0.50	
^{125}Sb	< 1.35	
^{131}I	< 0.51	
^{134}Cs	< 0.50	
^{137}Cs	< 0.55	
^{140}Ba	< 1.35	
^{140}La	< 0.64	
^{141}Ce	< 0.74	
^{144}Ce	< 3.08	

Table 42: Minimum detection limits for γ-spectrometry measurements of bananas (program item III.2).

Sampling Location	Sampling Date	Specific Activity in pCi/g ash			
		Gross Alpha (related to ^{241}Am)	Gross Beta (related to ^{40}K)	^{40}K	^{137}Cs
Faz. near Mambucaba	13.09.1979	< 0.9	387 ± 81	321 ± 45	1.4 ± 1.3
(WSW)	09.07.1980	< 3.1	247 ± 54	215 ± 28	0.65 ± 0.45
	17.09.1980	< 3.0	373 ± 78	331 ± 43	< 0.54
	19.03.1981	4.1 ± 2.8	309 ± 64	291 ± 39	1.4 ± 0.90

Table 43: Radioactivity in manioc (program item III.3).

Nuclide	Specific Activity in pCi/g ash	Measurement Conditions
^{51}Cr	< 4.1	Counting time:
^{54}Mn	< 0.40	1,000 min
^{57}Co	< 0.32	
^{58}Co	< 0.38	Detector:
^{59}Fe	< 0.82	Ge(Li)
^{60}Co	< 0.46	
^{65}Zn	< 1.1	Geometry:
^{95}Zr	< 0.79	Ash analyzed in
^{95}Nb	< 0.40	plastic cups of 7 cm
^{103}Ru	< 0.42	diameter filled to
$^{106}Ru/Rh$	< 2.1	3 cm height
^{110m}Ag	< 0.41	
^{124}Sb	< 0.42	
^{125}Sb	< 1.2	
^{131}I	< 0.44	
^{134}Cs	< 0.42	
^{137}Cs	< 0.46	
^{140}Ba	< 1.2	
^{140}La	< 0.53	
^{141}Ce	< 0.64	
^{144}Ce	< 2.7	

Table 44: Minimum detection limits for γ-spectrometry measurements of manioc (program item III.3).

Sampling Location	Sampling Date (species)	Specific Activity in pCi/g ash		
		Gross Alpha (related to ^{241}Am)	Gross Beta (related to ^{40}K)	^{40}K
Fazenda Grataú (NNE)	27.03.1980 (lima)	7.1 ± 3.8	242 ± 50	155 ± 20
	08.07.1980 (pera)	3.8 ± 3.6	292 ± 61	312 ± 42
	18.03.1981	< 2.2	202 ± 42	245 ± 31
	10.06.1981	5.2 ± 3.2	220 ± 46	252 ± 32

Table 45: Radioactivity in oranges (program item III.4).

Nuclide	Specific Activity in pCi/g ash	Measurement Conditions
^{51}Cr	< 6.37	Counting time:
^{54}Mn	< 0.61	1,000 min
^{57}Co	< 0.43	
^{58}Co	< 0.58	Detector:
^{59}Fe	< 1.24	Ge(Li)
^{60}Co	< 0.68	
^{65}Zn	< 1.59	Geometry:
^{95}Zr	< 1.21	Ash analyzed in
^{95}Nb	< 0.60	plastic cups of 7 cm
^{103}Ru	< 0.64	diameter filled to
$^{106}Ru/Rh$	< 3.29	3 cm height
^{110m}Ag	< 0.63	
^{124}Sb	< 0.65	
^{125}Sb	< 1.76	
^{131}I	< 0.68	
^{134}Cs	< 0.65	
^{137}Cs	< 0.72	
^{140}Ba	< 1.73	
^{140}La	< 0.82	
^{141}Ce	< 1.00	
^{144}Ce	< 4.14	

Table 46: Minimum detection limits for γ-spectrometry measurements of oranges (program item III.4).

Sampling Location	Sampling Date (species)	Specific Activity in pCi/g ash		
		Gross Alpha (related to ^{241}Am)	Gross Beta (related to ^{40}K)	^{40}K
1. Northern area of the Saco Piraquara de Fora (E)	07.11.1979 (Dictyopteris)	< 1.0	76 ± 16	50 ± 8
	26.03.1980 (Sargassum)	17.9 ± 5.8	85 ± 18	31 ± 6
	04.12.1980 (Sargassum)	3.8	116 ± 25	104 ± 14
	18.03.1981 (Sargassum)	< 2.6	105 ± 22	68 ± 11
2. Southern area of the Saco Piraquara de Fora (ESE)	Nov. 1979	< 1.0	63 ± 13	55 ± 9
	06.11.1979 (Acantophora)	6.6 ± 3.8	81 ± 17	26 ± 12
	26.03.1980 (Calcárea, Anphyroa sp.)	< 2.6	87 ± 19	43 ± 9
	04.12.1980 (Sargassum)	4.3 ± 2.7	125 ± 27	117 ± 16
	18.03.1981 (Acantophora)	< 2.6	147 ± 31	103 ± 14

Table 47: Radioactivity in algae (program item III.5).

Sampling Location	Sampling Date (species)	Specific Activity in pCi/g ash		
		Gross Alpha (related to ^{241}Am)	Gross Beta (related to ^{40}K)	^{40}K
3. Ilha do Brandão, southern part (ESE)	18.02.1981 (Geliales)	< 2.5	119 ± 19	56 ± 13
	18.02.1981 (Laurencia)	< 2.5	150 ± 32	33 ± 25
4. Marina, located at the Saco Piraquara de Fora (ESE)	06.11.1979 (Padina)	9.5 ± 4.6	92 ± 20	23 ± 7
	28.03.1980 (Padina)	3.2 ± 3.0	94 ± 20	57 ± 10
	04.09.1980 (Sargassum)	5.7 ± 3.4	142 ± 30	146 ± 20
	18.03.1981 (Padina)	7.0 ± 3.0	107 ± 22	62 ± 9
5. Baia de Tarituba	Nov. 1979	3.2 ± 1.2	84 ± 17	58 ± 8
	06.11.1979 (Acantophora)	11.7 ± 4.6	80 ± 17	66 ± 10
	27.03.1980 (Acantophora)	12.4 ± 4.5	106 ± 22	65 ± 11
	18.03.1981 (Acantophora)	9.3 ± 4.0	165 ± 34	142 ± 18

Table 47: Radioactivity in algae (cont.).

Nuclide	Specific Activity in pCi/g ash	Measurement Conditions
^{51}Cr	< 1.4	Counting time:
^{54}Mn	< 0.14	1,000 min
^{57}Co	< 0.11	
^{58}Co	< 0.13	Detector:
^{59}Fe	< 0.27	Ge(Li)
^{60}Co	< 0.16	
^{65}Zn	< 0.35	Geometry:
^{95}Zr	< 0.27	Ash analyzed in
^{95}Nb	< 0.13	plastic cups of 7 cm
^{103}Ru	< 0.14	diameter filled to
$^{106}Ru/Rh$	< 0.71	3 cm height
^{110m}Ag	< 0.14	
^{124}Sb	< 0.14	
^{125}Sb	< 0.38	
^{131}I	< 0.15	
^{134}Cs	< 0.14	
^{137}Cs	< 0.15	
^{140}Ba	< 0.38	
^{140}La	< 0.18	
^{141}Ce	< 0.21	
^{144}Ce	< 0.87	

Table 48: Minimum detection limits for γ-spectrometry measurements of algae (program item III.5).

Sampling Location	Sampling Date (species)	Specific Activity in pCi/g ash		
		Gross Alpha (related to ^{241}Am)	Gross Beta (related to ^{40}K)	^{40}K
Baia de Tarituba (WSW)	27.03.1980 (Camarão ≙ shrimp)	< 2.8	61 ± 14	18.2 ± 5.2
	18.09.1980 (Camarão)	9.0 ± 3.8	83 ± 17	43.8 ± 7.7
	18.03.1981 (Camarão)	< 2.6	79 ± 17	59.5 ± 9.9

Table 49: Radioactivity in crustacea and mollusks (program item III.6).

Nuclide	Specific Activity in pCi/g ash	Measurement Conditions
^{51}Cr	< 2.21	Counting time:
^{54}Mn	< 0.22	1,000 min
^{57}Co	< 0.17	
^{58}Co	< 0.21	Detector:
^{59}Fe	< 0.44	Ge(Li)
^{60}Co	< 0.24	
^{65}Zn	< 0.57	Geometry:
^{95}Zr	< 0.43	Ash analyzed in
^{95}Nb	< 0.21	plastic cups of 7 cm
^{103}Ru	< 0.23	diameter filled to
$^{106}Ru/Rh$	< 1.16	3 cm height
^{110m}Ag	< 0.22	
^{124}Sb	< 0.23	
^{125}Sb	< 0.62	
^{131}I	< 0.24	
^{134}Cs	< 0.23	
^{137}Cs	< 0.25	
^{140}Ba	< 0.63	
^{140}La	< 0.30	
^{141}Ce	< 0.34	
^{144}Ce	< 1.42	

Table 50: Minimum detection limits for γ-spectrometry measurements of crustacea and mollusks (program item III.6).

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Appendix

An assortment of national and international intercomparison results from radioactivity measurements performed on various environmental and effluent samples relevant to NPP monitoring is presented in this Appendix.

Radionuclides	Activity Concentration in pCi/l			Ratio of Measurement Results		
	IRD	FURNAS	KfK	IRD/FURNAS	IRD/KfK	FURNAS/KfK
^{54}Mn	124 ± 5	107 ± 7	133 ± 1	1.16	0.93	0.80
^{60}Co	290 ±12	244 ±14	370 ±20	1.19	0.78	0.66
^{65}Zn	49 ± 2	39 ± 5	70 ± 2	1.26	0.70	0.56
^{106}Ru	48 ± 3	28 ± 5	57 ± 5	1.71	0.84	0.49
^{125}Sb	83 ± 4	55 ± 7	8.3± 2.0	1.51	1.00	0.66
^{134}Cs	25 ± 1	14 ± 2	31 ± 1	1.79	0.81	0.45
^{137}Cs	285 ±11	208 ±12	250 ±20	1.37	1.14	0.83
^{144}Ce	8.0± 0.8	6.6± 1.4	8.7± 1.8	1.21	0.92	0.76
^{155}Eu	4.8± 0.5	2.6± 0.9	2.9± 1.3	1.85	1.66	0.90
^{241}Am	66 ± 2	42 ± 3	31 ± 2	1.57	2.13	1.35

Table A1: Intercomparison of γ-spectrometry measurements, made by IRD, FURNAS and KfK.

Type of sample: 100 ml of liquid effluents from KfK.

The errors indicated are based on a 3σ confidence level.

Radionuclide	Specific Activity in pCi/g ash		Ratio of Measurement Results
	IRD	KfK	IRD/KfK
^{137}Cs	1.5 ± 0.9	1.7 ± 0.3	0.88

Table A2: Intercomparison of γ-spectrometry measurements, made by IRD and KfK.

Type of sample: Manioc, taken from Angra region.

The errors indicated are based on a 3σ confidence level.

Kind of Sample	Tritium Concentration in nCi/l		Ratio of Measurement Results
	IRD	KfK	IRD/KfK
Liquid effluents	120 ±7	105 ±5	1.14
Standard solution	210 ±6	221 ±9	0.95
" "	2.5±0.5	2.2±0.3	1.14
Ground water	8.8±1.5	8.4±0.5	1.05
Surface water	0.6±0.3	0.4±0.2	1.5
Average	-	-	1.16

Table B: Intercomparison of tritium measurements, made by IRD and KfK. Samples taken at KfK.

The errors indicated are based on a 3σ confidence level.

Kind of Sample	Specific Gross Beta Activity in pCi/g		Ratio of Measurement Results
	IRD	FURNAS	IRD/FURNAS
Migratory Fish[1]	43 ± 9	33 ± 8	1.30
Sediment[2]	61 ± 14	39 ± 8	1.56
Sand (a)[2]	28 ± 7	24 ± 5	1.17
Sand (b)[2]	15 ± 4	19 ± 3	0.79
Grass[1]	160 ± 33	160 ± 36	1.00
Average	-	-	1.16

[1] = Ash.
[2] = Dry material.

Table C: Intercomparison of specific gross beta activity measurements, made by IRD and FURNAS.

Type of sample: Actual environmental samples from the Angra region.

The errors indicated are based on a 3σ confidence level.

Kind of Sample	Specific Activity in pCi/g								
	Gross Alpha			Gross Beta			^{40}K		
	IRD	KfK	IRD/KfK	IRD	KfK	IRD/KfK	IRD	KfK	IRD/KfK
Sand[2]	7.2±3.7	5.5±2.3	1.31	28± 7	29± 5	0.97	7.6± 2.4	7.0± 1.9	1.09
Algae[1]	3.2±1.2	4.8±2.1	0.67	84±17	86±12	0.98	58 ± 8	38 ±10	1.53
Soil[2]	14 ±5	16 ±4	0.88	32± 8	25± 4	1.28	< 1.8	1.0± 0.5	< 1.8*
Grass[1]	9 ±2	14 ±4	0.64	160±33	180±24	0.89	170 ±23	140 ±39	1.21
Sediment[2]	29 ±8	33 ±7	0.88	60±14	54± 8	1.11	19 ± 4	16 ± 3	1.19
Manioc[1]	< 3.1	2.4±1.6	< 1.29*	250±52	240±33	1.04	215 ±28	200 ±54	1.09
Average excluding *	-	-	0.88	-	-	1.05	-	-	1.22

[1] = Ash.
[2] = Dry material.

Table D: Intercomparison of specific gross alpha, beta and Potassium-40 activity measurements, made by IRD and KfK.

Type of sample: Actual environmental samples from the Angra region.

The errors indicated are based on a 3σ confidence level.

Kind of Sample	Agency	Specific ^{90}Sr-Activity			Ratio of Measurement Results
		Agency	IRD	Units	IRD/Agency
Mollusk (Anadora gramosa)	IAEA Monaco	7.4 ± 0.8	4.4± 1.6	pCi/g	0.59
Mollusk (Aplysia benedicti)	" "	0.25± 0.07	< 1.2	pCi/g	< 4.8*
Milk (a)	IRC - WHO	11.3 ± 0.6	10.1± 2.1	pCi/l	0.89
Milk (b)	" "	14.0 ± 0.8	12.5± 0.9	pCi/l	0.89
Animal bone	" "	8.3 ± 0.2	6.6± 0.3	pCi/g	0.80
Freshwater fish	" "	6,300 ±300	4,700 ±180	pCi/kg	0.75
Wheat	" "	18.2 ± 1.0	14.5± 1.1	pCi/kg	0.80
Average excluding *		-	-	-	0.79

Table E: Intercomparison of ^{90}Sr measurements, made by IRD and international agencies.

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