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First Atmospheric Diffusion Experiment Campaign at the Angra Site

— Measured Data —

R. Biagio, J. Godoy, I. Nicoli
Instituto de Radioproteção e Dosimetria, CNEN
D. Nicolli
Comissão Nacional de Energia Nuclear
P. Thomas
Institut für Meteorologie und Klimaforschung

Kernforschungszentrum Karlsruhe

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R. Biagio, J. Godoy, I. Nicoli
Instituto de Radioproteção e Dosimetria,
Comissão Nacional de Energia Nuclear
Rio de Janeiro, República Federativa do Brasil

D. Nicolli
Comissão Nacional de Energia Nuclear
Rio de Janeiro, República Federativa do Brasil

P. Thomas
Kernforschungszentrum Karlsruhe GmbH
Karlsruhe, Bundesrepublik Deutschland

Kernforschungszentrum Karlsruhe GmbH, Karlsruhe
Comissão Nacional de Energia Nuclear, Rio de Janeiro

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PREFACE

The Federative Republic of Brazil and the Federal Republic of Germany signed an Agreement of Nuclear Cooperation in 1975. Within the framework of this accord, a special agreement providing for scientific and technical cooperation between the Brazilian National Nuclear Energy Commission (CNEN) and the Karlsruhe Nuclear Research Center (KfK) was signed on March 8, 1978. The exchange of scientists and researchers that ensued between the Institute for Radioprotection and Dosimetry of CNEN and the Central Safety Department of KfK led to programs of cooperation in environmental monitoring at nuclear facilities. Since 1985 special topics of this program are performed by the Institute of Meteorology and Climatology of KfK.

For environmental monitoring and risk assessments of nuclear power plants it is important to understand the transport and dispersion of airborne nuclear pollutants. For this purpose, CNEN and KfK decided to cooperate in the performance of tracer studies at the site of the first nuclear power plant in Brazil and in their subsequent evaluation.

On behalf of CNEN and KfK we take great pleasure in presenting this joint report on the results of the first atmospheric diffusion experiment campaign at the CNAAA-site near Angra dos Reis. The exchange of data and experiences within this program was very important to both institutes. The program and this report constitute an excellent example of successful international cooperation.

Dr. Carlos Eduardo V. de Almeida

Director of the Institute for
Radioprotection and Dosimetry,
Federative Republic of Brazil

Rio de Janeiro, May 1985

Dipl.-Phys. Winfried Koelzer

Head of the Central Safety Department,
Karlsruhe Nuclear Research Center,
Federal Republic of Germany

Karlsruhe, May 1985

SUMMARY

Results of the first five atmospheric diffusion experiments conducted at the NPP Angra 1 site, from November 28 to December 4, 1984, are presented. The Angra 1 site is characterized by complex terrain with steep hills near to the sea coast. Tritiated water vapor (HTO) was used as a tracer and released from the top of a 100 m high tower. Water moisture was then collected downwind at 25 positions where three consecutive samplings were effected, each covering a period of 30 min of exposition. During the experiments meteorological data were obtained on four towers. Temperature and air humidity were additionally measured at some sampling points.

Erstes Feldexperiment zur atmosphärischen Ausbreitung am Standort Angra - Meßwerte -

ZUSAMMENFASSUNG

Es wird über die Ergebnisse von fünf atmosphärischen Ausbreitungsexperimenten berichtet, die vom 28. November bis 4. Dezember 1984 in der Umgebung des KKW Angra 1 durchgeführt wurden. Der Standort liegt an der Küste und wird von steilen Hügeln umgeben. Tritiierter Wasserdampf (HTO) wurde als Tracer von der Spitze eines 100 m hohen Mastes freigesetzt. Die Luftfeuchtigkeit wurde im Lee der Quelle an 25 Stellen während drei aufeinanderfolgenden Perioden von jeweils 30 min Dauer gesammelt. Während der Experimente wurden meteorologische Daten an vier Masten und zusätzlich Temperatur und Luftfeuchte an einigen Sammelstellen gemessen.

Primeira Companha de Experimentos de Difusão Atmosférica no Locol da Central Nuclear Almirante Álvaro Alberto - Dados medidos -

RESUMO

Entre 28 de novembro e 4 de dezembro de 1984, realizou-se a primeira série de experimentos de difusão atmosférica no sítio da usina nuclear Angra 1. O local é caracterizdao por terreno montanhoso perto da costa oceânica. Foram feitos no período cinco experimentos. O traçador trítio (HTO), na forma de vapor, foi liberado do alto de uma torre de 100m de altura. Em 25 posições, seguindo a direção do vento, foi coletada água do ar, em três períodos consecutivos, cada um cobrindo 30 minutos de exposição. Durante os experimentos foram obtidos dados meteorológicos em quatro torres. Além disso foi medida a temperatura e umidade do ar em alguns pontos de amostragem.

CONTENTS

		Page
Summary; Zusammenfassung; Resumo		I
1.	Introduction	1
2.	Description of the Site	2
3.	Meteorological Monitoring	3
4.	Experimental Technique	3
	4.1 Release of the Tracer	3
	4.2 Sampling	4
	4.3 Analysis of the Samples	6
5.	Synoptic Weather Conditions	6
6.	Measured Data	7
	6.1 Meteorological Data	7
	6.2 Tracer Data	8
References		9
Acknowledgements		10
Tables and Figures		11

1. INTRODUCTION

At CNAAA-site (Central Nuclear Almirante Álvaro Alberto) one PWR power plant (600 MWe) is operated and two PWR power plants (1300 MWe each) are under construction in a complex terrain characterized by steep hills. Besides this, wind systems and turbulence are complicated by the land-sea-interface and high insolation due to the low latitude. For environmental monitoring and risk assessments it is important to understand the transport and dispersion of airborne nuclear pollutants in this complex terrain. The art of numerical simulation has not yet progressed to the point where accurate predictions can be made for a complex terrain.

Besides, the results of these simulations may be limited by the lack of sufficient meteorological data to characterize the three dimensional flow field and its turbulence throughout the time and region of interest. In view of the above, atmospheric tracer studies should be conducted in order to help to develop a general understanding of the flow patterns at CNAAA-site and their influence on dispersion.

For this purpose, CNEN (Comissão Nacional de Energia Nuclear) of Brasil and KfK (Kernforschungszentrum Karlsruhe) of the Federal Republic of Germany decided to cooperate in the performance of the tracer studies and in their subsequent evaluation.The main reason for this cooperation is that CNEN as the governmental authority supervises the environmental monitoring at the site. And at KfK more than 70 short range tracer experiments have been performed (1, 2, 3).

Tritiated water vapor has been used as a tracer for the following reasons: With this tracer many experiments have been performed at KfK, therefore the corresponding know-how is available. The sampling devices are simple and low expensive. The equipment for sample analysis is available at CNEN and its technique is well known since tritium is routinely measured in environmental monitoring.

2. DESCRIPTION OF THE SITE

The site is located at the southeastern coast of Brasil (23,0°S; 44,5°W) about half way between Rio de Janeiro and Santos (see Fig. 1a).

It is a bowl-shaped area with hills on three sides and a bay on the fourth side (Figs. 1 and 2). The highway Rio de Janeiro - Santos is directly beside the northern and eastern fences of the NPP. The installations and buildings of the central cover a fenced area of about 800 ha. The highest building is the containment of Angra 1, its height is 64m. The curved shoreline is oriented NNW to SSE with the bay to the west. To the north of the NPP area and the highway there are bluffs rising up to 700m, to the east of the NPP and the highway and to the southeast of the NPP hills rise to less than 300m. The hills are covered with a tropical forest of a dense canopy. Only two paved roads are available in the forest. Therefore, free access to the sampling positions is restricted only to some transport directions.

The site region, with the exception of Angra dos Reis, is sparcely populated by small villages along the coast from Angra dos Reis to Parati. Based on the 1980 census the following figures are established:

- within a 10km radius: 10,000 inhabitants,
- Angra dos Reis at 15km east to the site: 22,000 inhabitants,
- within a 20km radius:37,000 inhabitants,
- within a 50km radius: 120,000 inhabitants.

The uses of the adjacent lands and waters in the site region are:

- agricultural activities of mainly subsistence nature, based on banana, manioc, corn and beans;
- spotty cattle been raised on a small scale;
- fishing;
- boating and swimming by the small population and by an increasing group of tourists during certain periods of the year.

3. METEOROLOGICAL MONITORING

Due to the complex topography, the meteorological conditions on the site are monitored by four meteorological towers located in different altitudes above MSL. The instrumentation of the towers are summarized in Tab. 1. In Fig. 2 the position of each tower is indicated. Taking tower A (Fig. 3) as a reference point the coordinates of tower D are (1200m, 98^{o}), tower B are (1450m, 183^{o}) and tower C are (1450m, 286^{o}).

The electronic signals emmited by the sensors are scanned every 15s and are compressed to 15 min mean values by a PDP/11 - computer, where the data are finally stored on magnetic discs.

4. EXPERIMENTAL TECHNIQUE

Tritiated water vapor (HTO) was released as a tracer from the 100-m-platform of tower A (140 m above MSL). Air humidity was sampled manually at 25 positions downwind of the source during three successive periods of 30 min each. In total five experiments have been performed.

4.1 - Release of the tracer

The tracer was released from an evaporator, (Fig.4), wich was equipped with a power control and monitoring system for the remote sensing of its operational parameters.

The evaporator, a cylindrical vessel made of stainless steel, has a capacity of about 25ℓ. The empty evaporator weights about 34kg, and has the following components:

- a set of heating resistances located close to its botton;
- a safety system designed to prevent resistance overheating;
- a magnetic switch;
- a special chamber to crash the tritium ampule under radiation protection conditions;
- a vapor outlet;
- an electronic balance to remotely control and measure the weight during the release of the tracer.

During the experiments, the evaporator was installed at the top of the 100m high meteorological tower. It was connected with cables to the power and weight control system at the ground. In this way voltage, current, water temperature, and the weight of evaporator could be remotely monitored.

The following operational parameters were used:

- volume of water: 16ℓ
- voltage at evaporator input: 200V
- current at evaporator input: 24.0 A
- evaporation rate: 6.5 ℓ/h

After each evaporation period, about 3ℓ of water remained in the evaporator. This amount of water was necessary to submerge the heating coil, wich could otherwise be damaged in dry operation.

A constant emission rate was attained 15 min before the beginning of the first sampling period and was maintained up to the end of the last sampling period. In the last experiment however the constant emission rate was attained 45 min before the start of the samplings.

4.2 - Sampling

A number of 42 sampling positions were defined some time before the experiments, as indicated in Fig. 2. The downwind distance, azimuth and height above MSL of these positions are listed in Tab. 2. The azimuth is measured relative to the northern direction and counted clockwise. The errors of these coordinates are about 5%, 2° and 3m, respectively. The positions have been chosen in accordance with:

- most probable wind directions and stability classes to be expected during the experiments,
- results of preliminary smoke releases,
- accessibility.

The positions have been clearly labelled with yellow stakes and numbered to be easily found. Immediately before the experiment took place, 25 positions were chosen for sampling in agreement with the prevailing wind direction and stability class.

Sampling was carried out by putting an aluminium plate of 40 x 60 cm^2 on two slabs of dry ice (30 x 30 x 2 cm^3). The slabs of dry ice were housed in a wooden box lined with styropor for thermal insulation. The aluminium plate served as a lid for the box. The airborne water vapor congelated on the cold aluminium plate and formed a layer of hoar-frost. The aluminium plate was horizontal and located about 40cm above the ground. The device had to be assembled about 15 min before the start of the first sampling period. At the beginning of the first sampling period, the frost was scraped off manually and disposed of. At the end of the first sampling period and the beginning of the second the frost was scraped off again and filled into a test flask. With an absolute air humidity of 18 g/m^3 about 20 mℓ water were sampled. To protect the aluminium plates and the hoar-frost from direct insolation, sun umbrellas were used. Fig. 5 shows a photo of a sampling device.

Absolute air temperature and relative air humidity have been measured at five sampling positions to determine h, the absolute air humidity, (Tabs. 3 to 7). h is needed to calculate C, the HTO-activity concentration, in the air from the directly measured specific HTO- activity a, in the sampled water vapor:

$$C = h \times a$$

The differences between the absolute air humidities measured at different positions and times during one experiment were only slightly greater than the error in measurement. Therefore the arithmetic mean value of the humidities measured at all positions and times was used to calculate the activity concentration C. These mean values are listed in Tabs. 3 to 7.

4.3 - Analysis of samples

The specific activity of tritium in air humidity was analyzed by the liquid scintillation method.

In order to avoid quenching effects, the sampled water was distilled. As scintillation cocktail INSTA-GEL was used in the proportion of 12 mℓ to 10 mℓ of sampled air humidity. The ultrasonic technique was used to make the mixture homogenous and this was accomplished at a temperature of 50^{o}C during one hour. The same procedures were applied to the standards and to the blanks.

A Beckmann LS-100 scintillation detector was used. With the tritium channel an efficiency of (22.4$\pm$0.7)% was obtained and a background of 28 counts per minutes. The counting time was 20 min, and the detection limit 26Bq/ℓ. The background at the site is considerably below this value. From 1979 to 1983, 150 samples had been analyzed showing a specific activity between 0.3Bq/ℓ and 2.9Bq/ℓ/ (4).

In the case of samples with less than 10 ml, the Internal Standardization Method was used. The External Standard Ratio was applied to control the quality of preparation of the samples.

5. SYNOPTIC WEATHER CONDITIONS

On Nov. 27th, the eve of the first experiment, it rained all the whole day at the site, due to the passage of a cold front over the area, as can be seen from the weather map in Fig. 6.

On Nov. 28th, the cold front had passed to the northeastern region of Rio de Janeiro (see Fig. 7), and a polar maritime anticyclone was centered at about 5 degrees southwest of Angra. The sky was clear and southeasterly winds prevailed. The sea breeze developed after 10:00 am. On Nov. 29th, the day during which the second experiment was performed, the meteorological situation did not change significantly, as can be seen from Fig. 8.

The center of the polar maritime anticyclone remained stationary with a maximum pressure of 1016mb. At the 10m level of tower A the temperature was about $1^{o}C$ higher than at the preceding day. The absolute air humidity increased from about $14g/m^3$ to about $15g/m^3$.

On Nov. 30^{th}, when the third experiment was performed, the absolute air humidity had increased to about $18g/m^3$. The temperature measured at the 10m height did not change appreciably. From the weather map in Fig. 9 can be seen that the polar maritime anticyclone was under transformation to a tropical maritime one. Due to the heating of the terrain the sea breeze developed earlier. A new cold front started over Uruguay just at the southern frontier of Brazil. Over the continent, near to the surface the winds backed to the direction NE-N. The sea breeze could not reach considerable heights in the atmosphere.

On Dec. 1^{st}, the day of the forth experiment, the sky was covered and a cold front occluded over the Brazilian state Rio Grande do Sul; (see Fig. 10). The absolute humidity of air increased to $19g/m^3$.

On Dec. 2^{nd} and 3^{rd} it rained. The fifth experiment was accomplished under overcast weather conditions between 12:00 a.m. and 1:30 p.m. on Dec. 4^{th}. After that time it was raining again. On Dec. 2^{nd} the cold front had reached its maximum intensity near to the south of Angra. On the following day it had crossed the site northeastward and lost intensity. On Dec. 4^{th} a new polar maritime anticyclone established itself southwest of Angra and southeasterly winds blowed to the coast (see Figs. 11, 12 and 13).

6. MEASURED DATA

6.1 - Meteorological data

During the experiments meteorological data were obtained on four meteorological towers. Additionaly air temperature and relative humidity were measured at some sampling positions. These data are presented in Tabs. 3 to 7.

Wind speed and direction and vertical temperature difference between the heights 10m and 100m are showed in Tabs.8 to 12. The stability classes were defined by the temperature differences over every 15 min interval as indicated by the following table published by IAEA in the Safety Series No. 50-SG-S3 (5).

Δ T(K/100m)	< -1.9	-1.9 to -1.7	-1.7 to -1.5	-1.5 to -0.5	-0.5 to 1.5	> 1.5
Pasquill class	A	B	C	D	E	F

6.2 - Tracer data

The tracer data of the five experiments are compiled in Tabs. 13 to 17. These tables show:

- the data of the experiment,
- the schedule of sampling in Brasilia time,
- the emission rate in Bq/s,
- the number of the sampling position,
- the specific HTO-activities measured during the three consecutive sampling periods at the corresponding sampling position with the error in Bq/mℓ.
- the HTO-activity concentration

Dashes in the activity data column refer to samples not evaluated; due to inadequate arrangement of the slabs of dry ice no ambient water vapor had been sampled at these positions.

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TABLE CAPTIONS

Table 1: Meteorological instrumentations for operational program at Angra site
Table 2: Coordinates of sampling positions
Table 3: Humidity data during Ex.01 (Nov. 28. 1984)
Table 4: Humidity data during Ex.02 (Nov. 29. 1984)
Table 5: Humidity data during Ex.03 (Nov. 30. 1984)
Table 6: Humidity data during Ex.04 (Dec. 01. 1984)
Table 7: Humidity data during Ex.05 (Dec. 04. 1984)

Table 8: Meteorological data during Ex.01 (Nov. 28. 1984)
Table 9: Meteorological data during Ex.02 (Nov. 29. 1984)
Table 10: Meteorological data during Ex.03 (Nov. 30. 1984)
Table 11: Meteorological data during Ex.04 (Dec. 01. 1984)
Table 12: Meteorological data during Ex.05 (Dec. 04. 1984)

Table 13: Tracer data of experiment 01 (Nov. 28. 1984)
Table 14: Tracer data of experiment 02 (Nov. 29. 1984)
Table 15: Tracer data of experiment 03 (Nov. 30. 1984)
Table 16: Tracer data of experiment 04 (Dec. 01. 1984)
Table 17: Tracer data of experiment 05 (Dec. 04. 1984)

INSTRUMENT	RECORDED PARAMETER	TOWER	APPROXIMATE HEIGHT ABOVE TOWER BASE (m)	TOWER BASE HEIGHT (m) REFERENCED TO MSL	INSTRUMENT CHARACTERISTICS
Wind	Wind speed and direction	A	100/60/10	40	WM-Model W103-3SS (speed), cuptype anemometer 0.9 mph threshold and 0.15 mph accuracy. Distance constant is 14.3 feet; WM-Model M104 (direction). Distance constant is 3.5 feet, vane has 0.75 mph threshold and damping ratio of 0.4. Accuracy $\pm$ 1.8°.
Wind	(Same as above)	B	15	12	(Same as above)
Wind	(Same as above)	C	15	166	(Same as above)
Wind	(Same as above)	D	15	290	(Same as above)
Temperature	$T_{100} - T_{10}$	A	100/10	40	Thermistor in aspirated solar radiation shield. Accuracy $\pm$ 0.1°C.
Temperature	$T_{60} - T_{10}$	A	60/10	40	(Same as above)
Temperature	Reference Temperature	A	10	40	Thermistor in aspirated solar radiation shield. Accuracy $\pm$ 0.125°C.
Precipitation	Rainfall	Near A	-	-	-
Humidity	Humidity	Near A	-	-	Fuess - Model nº 79t thermohygrograph. Accuracy $\pm$ 0.2°C to 0.5°C, and 2.5%. Measuring-extent - 10 to + 45° C and 0 to 100 % rel. humidity.

TABLE - 1 : Meteorological instrumentation for operational program at Angra Site

	COORDINATES IN RESPECT TO THE SOURCE		
Nº OF POSITION	DOWNWIND DISTANCE (m)	AZIMUTH (DEGREES)	HEIGHT ABOVE MSL (m)
1	130	205	5
2	280	285	50
3	135	324	60
4	100	13	60
5	100	43	50
6	100	73	45
7	100	103	33
8	200	13	77
9	200	40	65
10	200	74	45
11	200	103	7
12	300	43	90
13	300	74	35
14	300	103	15
15	400	43	113
16	400	59	70
17	400	76	35
18	420	101	30
19	575	33	153
20	565	66	67
21	610	77	70
22	600	89	73
23	605	95	77
24	635	104	77
25	705	80	87
26	700	87	87
27	805	75	100
28	815	81	125
29	970	76	177
30	1070	59	205
31	500	78	45
32	180	149	5
33	375	28	100
34	750	125	63
35	935	131	86
36	1200	77	225
37	935	98	282
38	960	38	255
39	915	33	280
40	825	250	47
41	1620	260	80
42	2270	267	5

TABLE 2: Coordinates of sampling positions

	POSITION OF INSTRUMENT	BRASILIA TIME						
		10:30	10:45	11:00	11:15	11:30	11:45	12:00
Temperature (°C)	A/10m	22.7	23.0	23.1	22.3	22.3	22.5	22.4
	P.17	-	-	-	-	-	-	-
	P.20	-	-	-	-	-	-	-
	P.26	22.0	22.5	23.0	23.0	23.0	23.5	24.0
	P.38	27.0	27.5	28.0	28.5	29.0	29.0	29.0
Rel. humidity (%)	P.17	63	-	62	-	64	-	65
	P.20	60	-	58	-	62	-	62
	P.26	71	70	69	68	67	70	71
	P.38	53	49	45	45	44	46	48
Abs. humidity (g/m^3)	P.17	-	-	-	-	-	-	-
	P.20	-	-	-		-	-	-
	P.26	13.8	14.0	14.2	14.0	13.8	14.9	15.5
	P.38	13.7	13.0	12.3	12.6	12.7	13.3	13.8
	ARITHMETIC MEAN VALUE: 13.7 (g/m^3)							

TABLE - 3: Humidity data during EX. 01 (Nov. 28. 1984)

	POSITION OF INSTRUMENT	BRASILIA TIME						
		10:30	10:45	11:00	11:15	11:30	11:45	12:00
Temperature (°C)	A/10m	24.0	23.3	23.4	23.6	23.6	23.7	23.9
	P.17	-	-	-	-	-	-	-
	P.20	-	-	-	-	-	-	-
	P.26	24.0	24.0	24.0	25.0	26.0	26.0	26.5
	P.38	27.0	28.0	29.0	28.5	28.0	29.0	30.0
Rel. humidity (%)	P.17	66	66	66	66	65	64	61
	P.20	60	59	58	60	62	62	62
	P.26	70	71	73	70	66	64	63
	P.38	52	53	55	55	55	52	50
Abs. humidity (g/m^3)	P.17	-	-	-	-	-	-	-
	P.20	-	-	-	-	-	-	-
	P.26	15.3	15.5	15.9	16.2	16.1	15.6	15.8
	P.38	13.4	14.5	15.9	15.4	15.0	15.0	15.2
	ARITHMETIC MEAN VALUE: 15.3 (g/m^3)							

TABLE - 4 : Humidity data during EX. 02 (Nov. 29.1984)

	POSITION OF INSTRUMENT	BRASILIA TIME						
		10:30	10:45	11:00	11:15	11:30	11:45	12.00
Temperature (°C)	A/10m	23.8	23.9	23.8	24.3	24.2	24.2	24.0
	P.17	-	-	-	-	-	-	-
	P.20	-	-	-	-	-	-	-
	P.26	25.0	25.0	25.0	26.0	26.5	27.0	28.0
	P.38	27.0	28.0	29.0	29.5	30.0	30.0	31.0
Rel. humidity (%)	P.17	76	76	77	76	76	74	72
	P.20	69	70	72	67	63	66	70
	P.26	75	75	75	72	70	69	68
	P.38	69	66	63	59	55	56	56
Abs. humidity (g/m³)	P.17	-	-	-	-	-	-	-
	P.20	-	-	-	-	-	-	-
	P.26	17.3	17.3	17.3	17.6	17.6	17.8	18.6
	P.38	17.8	18.0	18.2	17.5	16.7	17.5	18.0
	ARITHMETIC MEAN VALUE: 17.7 (g/m³)							

TABLE - 5 : Humidity data during EX.03 (Nov. 30. 1984)

	POSITION OF INSTRUMENT	BRASILIA TIME						
		10:30	10:45	11:00	11:15	11.30	11.45	12.00
Temperature (°C)	A/10m	24.3	24.2	24.4	24.9	24.2	24.3	24.7
	P.17	26.0	26.5	27.0	28.5	27.5	27.5	27.5
	P.20	28.5	29.0	29.0	29.0	28.5	29.0	29.0
	P.26	27.0	27.0	28.0	28.0	28.0	28.0	28.0
	P.38	31.0	30.0	29.0	28.5	28.0	28.5	29.0
Rel. humidity (%)	P.17	76	77	75	71	72	73	72
	P.20	72	71	71	70	68	68	68
	P.26	74	75	73	74	69	70	70
	P.38	56	59	62	63	64	64	64
Abs. humidity (g/m³)	P.17	18.5	19.3	19.3	19.9	19.1	19.4	19.1
	P.20	20.2	20.5	20.5	20.2	19.1	19.6	19.6
	P.26	19.1	19.4	19.9	20.2	18.8	19.1	19.1
	P.38	18.0	18.0	18.0	17.7	17.5	18.0	18.5
	ARITHMETIC MEAN VALUE: 18.1 (g/m³)							

TABLE - 6 : Humidity data during EX.04 (Dec. 01. 1984)

	POSITION OF INSTRUMENT	BRASILIA TIME					
		12:15	12:30	12:45	13:00	13:15	13:30
Temperature (^{o}C)	A/10m	24.6	24.8	24.8	25.5	24.8	24.5
	P.17	26.5	27.0	27.0	27.5	26.5	26.0
	P.20	27.0	27.0	28.0	29.0	28.5	28.0
	P.26	28.0	28.0	29.0	30.0	26.0	26.0
	P.38	30.0	27.0	28.5	29.0	27.5	26.0
Rel. humidity (%)	P.17	75	73	72	71	74	73
	P.20	72	74	70	67	70	74
	P.26	68	69	64	58	71	73
	P.38	60	70	65	65	70	75
Abs. humidity (g/m^3)	P.17	18.8	18.6	18.6	18.6	18.6	17.8
	P.20	18.6	19.1	19.1	19.3	19.6	20.2
	P.26	18.6	18.6	18.5	17.7	17.3	17.8
	P.38	18.3	18.1	18.2	18.7	18.6	18.3
	ARITHMETIC MEAN VALUE: 18.6 (g/m^3)						

TABLE 7: Humidity data during EX.05 (Dec. 4. 1984)

	POSITION OF INSTRUMENT	BRASILIA TIME						
		10:30	10:45	11:00	11:15	11:30	11:45	12:00
WIND DIRECTION (Degrees)	A/100m	163	144	146	189	197	191	200
	A/ 60m	188	152	157	186	199	195	204
	A/ 10m	239	207	210	222	232	227	219
	B/ 15m	173	166	180	188	194	189	200
	C/ 15m	172	144	163	167	168	171	173
	D/ 15m	1	1	1	11	146	132	163
WIND SPEED (Knots)	A/100m	2.9	3.6	4.1	3.8	3.6	4.4	5.8
	A/ 60m	3.7	3.4	4.0	5.1	4.9	5.7	5.9
	A/ 10m	4.1	3.1	3.5	5.8	4.9	5.6	5.6
	B/ 15m	4.6	6.1	5.3	4.9	5.6	5.1	6.8
	C/ 15m	5.2	5.8	5.2	5.6	4.3	4.0	4.2
	D/ 15m	4.0	3.7	3.5	2.8	2.3	2.6	3.1
TEMPERATURE DIFFERENCE (K) A/100m - 10m		-1-1	-1.2	-1.3	-0.7	-1.0	-1.2	-1.3
STABILITY CLASS		D	D	D	D	D	D	D

TABLE - 8 : Meteorological data during EX.01 (Nov. 28 , 1984)

	POSITION OF INSTRUMENT	BRASILIA TIME						
		10:30	10:45	11:00	11:15	11:30	11:45	12:00
WIND DIRECTION(Degrees)	A/100m	203	199	208	214	222	224	223
	A/ 60m	202	199	209	213	223	220	224
	A/ 10m	237	219	234	231	241	242	247
	B/ 15m	188	195	195	211	223	231	231
	C/ 15m	168	171	170	168	173	186	182
	D/ 15m	162	182	181	238	246	248	255
WIND SPEED (Knots)	A/100m	7.0	5.7	5.5	5.4	4.6	4.7	4.6
	A/ 60m	6.7	5.3	5.6	5.2	4.7	5.1	4.5
	A/ 10m	5.7	4.6	4.8	4.0	4.1	4.6	4.0
	B/ 15m	7.2	6.2	5.1	5.3	4.3	4.9	4.8
	C/ 15m	6.1	5.3	4.6	4.2	4.0	3.5	3.3
	D/ 15m	4.1	3.2	1.9	5.0	4.8	5.2	4.5
TEMPERATURE DIFFERENCE (K) A/100m - 10m		-1.6	-1.2	-1.2	-1.3	-1.2	-1.1	-1.2
STABILITY CLASS		C	D	D	D	D	D	D

TABLE - 9 : Meteorological data during EX.02 (Nov. 29, 1984)

	POSITION OF INSTRUMENT	BRASILIA TIME						
		10:30	10:45	11:00	11:15	11:30	11:45	12:00
WIND DIRECTION(Degrees)	A/100m	212	217	228	232	260	242	228
	A/ 60m	211	212	214	212	221	216	214
	A/ 10m	232	239	238	237	237	241	242
	B/ 15m	217	218	210	187	168	173	180
	C/ 15m	188	171	175	164	153	156	160
	D/ 15m	257	262	281	270	180	103	46
WIND SPEED (Knots)	A/100m	5.6	3.7	2.4	1.6	1.8	2.9	4.2
	A/ 60m	5.6	4.1	3.3	2.5	2.9	4.0	5.3
	A/ 10m	4.9	4.3	3.7	3.1	4.7	4.9	5.6
	B/ 15m	5.0	4.1	3.4	2.8	3.6	4.7	4.8
	C/ 15m	3.8	3.9	3.3	2.8	3.7	4.9	4.6
	D/ 15m	4.9	3.8	2.4	2.0	0.7	1.0	0.8
TEMPERATURE DIFFERENCE (K) A/100m - 10m		-1.3	-1.4	-0.9	-0.9	-0.1	-0.4	-0.8
STABILITY CLASS		D	D	D	D	E	E	D

TABLE - 10 : Meteorological data during EX.03 (Nov. 30, 1984)

	POSITION OF INSTRUMENT	BRASILIA TIME						
		10:30	10:45	11:00	11:15	11:30	11:45	12:00
WIND DIRECTION (Degrees)	A/100m	-	229	238	214	229	224	232
	A/ 60m	-	212	211	206	206	208	215
	A/ 10m	-	128	19	351	345	91	204
	B/ 15m	-	222	218	194	215	217	212
	C/ 15m	-	181	164	153	187	207	198
	D/ 15m	-	284	338	80	282	279	286
WIND SPEED (Knots)	A/100m	-	4.8	1.4	1.2	3.1	3.3	2.8
	A/ 60m	-	4.8	2.9	3.7	4.6	3.7	2.6
	A/ 10m	-	3.5	1.3	2.4	2.2	1.3	2.6
	B/ 15m	-	3.8	2.7	3.4	4.4	4.2	3.4
	C/ 15m	-	3.7	2.4	4.9	3.0	2.3	2.4
	D/ 15m	-	1.6	1.5	1.5	1.1	3.6	3.4
TEMPERATURE DIFFERENCE (K) A/100m - 10m		-	-0.5	-0.4	-0.6	-0.4	-0.6	-0.5
STABILITY CLASS		-	E	E	D	E	D	E

TABLE - 11 : Meteorological data during EX.04 (Dec. 01, 1984)

	POSITION OF INSTRUMENT	BRASILIA TIME					
		12:15	12:30	12:45	13:00	13:15	13:30
WIND DIRECTION(Degrees)	A/100m	239	213	177	230	205	198
	A/ 60m	218	213	186	238	204	200
	A/ 10m	218	215	189	223	208	207
	B/ 15m	146	154	145	155	167	182
	C/ 15m	154	172	140	147	168	169
	D/ 15m	77	93	109	172	177	188
WIND SPEED (Knots)	A/100m	2.2	2.5	2.0	2.8	6.1	6.3
	A/ 60m	3.0	3.6	2.1	3.6	6.3	6.3
	A/ 10m	3.9	3.7	2.1	3.2	6.1	5.9
	B/ 15m	5.6	6.0	6.8	4.4	7.1	8.5
	C/ 15m	2.0	2.5	6.9	4.9	5.6	7.0
	D/ 15m	2.0	3.5	2.7	2.5	2.6	3.0
TEMPERATURE DIFFERENCE (K) A/100m - 10m		-0.8	-1.0	-1.0	-1.2	-0.9	-0.9
STABILITY CLASS		D	D	D	D	D	D

TABLE - 12 : Meteorological data during EX.05 (Dec. 04. 1984)

Nº of Position	PERIOD 1		PERIOD 2		PERIOD 3	
	Sample concentration (Bq/mℓ)	In the air (Bq/m³)	Sample concentration (Bq/mℓ)	In the air (Bq/m³)	Sample concentration (Bq/mℓ)	In the air (Bq/m³)
	$x10^{-2}$	$x10^{-2}$	$x10^{-2}$	$x10^{-2}$	$x10^{-2}$	$x10^{-2}$
1	NA		NA		NA	
2	NA		NA		NA	
3	*		*		*	
4	-		*		*	
5	*		*		*	
6	NA		NA		NA	
7	*		*		*	
8	*		*		*	
9	*		4.66± 2.33	64	*	
10	NA		NA		NA	
11	NA		NA		NA	
12	NA		NA		NA	
13	*		*		*	
14	*		12.73± 2.74	134	*	
15	45.55± 4.40	624	200.91±12.40	2752	407.44±23.09	5582
16	*		5.59± 2.37	76	89.13± 6.66	1221
17	NA		NA		NA	
18	2.55± 2.22	35	*		*	
19	NA		NA		NA	
20	*		*		*	
21	*		*		3.40± 2.26	47
22	*		*		*	
23	NA		NA		NA	
24	*		*		*	
25	*		*		*	
26	*		-		*	
27	*		*		*	
28	*		*		*	
29	*		*		2.55± 2.22	35
30	*		*		2.81± 2.26	39
31	NA		NA		NA	
32	NA		NA		NA	
33	94.61± 6.92	1296	311.65±18.09	4270	517.48±28.71	7090
34	NA		NA		NA	
35	*		*		560.92±30.93	7685
36	*		*		*	
37	NA		NA		NA	
38	*		156.88±10.14	2149	*	
39	NA		NA		NA	
40	NA		NA		NA	
	Air humidity: 13.7 g/m³ * = lower than the minimum detectable activity: 2.52 x 10^{-2} Bq/mℓ					

TABLE 13 : EX.01 (Nov. 28.1984) Time:10:30 - 12:00

Emission rate: 20.46 MBq/s NA = Not available

Nº of Position	PERIOD 1		PERIOD 2		PERIOD 3	
	Sample concentration (Bq/mℓ)	In the air (Bq/m³)	Sample concentration (Bq/mℓ)	In the air (Bq/m³)	Sample concentration (Bq/mℓ)	In the air (Bq/m³)
	x10⁻²	x10⁻²	x10⁻²	x10⁻²	x10⁻²	x10⁻²
1	NA		NA		NA	
2	NA		NA		NA	
3	NA		NA		NA	
4	NA		NA		NA	
5	NA		NA		NA	
6	NA		NA		NA	
7	NA		NA		NA	
8	*		*		929.88±34.41	14227
9	*		431.24± 24.27	6598	1778.89±65.31	27217
10	NA		NA		NA	
11	NA		NA		NA	
12	NA		NA		NA	
13	*		*		4.92± 1.37	75
14	*		*		2.89± 1.33	44
15	406.33±22.98	6217	1338.96± 71.00	20486	3262.29±119.29	49913
16	2.59± 2.22	40	2381.32±124.69	36434	1664.37± 61.12	25465
17	*		*		2.59± 1.33	40
18	*		*		*	
19	NA		NA		NA	
20	*		178.60± 11.25	2733	60.61± 3.00	927
21	*		*		3.37± 1.37	58
22	*		*		3.26± 1.37	50
23	NA		NA		NA	
24	*		*		*	
25	*		*		*	
26	*		*		3.44± 1.37	53
27	*		*		*	
28	*		*		4.00± 1.37	61
29	*		*		3.55± 1.37	54
30	*		3.48± 2.29	53	5.65± 1.41	86
31	*		*		3.59± 1.37	55
32	NA		NA		NA	
33	1108.15±59.13	16955	1179.45± 62.79	18046	2389.90±87.57	36566
34	*		*		2.55± 1.33	39
35	*		*		*	
36	*		27.64± 3.52	423	*	
37	*		*		2.59± 1.33	40
38	976.36±52.32	14938	505.98± 28.12	7741	635.11±23.64	9717
39	NA		NA		NA	
40	NA		NA		NA	
	Air humidity: 15.3 g/m³ * = lower than the minimum detectable activity: 2.52 x 10⁻² Bq/mℓ					

TABLE 14: EX.02 (November 29, 1984) Time: 10:30 - 12:00
Emission rate: 25.34MBq/s - NA = Not available.

Nº Position	PERIOD 1		PERIOD 2		PERIOD 3	
	Sample concentration (Bq/mℓ)	In the air (Bq/m³)	Sample concentration (Bq/mℓ)	In the air (Bq/m³)	Sample concentration (Bq/mℓ)	In the air (Bq/m³)
	$\times 10^{-2}$	$\times 10^{-2}$	$\times 10^{-2}$	$\times 10^{-2}$	$\times 10^{-2}$	$\times 10^{2}$
1	NA		NA		NA	
2	*		*		3.40 ± 1.37	60
3	NA		NA		NA	
4	NA		NA		NA	
5	NA		NA		NA	
6	NA		NA		NA	
7	NA					
8	60.20 ± 5.18	1066	758.02 ± 41.11	13417	48.43 ± 2.59	857
9	1230.58 ± 65.42	21781	1117.10 ± 59.57	19773	124.10 ± 5.18	2197
10	NA		NA		NA	
11	NA		NA		NA	
12	NA		NA		NA	
13	10.62 ± 2.63	188	19.13 ± 3.07	339	42.51 ± 2.41	752
14	*		*		2.59 ± 1.33	46
15	1900.36 ± 99.94	33636	1503.14 ± 69.15	23065	532.13 ± 19.94	9419
16	114.67 ± 7.96	2032	840.16 ± 45.33	14879	550.01 ± 20.61	9735
17	103.97 ± 7.40	1840	247.35 ± 14.80	4378	228.85 ± 8.95	4051
18	12.10 ± 2.70	214	6.70 ± 2.44	118	5.11 ± 1.37	90
19	NA		NA		NA	
20	82.10 ± 6.29	1453	667.59 ± 36.45	11816	877.23 ± 32.49	15527
21	95.90 ± 6.99	1698	275.21 ± 16.21	4871	397.42 ± 15.02	7034
22	64.34 ± 5.37	1139	101.68 ± 7.29	1800	175.68 ± 7.03	3109
23	NA		NA		NA	
24	*		19.31 ± 3.07	342	5.51 ± 1.41	98
25	20.09 ± 3.11	356	153.99 ± 9.99	2726	219.74 ± 8.62	3889
26	104.53 ± 6.88	1850	71.74 ± 5.77	1270	136.12 ± 5.62	2409
27	NA		NA		NA	
28	38.41 ± 4.03	680	130.98 ± 8.81	2318	276.58 ± 10.66	4895
29	39.85 ± 4.11	705	185.59 ± 11.62	3285	204.65 ± 8.07	3622
30	121.03 ± 8.29	2142	209.12 ± 12.84	3701	189.26 ± 7.51	3350
31	144.67 ± 9.51	2561	212.31 ± 12.99	3758	287.98 ± 10.95	5026
32	NA		NA		NA	
33	1605.58 ± 84.73	28419	1115.55 ± 59.57	19745	151.77 ± 6.18	2686
34	4.07 ± 2.29	72	13.58 ± 2.78	240	4.77 ± 2.33	85
35	*		14.54 ± 2.85	257	6.92 ± 1.41	122
36	NA		NA		NA	
37	4.14 ± 2.29	73	36.96 ± 3.96	654	11.47 ± 1.52	203
38	220.15 ± 13.39	3897	462.09 ± 25.86	8179	110.78 ± 4.74	1961
39	192.62 ± 11.99	3409	451.70 ± 25.31	7995	101.79 ± 4.40	1802
40	NA		NA		NA	
	Air humidity: 17.7 g/m³ * = lower than the minimum detectable activity: 2.52×10^{-2} Bq/mℓ					

TABLE 15: EX.03 (November 30, 1984) Time: 10:30 - 12:00
Emission rate: 20.46 MBq/s - NA = Not available

Nº Position	PERIOD 1 Sample concentration (Bq/mℓ)	PERIOD 1 In the air (Bq/m³)	PERIOD 2 Sample concentration (Bq/mℓ)	PERIOD 2 In the air (Bq/m³)	PERIOD 3 Sample concentration (Bq/mℓ)	PERIOD 3 In the air (Bq/m³)
	$x10^{-2}$	$x10^{-2}$	$x10^{-2}$	$x10^{-2}$	$x10^{-2}$	$x10^{-2}$
1	NA		NA		NA	
2	4.55 ± 2.33	82	4.92 ± 2.37	89	3.11 ± 2.66	56
3	NA		NA		NA	
4	NA		NA		NA	
5	NA		NA		NA	
6	NA		NA		NA	
7	NA		NA		NA	
8	199.39 ± 12.32	3609	445.30 ± 24.98	8060	81.81 ± 3.70	1481
9	1223.41 ± 65.07	22144	437.64 ± 24.61	7921	548.56 ± 20.54	9929
10	NA		NA		NA	
11	NA		NA		NA	
12	NA		NA		NA	
13	NA		NA		NA	
14	6.96 ± 2.44	126	53.91 ± 4.85	976	7.81 ± 1.44	141
15	1749.40 ± 92.13	31664	1898.54 ± 99.83	34364	2070.52 ± 75.92	37476
16	1024.12 ± 54.80	18537	712.47 ± 38.74	12896	728.53 ± 27.08	13186
17	434.12 ± 24.42	7856	238.80 ± 14.36	4322	51.25 ± 2.66	928
18	16.02 ± 2.92	290	81.92 ± 6.29	1483	6.07 ± 1.41	110
19	NA		NA		NA	
20	618.27 ± 33.89	11191	387.87 ± 22.02	7020	71.37 ± 3.33	1292
21	657.49 ± 35.93	11901	312.17 ± 18.13	5650	23.20 ± 1.44	420
22	266.66 ± 15.80	4827	199.58 ± 12.32	3612	51.50 ± 2.70	932
23	NA		NA		NA	
24	93.68 ± 5.88	1696	48.25 ± 4.55	873	26.28 ± 1.63	195
25	329.08 ± 18.98	5956	280.57 ± 16.50	5078	89.21 ± 3.96	1615
26	322.05 ± 18.65	5829	198.58 ± 12.28	3594	15.61 ± 1.63	283
27	NA		NA		NA	
28	358.86 ± 20.54	6495	279.17 ± 16.43	5053	—	
29	458.28 ± 25.64	8295	359.27 ± 20.54	6503	120.07 ± 5.03	2173
30	522.92 ± 28.97	9465	393.75 ± 22.31	7127	214.08 ± 8.40	3875
31	691.53 ± 37.67	12517	125.65 ± 8.51	2274	80.48 ± 3.66	1457
32	NA		NA		NA	
33	846.26 ± 45.62	15317	762.90 ± 41.33	13809	793.35 ± 29.45	14360
34	19.35 ± 3.07	350	29.79 ± 3.52	503	11.14 ± 1.52	202
35	19.02 ± 3.07	344	24.86 ± 3.37	450	8.81 ± 1.44	159
36	231.10 ± 13.95	4183	134.50 ± 8.99	2434	207.02 ± 8.18	3747
37	209.41 ± 12.84	3791	71.08 ± 5.74	1287	40.11 ± 2.33	726
38	393.35 ± 22.31	7120	502.28 ± 27.94	9091	328.56 ± 12.54	5947
39	NA		NA		NA	
40	NA		NA		NA	
	Air humidity: 18.1 g/m³					

TABLE 16: EX. 04 (December 01, 1984) Time: 10:30 - 12:00
Emission rate: 24.34 MBq/s - NA = Not available

Nº of Position	PERIOD 1		PERIOD 2		PERIOD 3	
	Sample concentration (Bq/mℓ)	In the air (Bq/m³)	Sample concentration (Bq/mℓ)	In the air (Bq/m³)	Sample concentration (Bq/mℓ)	In the air (Bq/m³)
	$x10^{-2}$	$x10^{-2}$	$x10^{-2}$	$x10^{-2}$	$x10^{-2}$	$x10^{-2}$
1	NA		NA		NA	
2	4.18 ± 2.33	78	2.37 ± 2.26	44	*	
3	*		144.52 ± 9.51	2688	11.06 ± 1.52	206
4	NA		NA		NA	
5	NA		NA		NA	
6	NA		NA		NA	
7	NA		NA		NA	
8	141.56 ± 9.36	2633	281.50 ± 16.54	5236	-	
9	4032.45 ± 209.57	75004	703.67 ± 38.62	13088	-	
10	NA		NA		NA	
11	NA		NA		NA	
12	NA		NA		NA	
13	NA		NA		NA	
14	*		4.74 ± 2.37	88	*	
15	1430.09 ± 75.67	26600	739.82 ± 40.15	13761	116.18 ± 4.92	2161
16	332.15 ± 19.17	6178	309.95 ± 18.02	5765	68.45 ± 3.26	1273
17	531.28 ± 29.42	9882	222.74 ± 13.54	4143	45.84 ± 2.52	853
18	*		3.59 ± 2.29	67	*	
19	NA		NA		NA	
20	208.04 ± 12.84	3886	84.58 ± 6.40	1566	14.91 ± 1.59	277
21	228.66 ± 12.84	4253	82.58 ± 6.33	1536	25.83 ± 1.89	480
22	41.66 ± 4.26	775	19.98 ± 3.15	372	9.14 ± 1.48	170
23	NA		NA		NA	
24	NA		NA		NA	
25	23.98 ± 3.33	446	41.77 ± 4.26	777	8.95 ± 1.48	167
26	18.09 ± 3.03	337	32.45 ± 3.77	604	4.26 ± 1.37	79
27	NA		NA		NA	
28	57.91 ± 5.07	1077	89.50 ± 6.70	1665	21.02 ± 1.78	391
29	-		38.33 ± 4.07	713	26.68 ± 1.89	496
30	-		37.85 ± 4.03	704	17.65 ± 1.67	328
31	258.37 ± 15.36	4806	133.16 ± 8.92	2477	39.04 ± 2.29	726
32	NA		NA		NA	
33	1113.70 ± 59.39	20715	636.29 ± 34.82	11835	86.95 ± 3.89	1617
34	NA		NA		NA	
35	NA		NA		NA	
36	*		*		5.62 ± 1.41	105
37	NA		NA		NA	
38	178.19 ± 11.25	3314	207.72 ± 12.77	3864	283.16 ± 10.92	5267
39	NA		NA		NA	
40	*		*		2.89 ± 1.33	54
41	*		*		3.00 ± 1.33	56
42	*		*		4.66 ± 1.37	87

Air humidity: 18.6 g/m³
* = Lower than the minimum detectable activity: 2.52×10^{-2} Bq/mℓ

TABLE 17: Ex. 05 (December 04, 1984) Time 12:15 - 13:30
Emission rate: 31.32 MBq/s - NA = Not available

FIGURE CAPTIONS

Fig. 1a: Topographic map of the Angra and Rio de Janeiro area

Fig. 1: Topographic map of the Angra Site

Fig. 2: Topographic map of the Angra Site (Expansion of insert in Figure 1)

Fig. 3: Meteorological tower A (Photo)

Fig. 4: Evaporating boiler for the release of the tracer (Photo)

Fig. 5: Sampler (Photo)

Fig. 6: Surface weather analysis of Nov. 27. 1984

Fig. 7: Surface weather analysis of Nov. 28. 1984

Fig. 8: Surface weather analysis of Nov. 29. 1984

Fig. 9: Surface weather analysis of Nov. 30. 1984

Fig. 10: Surface weather analysis of Dec. 01. 1984

Fig. 11: Surface weather analysis of Dec. 02. 1984

Fig. 12: Surface weather analysis of Dec. 03. 1984

Fig. 13: Surface weather analysis of Dec. 04. 1984

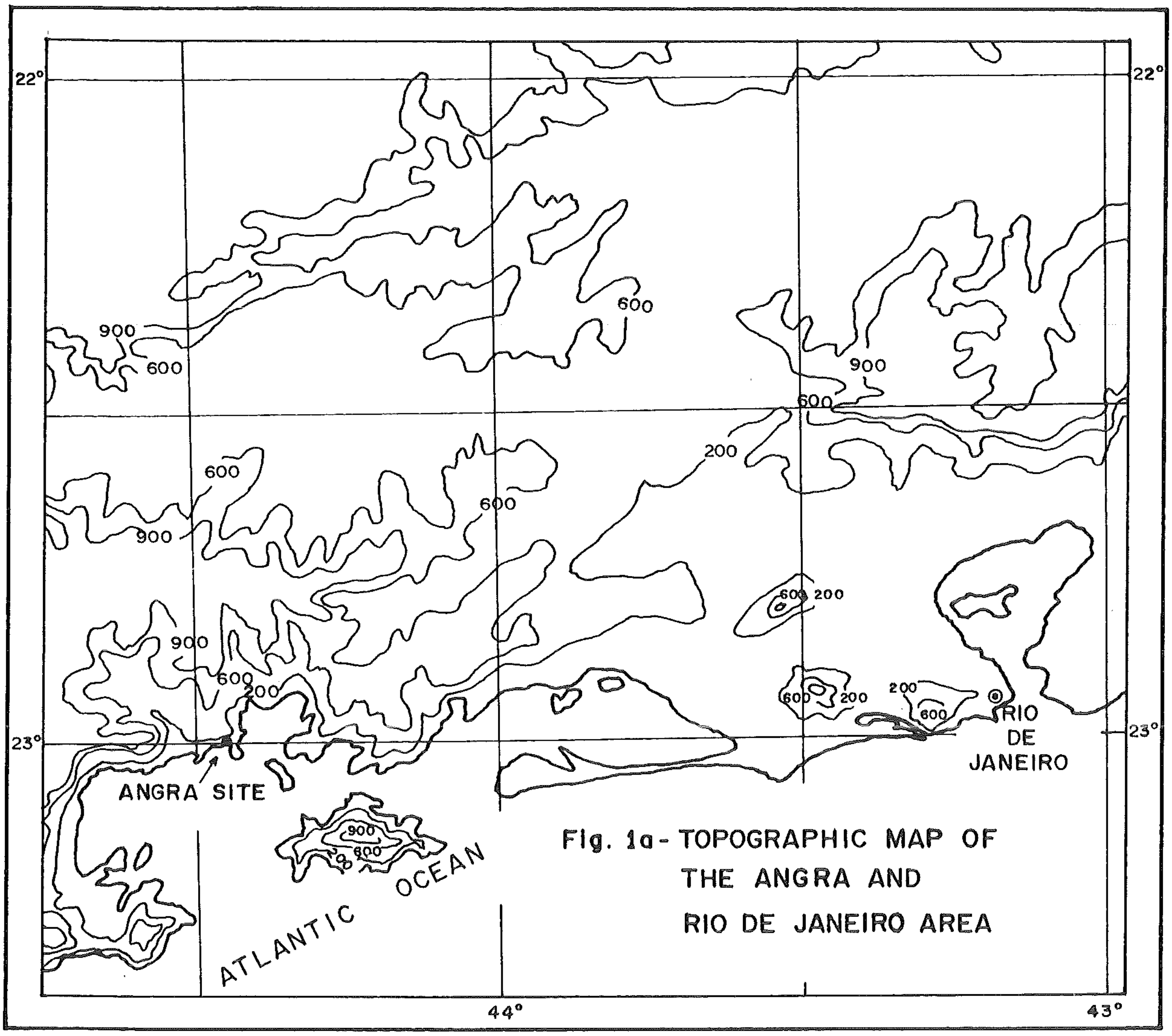

Fig. 1a - TOPOGRAPHIC MAP OF THE ANGRA AND RIO DE JANEIRO AREA

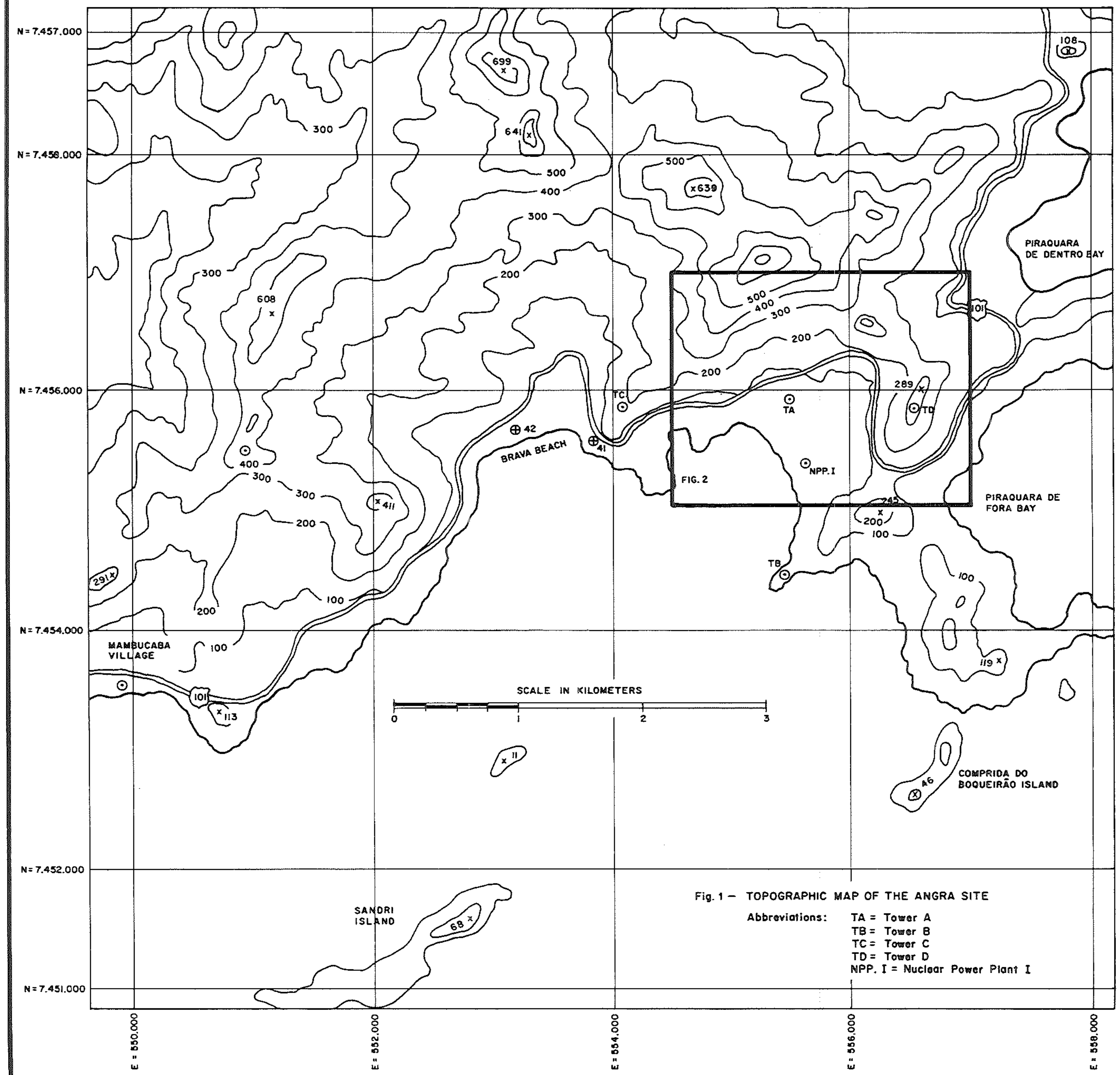

Fig. 1 — TOPOGRAPHIC MAP OF THE ANGRA SITE

Abbreviations: TA = Tower A
TB = Tower B
TC = Tower C
TD = Tower D
NPP. I = Nuclear Power Plant I

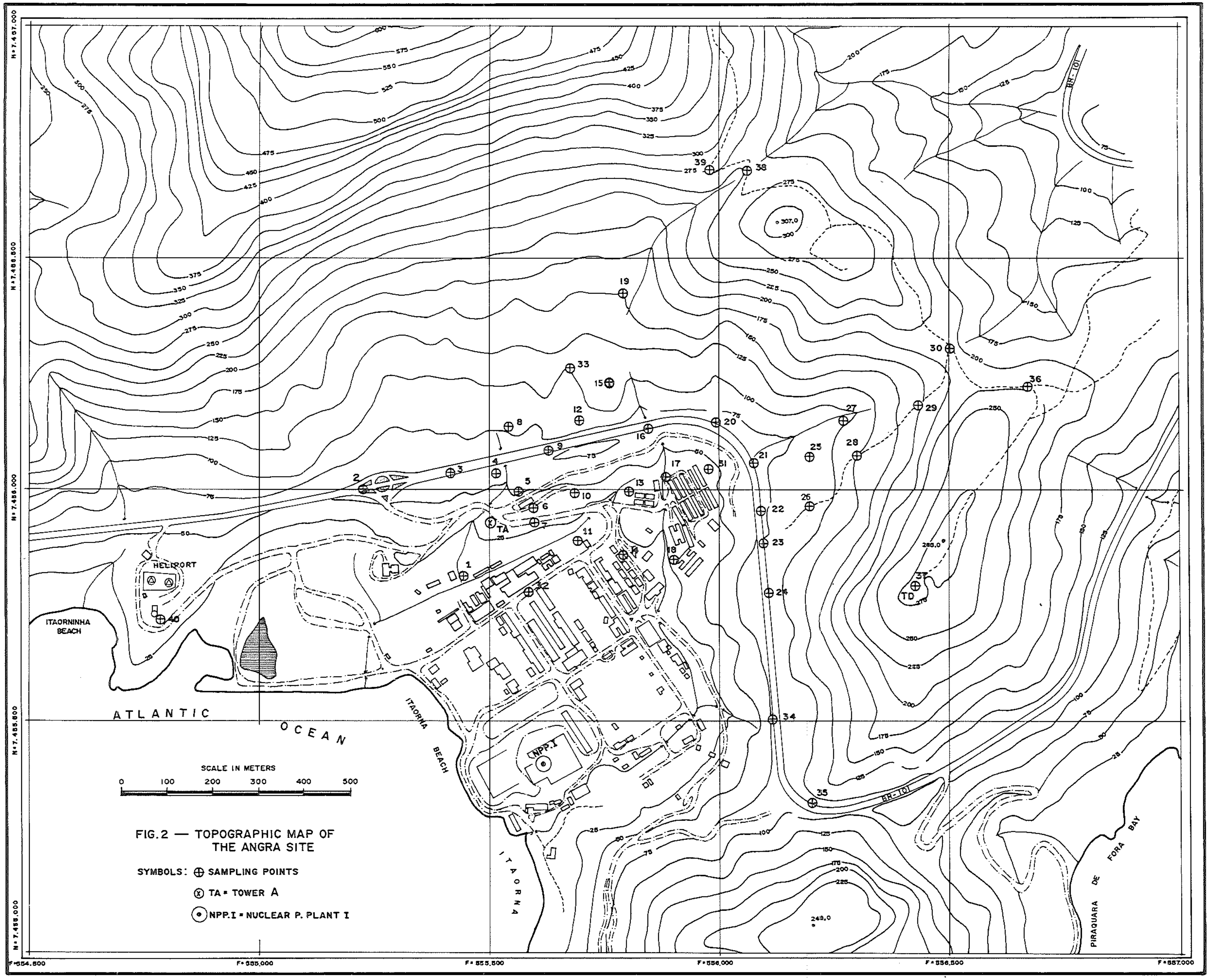

FIG. 2 — TOPOGRAPHIC MAP OF THE ANGRA SITE

SYMBOLS: ⊕ SAMPLING POINTS

Ⓧ TA = TOWER A

⊙ NPP.I = NUCLEAR P. PLANT I

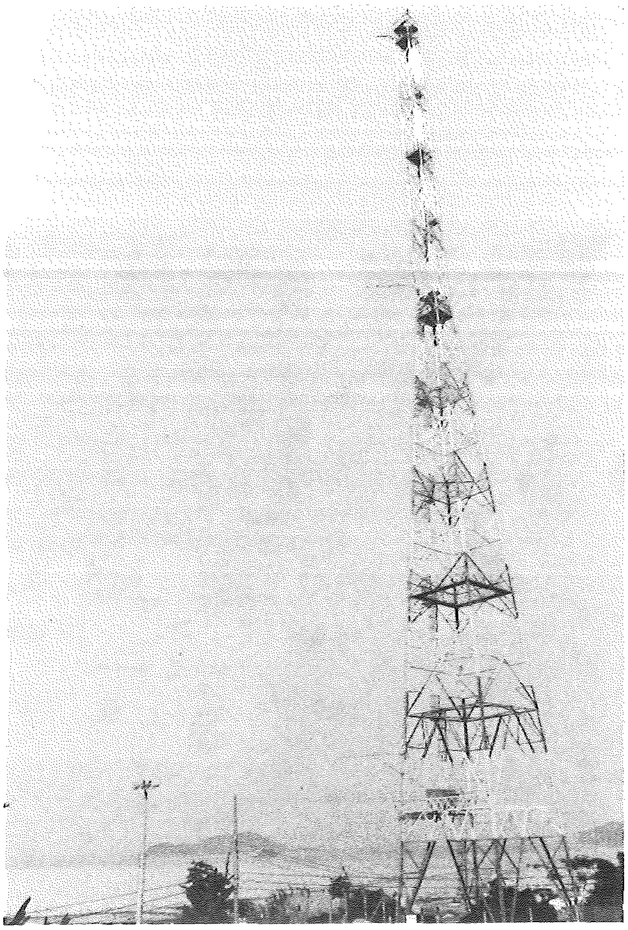

Fig. 3 - Meteorological tower A

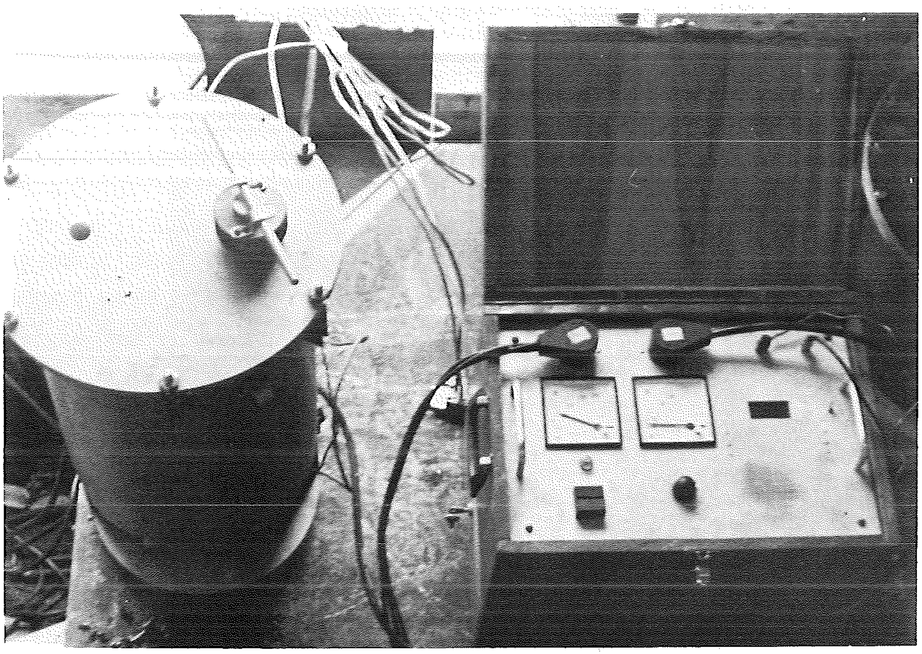

Fig. 4 - Evaporating boiler for the release of the tracer

Fig. 5 - Sampler

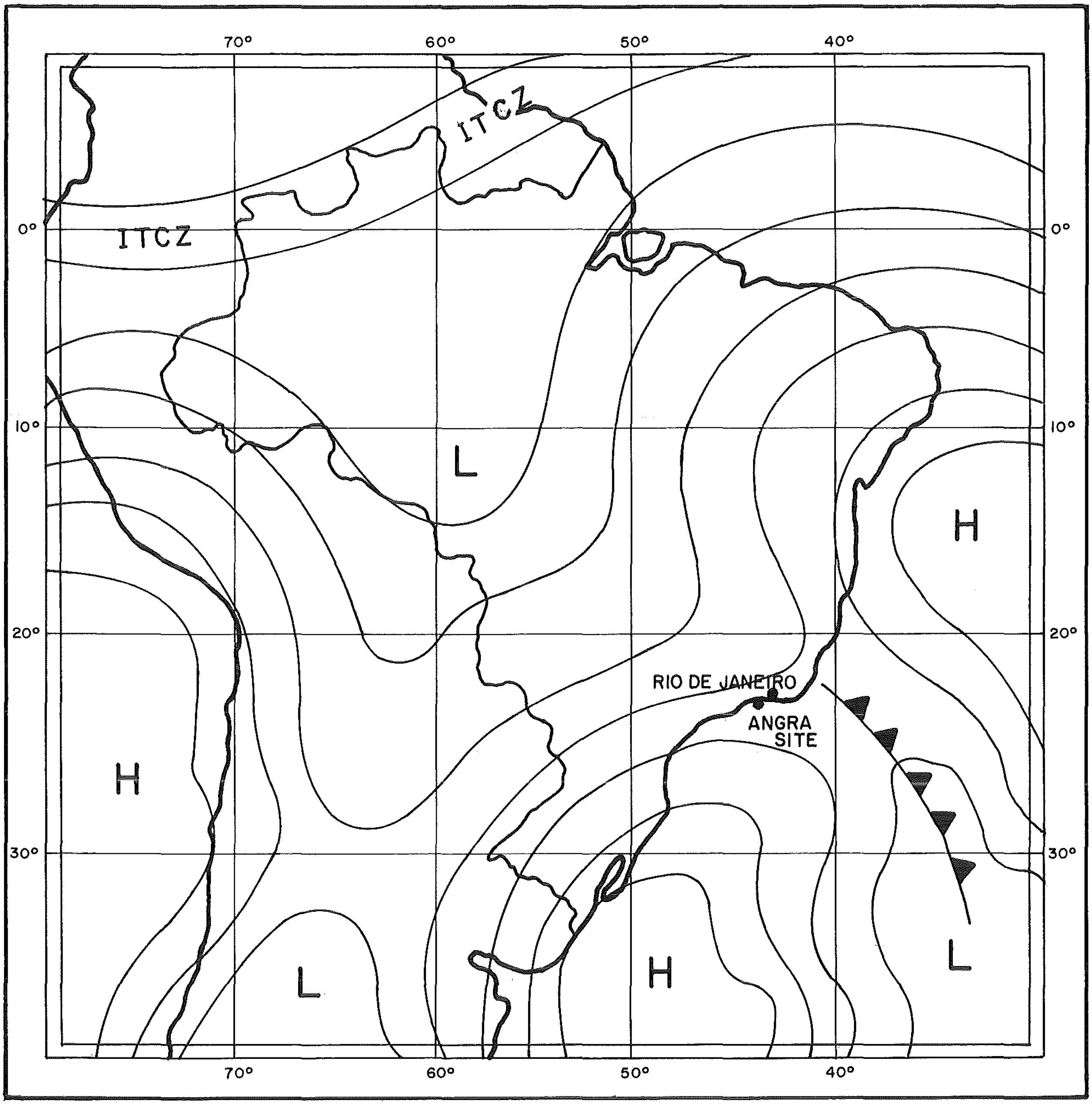

Fig. 6 – SURFACE WEATHER ANALYSIS OF NOV. 27, 1984

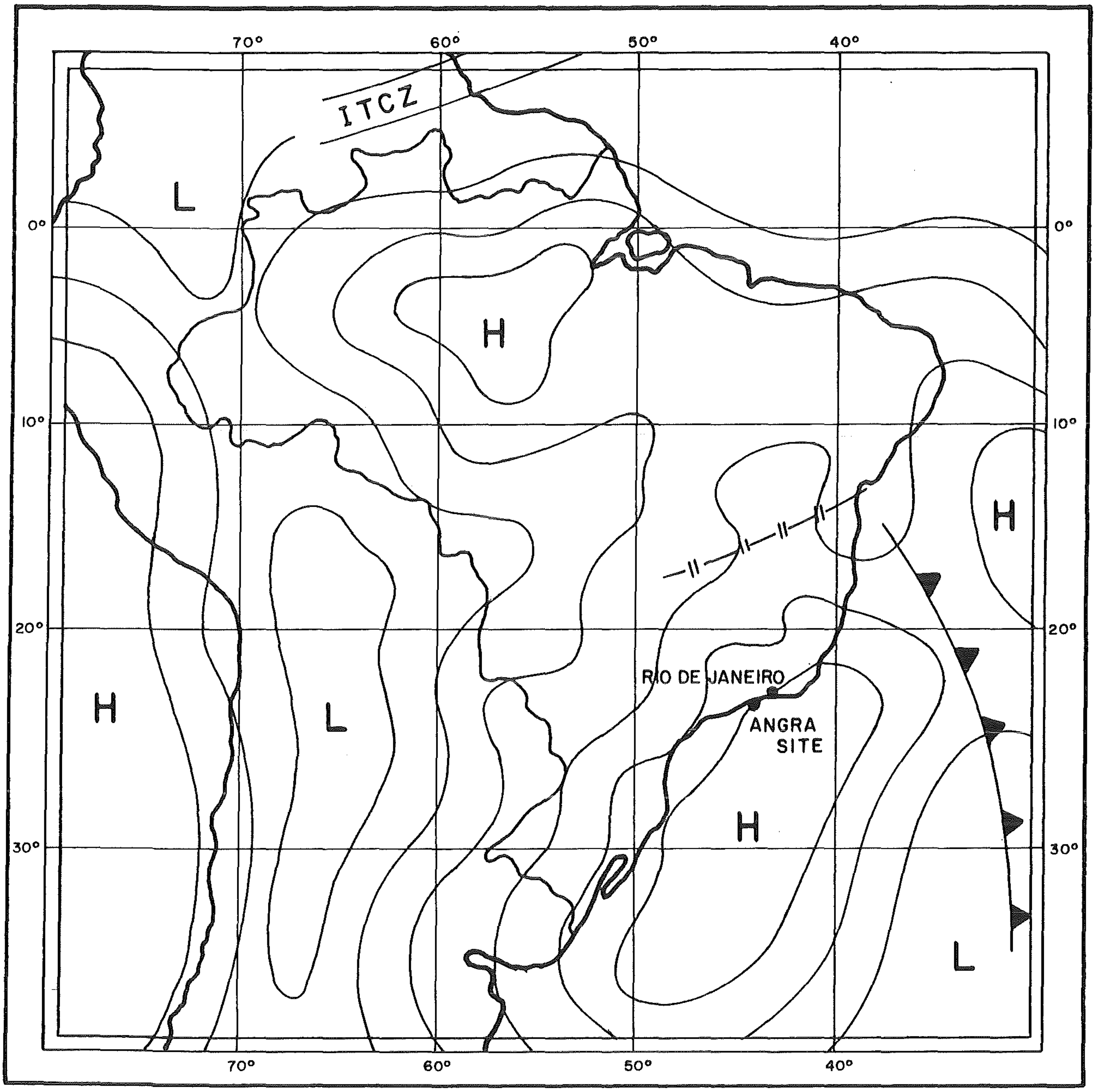

Fig. 7 — SURFACE WEATHER ANALYSIS OF NOV. 28, 1984

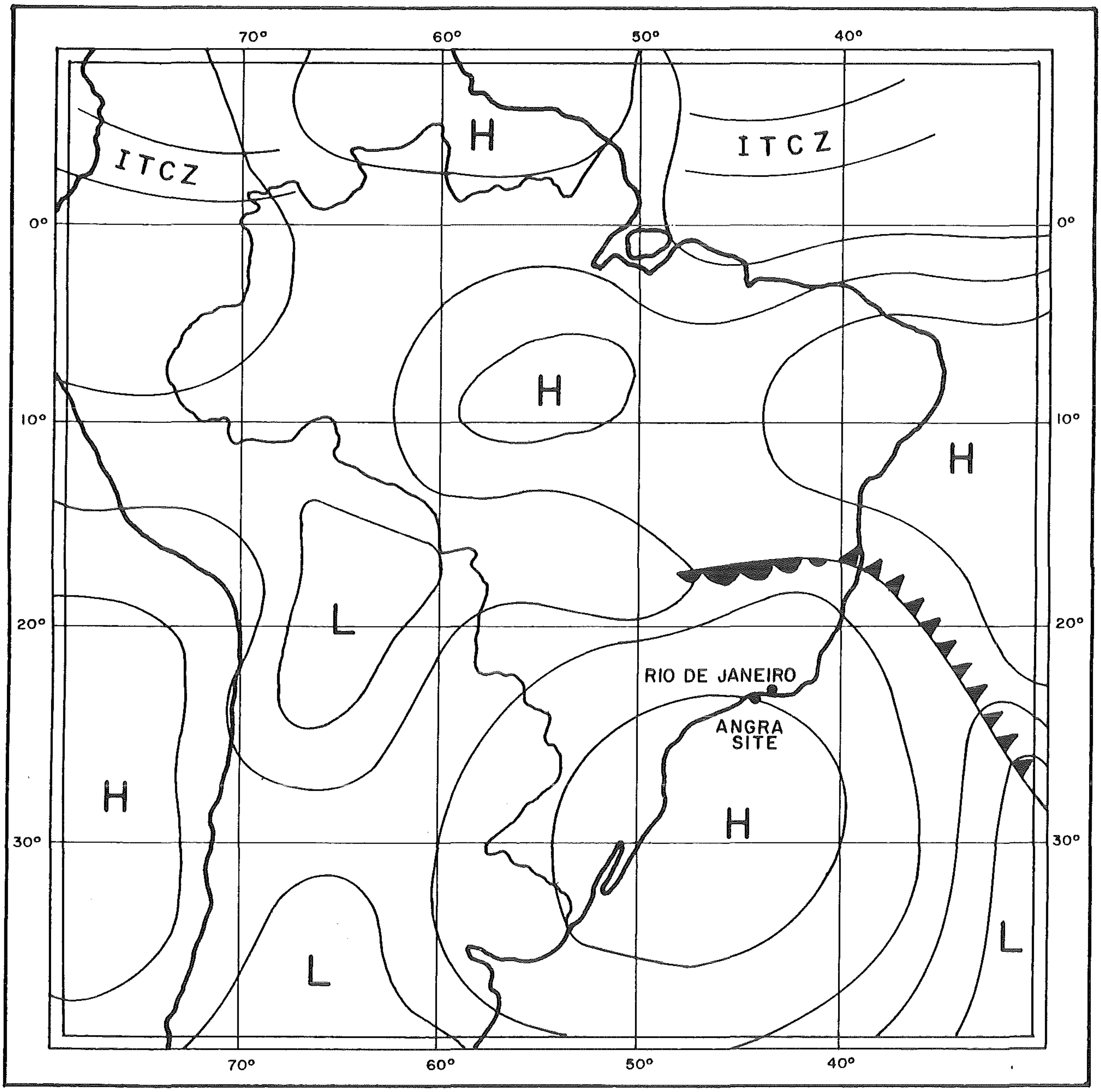

Fig. 8 - SURFACE WEATHER ANALYSIS OF NOV. 29, 1984

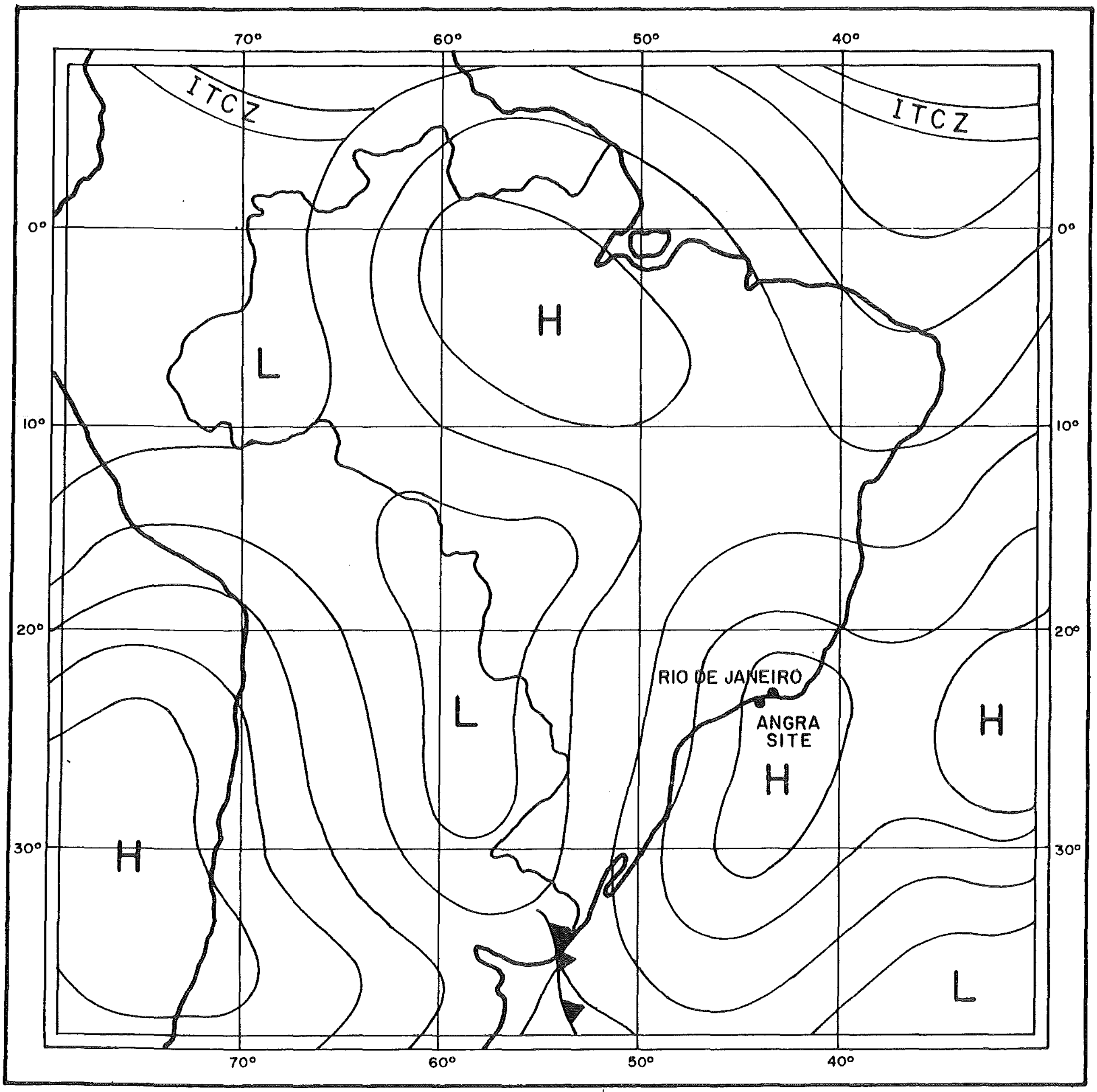

Fig. 9 - SURFACE WEATHER ANALYSIS OF NOV. 30, 1984

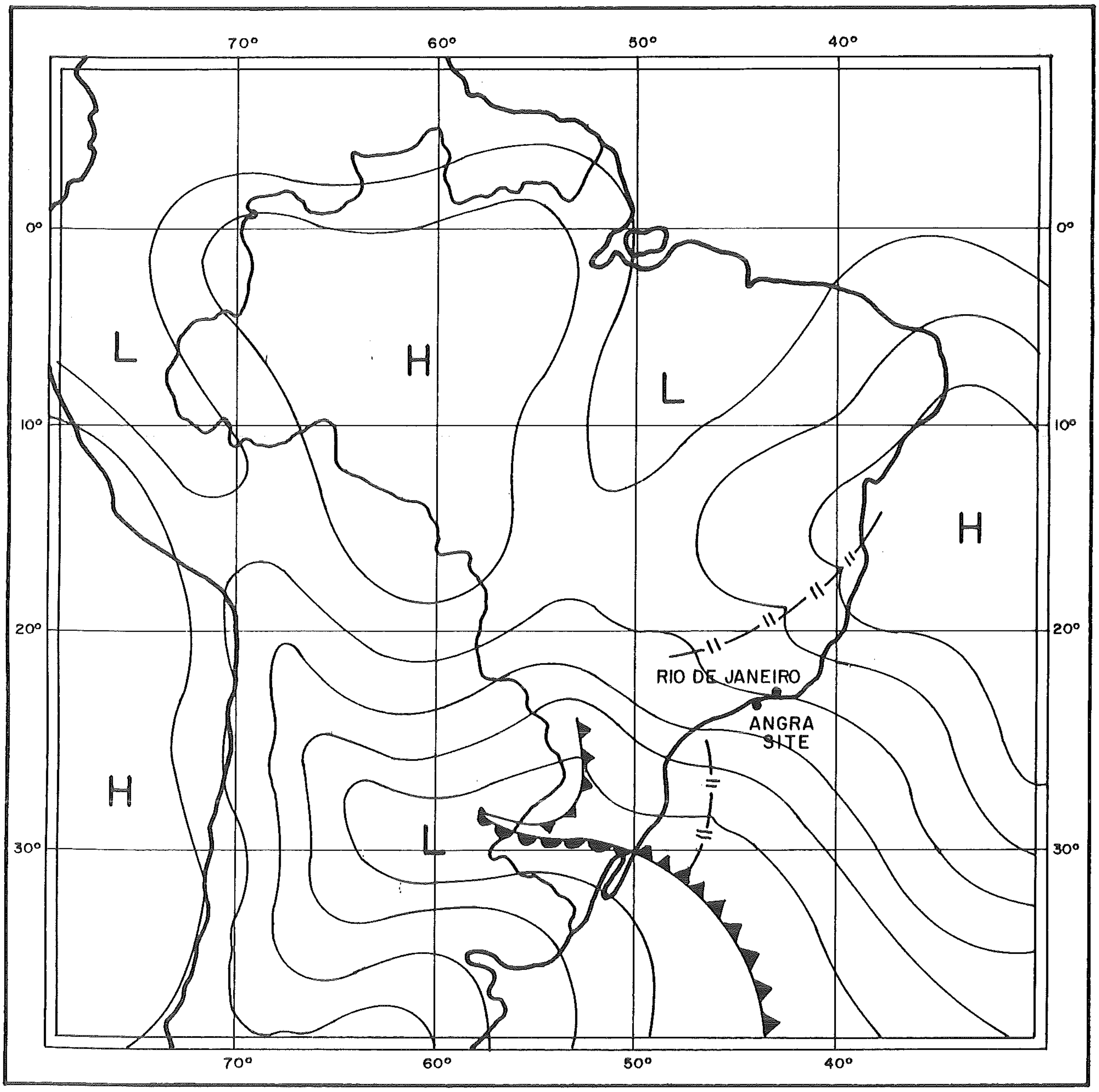

Fig.10 - SURFACE WEATHER ANALYSIS OF DEC. 1, 1984

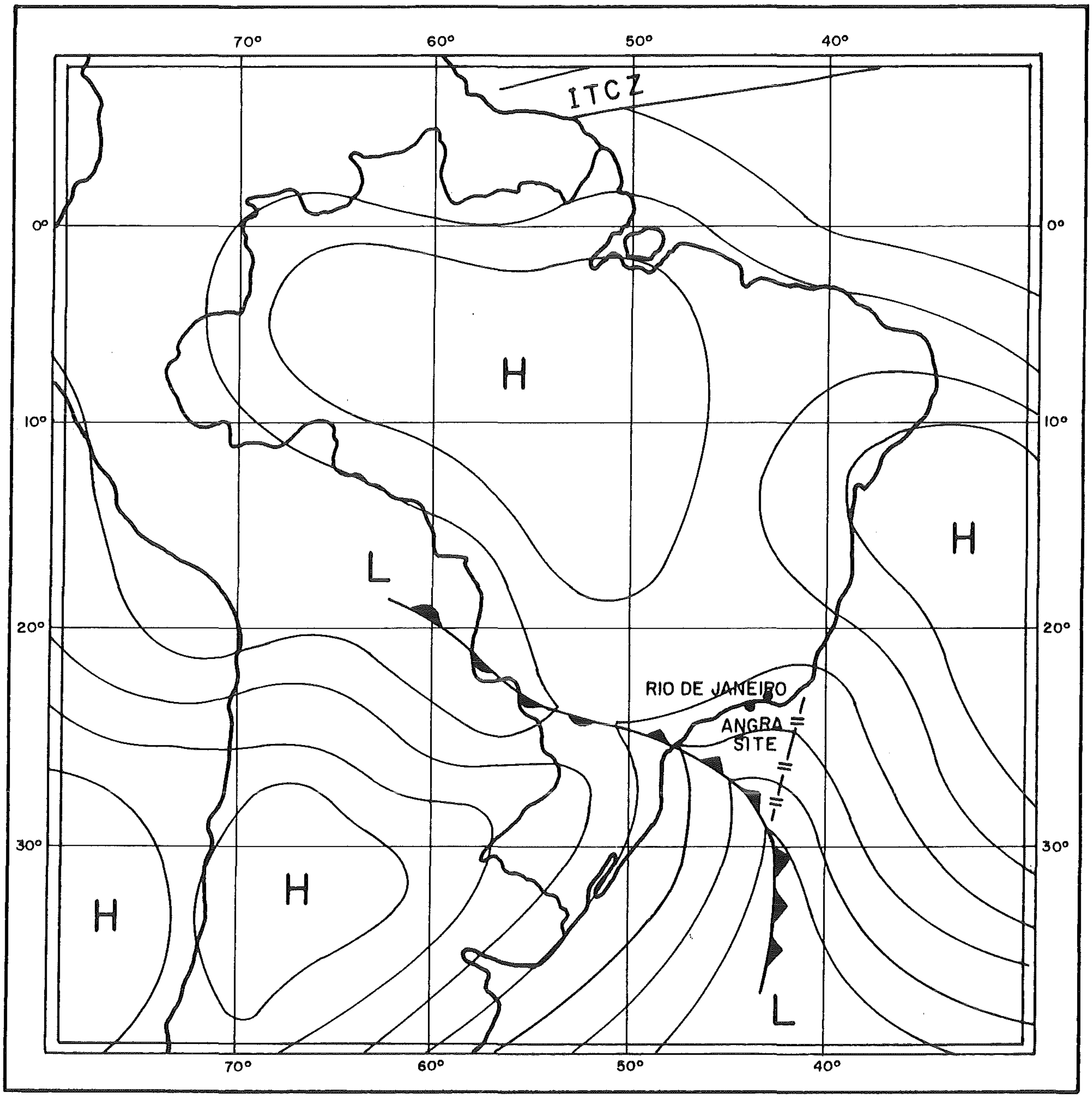

Fig.11 - SURFACE WEATHER ANALYSIS OF DEC. 2, 1984

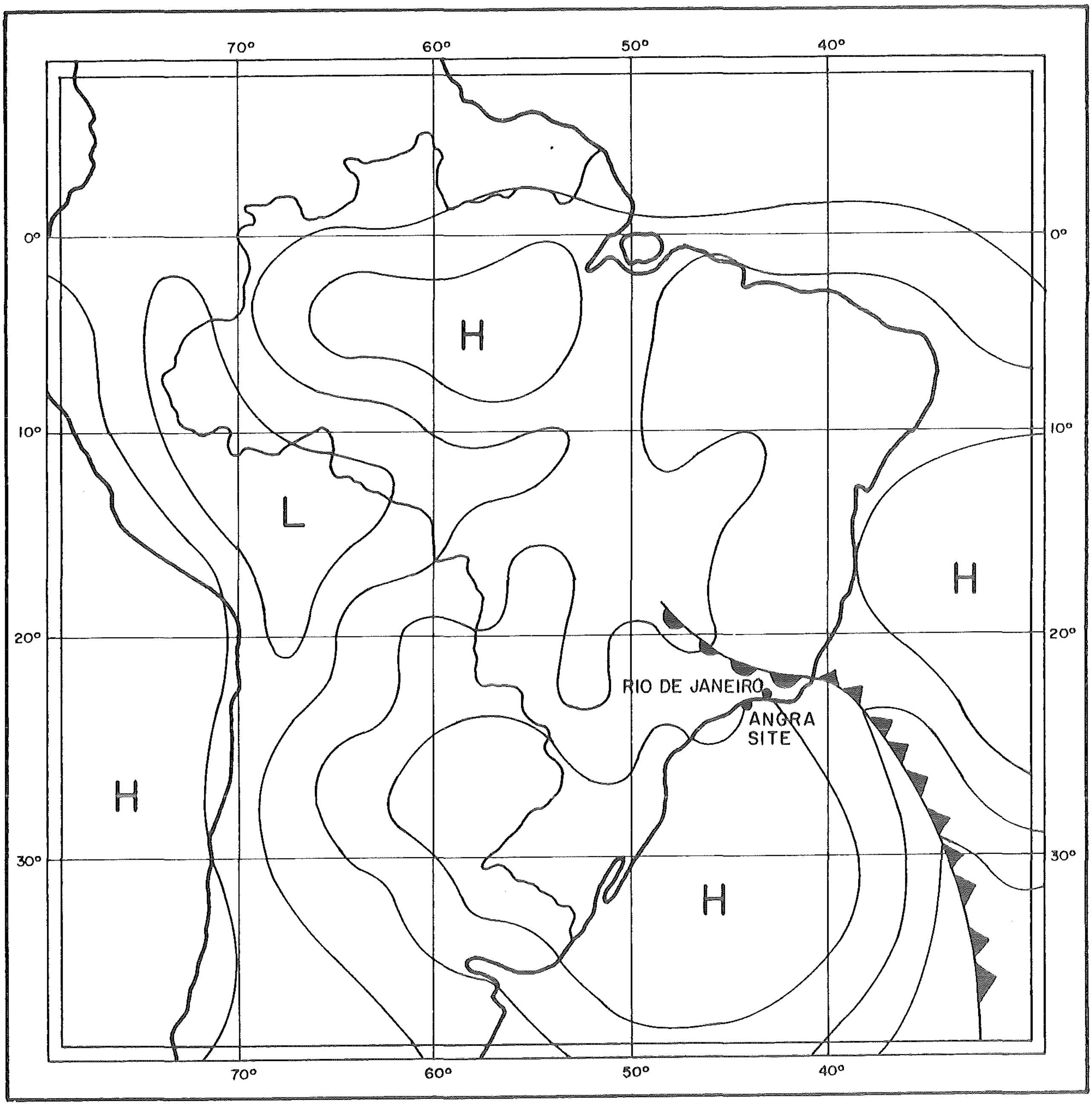

Fig. 12 - SURFACE WEATHER ANALYSIS OF DEC. 3, 1984

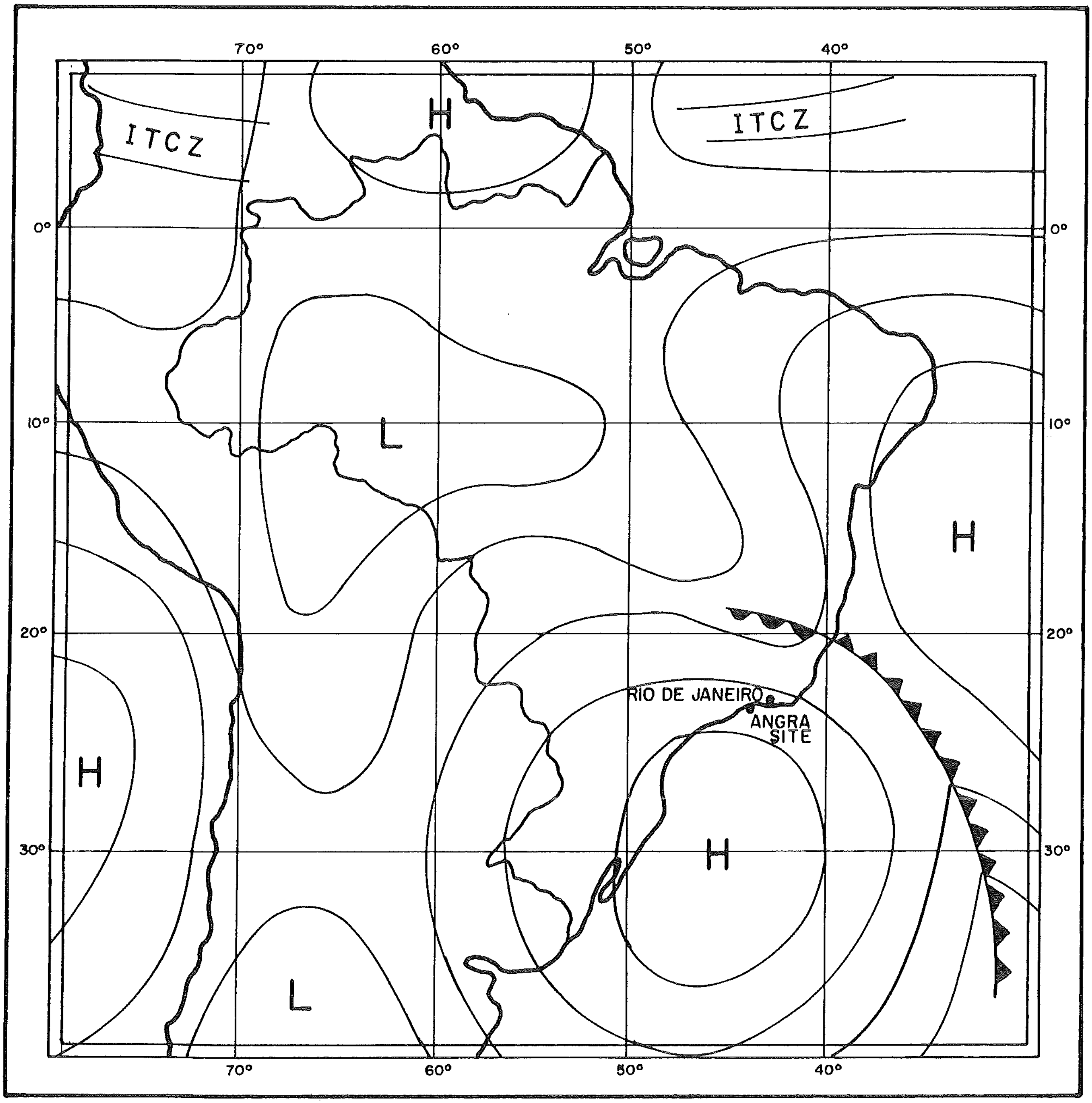

Fig.13 - SURFACE WEATHER ANALYSIS OF DEC. 4, 1984