PRE-OPERATIONAL SEARCH FOR BASELINE RADIO-ACTIVITY, CRITICAL FOOD AND POPULATION GROUP AT THE TARAPUR ATOMIC POWER STATION SITE

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Abstract—Two reactors each of 200 MWe are under construction at Tarapur, 100 km north of Bombay on the west coast. A pre-operational environmental survey laboratory was set up in 1964 to carry out environmental investigations and research.

In the first phase of the pre-operational programme 45 monitoring stations were established in the 0–32 km region from the station and nearly 1200 environmental samples were examined for natural and fallout radioactivity and trace element content. Information on social habits of people, land utilization and dietary habits were collected during the survey trips. In the near zone (0–8 km) of the reactors detailed information on dietary items and food consumption were collected from 100 families belonging to different professions and socio-economic groups.

Applying the data obtained from assays of environmental samples and demographic surveys, an attempt is made to predict the possible critical food and critical group of population in the region.

In the Indian diet most of the fallout contamination is obtained from cereals (predominantly from rice). Exposure from activation products is likely through intake of fish harvested from shore waters. $^{90}Sr/Ca$ ratios in Tarapur and New York diets are surprisingly in close agreement. However, Ca in N.Y. diet comes from milk, fish and meat whereas in Tarapur diet it comes from cereals and vegetables. The same observation applies to the availability of P in the two diets.

It is observed that the fishing population in the area could be the critical group in the environment under normal operating conditions.

The Tarapur Atomic Power Project (TAPP) site is on the west coast of India nearly 100 km north of Bombay. Two power reactors each of 200 MWe are under construction to go into operation in 1968.

Figure 1 gives the location of the TAPP site, monitoring stations and gamma radiation levels in the environment. The site gets heavy rains (up to 250 cm) from S.W. monsoons during the months of June–September, which constitute the principal source of fresh water. The land is flat up to about 16 km from the coastline and is used for farming. There is considerable export of fruits and hay from the area to adjacent towns and Bombay. A hold-up water reservoir is being built at Sakharepada beyond the 16 km zone for a supply of water to the power station, housing colony and for agricultural use. The project housing colony is beyond the 8 km range.

Being a coastal site with a headland jutting out of the coastline, the land spreads in a 170° arc behind the site. The coastal region is a popular fishing ground and fishermen live close to the site at Ghivali, Pophran and Dandepada. Between 4.8 km and 8 km from the reactors there are creeks where oysters and clams seasonally exist along with a luxuriant growth of sea weeds. There is an oyster farm at Uchali, 5 km away and a larger farm at Kelwa within 20 km. Dahanu in the north and Sathpathi in the south, both within 16 km from the station,

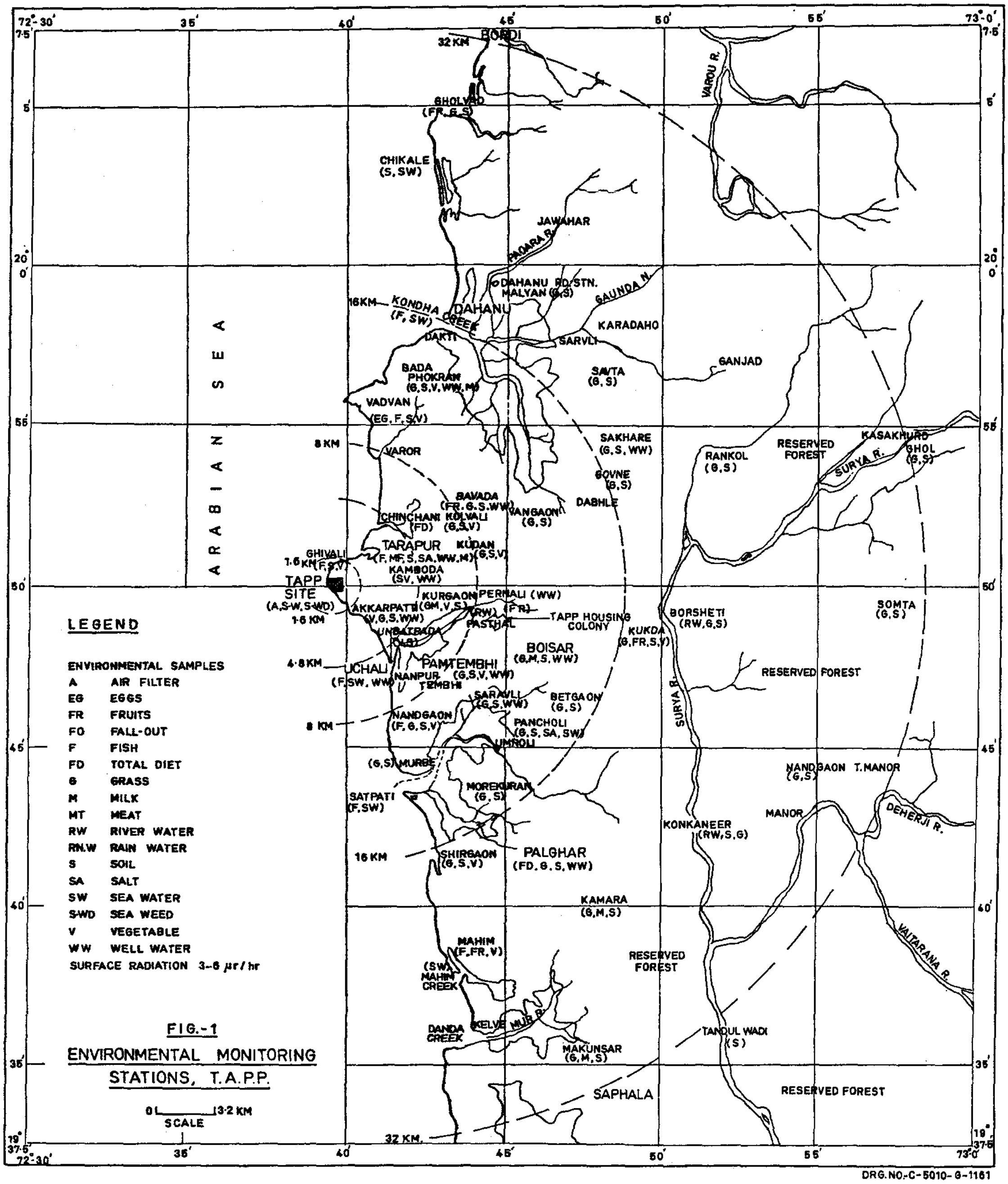

FIG. 1. Environmental monitoring stations, TAPP

are important fish landing centres. Large catches of pomfrets (*Pampus argenteus*) and Bombay duck (*Harpondon neherus*) are seasonally landed in these centres.

Table 1 gives the population and area under cultivation in the region up to 8 km from site. The principal population (1961 census) centres and occupations of the people in the 0–8 km zone are:

Ghivali (Pop. 2083)	Fishing.
Tarapur (Pop. 4232)	Agriculture, fishing, poultry farming and sea salt production.
Chinchani (Pop. 8446)	Agriculture, fishing, business and poultry farming.
Dandepada (Pop. 800)	Fishing.
Kudan (Pop. 1045)	Agriculture.
Kolvali, Bavada (Pop. 1097)	Vegetables and fruits farming, agriculture.
Akkarpatti, Pophran (Pop. 1950)	Fishing, agriculture.
Kurgaon (Pop. 492)	Cattle fodder cultivation, agriculture.
Pamtembhi (Pop. 2000)	Agriculture, hay production.
Uchali, Nawapur (Pop. 2890)	Fishing, oysters and poultry farming.

A pre-operational environmental survey laboratory was set up at the project site in December 1964 for environmental investigations and research. The paper presents:

1. Baseline radioactivity levels in the 0–8 km region of the TAPP site environment.
2. Distribution of significant elements and radionuclides in the different components of food and in the total diet.
3. Then attempts to identify the group in the population which would receive the highest exposure from environmental contamination.

BASELINE DATA

Survey programmes were drawn up first to monitor land and land produce, sea water, sea food, drinking water supplies and air in the 0–32 km region from the site. 1200 dietary and environmental samples were analysed for radioactivity and stable elements (Bhat *et al.*[1]). The results obtained for ^{90}Sr, ^{137}Cs, ^{226}Ra and stable elements like Ca, K, P, Sr, Mn and Zn are summarized in this paper.

Table 2 gives the values of particulate fallout activity in air at the site, ground deposited activity and rainfall between April 1965–March 1966. The air activity reported is the sum of weekly continuous air samples and fallout contamination on a roof top (16 m above ground), collected in polythene lined trays for dry deposition and plastic buckets during precipitation. The air activity was observed to be a maximum during pre-monsoon periods of April, May and early June and during these months the dust load in the atmosphere was also observed to be high. Air activity was a minimum during monsoon periods of June, July and August and ground deposition was maximum during these months.

The results of radionuclides and trace element determinations in soil, grass, water and foods are given in Tables 3–10.

Table 1. *Population and Land Under Cultivation within* 8 *km zone*

Zone from site km	Area in 170° arc (land) km²	Farming area km²	Total population (1961 census)
0–1.6	3.8	—	500
1.6–4.8	30.7	9.4	10,257
4.8–8.0	61.5	24.4	17,020

Table 2. Fallout Activity in Air and Ground Deposition (April 1965–March 1966)

Months	Air activity		Ground deposition		Rainfall mm
	^{90}Sr $\times 10^{-3}$ pCi/m^3	^{137}Cs $\times 10^{-3}$ pCi/m^3	^{90}Sr $\times 10^{-2}$ mCi/km^2	^{137}Cs $\times 10^{-2}$ mCi/km^2	
April 1965	36.0	74.0	5.7	8.5	—
May 1965	45.0	65.0	6.1	7.0	—
June 1965	21.2	26.4	73.0	85.0	475.7
July 1965	2.5	11.3	96.0	108.0	871.4
August 1965	3.7	4.2	29.0	31.0	239.8
Sept. 1965	4.5	6.4	16.7	25.0	1.8
Oct. 1965	3.8	5.2	4.1	7.1	—
Nov. 1965	3.6	7.3	No sample		—
Dec. 1965	2.6	4.9	1.7	2.5	—
Jan. 1966	6.3	9.3	0.8	1.2	—
Feb. 1966	11.6	15.5	0.9	1.4	—
March 1966	10.4	21.6	0.7	1.0	—

Table 3. Radioactivity and Stable Elements in Surface Soils

S. No.	Location	g/kg		pCi/kg		
		Ca	K	^{90}Sr	^{137}Cs	Ra (α)
1	Ghivali	2.06	0.64	45.0	135.0	1.8×10^3
2	Akkarpatti	11.70	8.00	35.0	47.0	2.94×10^3
3	Bavada	7.48	2.50	91.0	146.0	0.52×10^3
4	Kamara	10.10	1.36	84.1	126.0	0.37×10^3
5	Wangaon	—	6.90	138.0	224.0	0.83×10^3
6	Chinchani	9.58	2.19	24.0	54.0	1.8×10^3

Table 4. Fallout Radioactivity in Grass

S. No.	Location	Description (Local names)	nCi/kg of dry (110°C) grass	
			^{90}Sr	^{137}Cs
1	Kurgaon	Root and mat grass	0.88	1.81
2	Boisar	Root and mat	0.98	0.92
3	Badaphokran	Root and mat	0.45	1.09
4	Betegaon	Para grass	0.14	0.38
5	Palghar	Para grass	0.03	0.36
6	Kamara	Ber grass	0.11	0.64
7	Morekuran	Grass from cattle grazing land	0.23	1.09
8	Kamara	Kolum paddy grass	1.07	2.35
9	Vadhvan	Kudruk paddy grass	0.72	1.33
10	Kolvali	Dangi paddy grass	0.27	0.75
11	Umroli	Jirbhotty paddy grass	0.20	0.32
12	Murbe	Patni paddy grass	0.95	1.86
13	Akkarpatti	Berseem grass	0.14	1.47
14	Wangaon	Moosa grass	0.03	0.53
15	Betegaon	Gajraj grass	0.14	0.53

Table 5. Stable Elements and Radioactivity in Freshwater Samples

Location	Description	ppm					^{90}Sr pCi/l.	^{137}Cs pCi/l.	^{226}Ra $\times 10^{-6}$ pCi/ml
		Ca	K	Sr	Mn	Zn			
Sakhare-pada	Drinking water from the pond	58.0	0.005	—	0.013	0.08	**	**	6.30
Parnali	Drinking water from well	29.5	0.005	0.52	0.004	0.08	**	**	*
Tarapur	Well water	106.7	0.005	—	0.006	0.16	**	**	11.70
Borsheti	Surya river water	27.2	0.005	0.22	0.005	0.15	**	**	7.50
Pasthal	Banganga river water	25.0	0.005	—	0.003	0.02	**	**	0.20

* Below detection limit for 2 litre sample.
** Below detection limit for 10 litre sample.

Table 6. Stable Elements and Radioactivity in Fruits

Fruits	g/kg (wet wt.)		mg/kg (wet wt.)			pCi/kg (wet wt.)		
	Ca	K	Sr	Mn	Zn	^{90}Sr	^{137}Cs	^{226}Ra
Chikkoo (*Achras sapota*)	1.15	2.36	5.25	1.58	1.10	4.24	12.40	—
Banana (*Musa paradisiaca*)	0.13	3.60	4.10	1.13	0.82	Nil	10.80	—
Papaya (*Carica papaya*)	0.32	0.80	1.08	0.19	0.31	1.04	5.04	1.35
Jamboo (*Cugenia jambos*)	0.28	0.84	1.02	0.53	0.29	1.89	8.44	0.48
Peru (guava) (*Psidium guyava*)	0.19	2.16	1.60	1.68	1.12	3.54	22.50	2.06
Mangoes (*Mangifera indica*)	—	—	—	—	—	8.80	24.18	1.05
Palmtree fruit (*Borassus fabellifer*)	0.23	0.78	0.51	0.92	0.65	—	10.30	—

Table 7. Stable Elements and Fallout Activity in Milk

S. No.	Location	g/litre		mg/litre			pCi/litre	
		Ca	K	Sr	Mn	Zn	^{90}Sr	^{137}Cs
1	Kurgaon	1.41	0.88	1.55	0.14	2.88	11.45	21.0
2	Kamara	1.16	0.98	1.16	0.14	2.15	8.38	22.2
3	Makunsar	1.63	0.96	0.83	0.15	—	12.50	25.9
4	Gholvad	1.45	1.13	—	—	—	4.00	15.0
5	Badaphokran	1.41	1.12	—	—	—	10.80	25.9
6	Boisar	1.29	1.50	—	—	—	13.90	32.4

Table 8. Stable Elements and Radioactivity in Typical Vegetables and Condiments

S. No.	Vegetable	g/kg (wet wt.)		mg/kg (wet wt.)			pCi/kg (wet wt.)		
		Ca	K	Sr	Mn	Zn	^{90}Sr	^{137}Cs	Ra (α)
1	Radish root	0.37	2.96	1.90	1.03	2.20	10.90	6.65	3.30
2	Radish leaves	2.80	1.30	14.00	4.75	1.04	6.30	18.80	7.38
3	Brinjals	0.27	0.91	0.70	1.25	1.35	4.37	6.84	1.78
4	Spinach	0.47	10.00	—	—	—	5.24	2.90	12.90
5	Tomato	—	2.14	—	—	—	—	13.50	—
6	Okra (*Bendhi*)	0.59	0.89	—	—	—	15.40	19.70	3.34
7	Gowar (*Cyanopsis psoraliodes*)	1.30	2.40	—	3.80	1.90	19.10	60.40	11.70
8	Onion (bulb)	0.51	1.68	4.05	2.00	1.35	11.90	6.00	2.26
9	Onion (leaves)	1.06	2.12	5.40	3.20	1.30	3.10	5.30	2.30
10	Tondli (*Coccinia indica*)	0.28	1.25	—	—	—	1.40	9.36	1.98
11	Chillies (*Capsicum*)	0.14	0.90	—	—	—	12.40	45.70	—
12	Cabbage	0.50	1.60	—	—	—	2.36	8.50	—
13	Pumpkin (*Cucuribita*)	0.08	0.25	1.25	0.15	0.22	4.25	3.76	0.26
14	Coconut kernel	0.18	—	2.84	3.46	2.80	**	0.90	0.21
15	Coconut water	0.28	0.24	15.10	1.17	1.24	**	0.76	0.07
16	Tamarind (*Tamarindus indica*)	0.32	1.28	3.96	1.24	2.14	10.70	23.30	0.62
17	Betel leaves (*Piper betel*)	0.58	5.25	15.30	14.60	1.85	87.00	191.00	21.80
18	Plantain leaves	1.94	7.50	—	—	—	83.00	99.00	13.4

** Below detection limit.

Table 9. Stable Elements and Fallout Activity in Soft Tissues of Sea Food

S. No.	Sea food	g/kg			mg/kg			pCi/kg	
		Ca	K	P	Sr	Mn	Zn	^{90}Sr	^{137}Cs
1	Pomfret	1.90	2.64	0.79	1.62	1.85	3.20	1.4	2.50
2	Bombay duck (*Harpodon nehereus*)	1.70	1.60	0.64	8.90	0.53	1.53	*	4.95
3	Prawns	1.34	1.25	1.12	10.90	0.67	3.40	*	13.40
4	Shrimps	0.57	1.04	0.83	—	1.70	3.04	*	9.25
5	Oysters	0.79	1.34	0.56	3.20	4.35	5.30	4.1	8.90

* Below detection limit.

Table 10. Stable Elements and Radioactivity in Local Rice Samples

Local varieties of rice	g/kg		mg/kg			pCi/kg		
	Ca	K	Sr	Mn	Zn	^{90}Sr	^{137}Cs	^{226}Ra
Dangi	0.12	2.01	2.85	11.86	11.60	11.10	49.00	1.50
Jirbhotty	0.13	2.36	2.12	14.75	13.50	12.30	29.78	2.86
Kolum	0.22	1.61	—	—	—	4.44	29.10	—
Kudruk	0.10	2.34	—	—	—	10.10	31.20	—
Patni	0.21	2.53	2.23	15.10	11.05	10.24	10.10	—

DIETARY SURVEY

Dietary surveys have been carried out in India by the Indian Council of Medical Research and other national bodies periodically and statistical data have been compiled to prepare the *Diet Atlas of India.*[8] Such national data are of somewhat limited applicability when one considers the special conditions of a small region in a large country. For example, in a preliminary demographic survey, it was observed that the *per capita* fish consumption by the fishing community in the region of interest is about an order of magnitude higher than the *per capita* consumption in the state. Thus critical food evaluation required detailed study in the small area of the reactor environment, where sections of people falling in the category of special groups have to be defined on the basis of variations in dietary composition and daily intakes of minerals.

Table 9 gives the distribution of adults, children and occupation of the 100 families surveyed.

The first dietary survey was undertaken to cover 100 families to obtain a daily *per capita* food consumption. The families were chosen to cover the wide range of professional types: farmer, fisherman, businessmen, teachers, etc. (cf. Table 11).

Data on food habits of the families were compiled by checking weekly purchases and consumption for a month.

Table 12 gives the daily *per capita* intake of food by the three major groups in the population. Each person above 12 years of age was taken as one unit and each child (2–12 years) as a half unit; infants below 2 years were not considered for the computation.

In classifying the dietary information the following preliminary observations are made:

(i) Of the 100 families, only 10 indicated that they did not consume any fish, meat or eggs. Even amongst the declared non-vegetarians, diet principally (80%–90%) consists of rice, pulses and vegetables.

(ii) The cereals in the diet consist besides rice of small quantities of wheat, millets and jowar.

DISCUSSIONS ON INTAKE OF ELEMENTS AND RADIONUCLIDES

Daily intakes of significant elements and radioactivity were calculated from the diet components for two major groups of the local population within 2.4 km from the sea shore. Tables 14 and 15 give the daily intake data for farmers and fishermen. ^{226}Ra activity in the tables was calculated from ^{226}Ra activity reported by Chhabra[4] for the food stuffs obtained in Bombay.

Elemental intake from meals (2 meals a day) served in hotels (cf. Table 13) in the area agree reasonably well (except for K) with the intakes computed for farmers and fishermen from individual diet components. This agreement also demonstrates the consistency of elemental intakes by different groups of people in the environment.

Ca, ^{90}Sr AND Sr

Ca intake and pCi ^{90}Sr/g Ca ratios in New

Table 11. *Occupational Distribution of Families in the Diet Survey*

Occupation	Distance from sea shore km	No. of families surveyed	Members in the family		
			Adults and children > 12 yr	Children (12–2 yr)	Infants (< 2 yr)
Farming	(a) 0–2.4	25	171	61	15
	(b) > 2.4	27	207	71	11
Fishing	(a) 0–2.4	11	62	24	9
	(b) > 2.4	—	—	—	—
Business	(a) 0–2.4	4	12	9	1
	(b) > 2.4	7	50	12	7
Teaching and clerical trades	(a) 0–2.4	7	41	9	4
	(b) > 2.4	3	17	8	2
Miscellaneous (carpenters, mechanics, diemakers, electricians)	(a) 0–2.4	10	63	23	3
	(b) > 2.4	6	21	13	3
Total		100	644	230	55

Table 12. *Per Capita Dietary Data of Major Population Groups around TAPP*
(*Results of survey of* 100 *families*)

Dietary item	Farmers near the sea coast*	Farmers in the interior†	Fishermen	Average for Tarapur	Average for Maharashtra
	(Consumption per day in grams)				
Rice	575.0	465.0	490.0 }		
Wheat	49.5	29.4	81.3 }	552.7	444.0‡
Pulses	50.6	46.3	22.1	133.0	55.0
Vegetables	129.0	103.0	66.0	54.6	105.0
Fruits	10.0	10.0	5.0	10.2	18.0
Milk	97.0	110.0	38.0	115.0	113.0
Fish	65.0	41.5	170.0	74.3	14.0
Mutton	17.8	22.2	10.0	16.3 }	
Chicken	4.7	6.2	2.4	3.9 }	14.0
Eggs (No.)	(0.14)	(0.16)	(0.04)	(0.13) }	
Salt	18.4	11.2	19.6	15.8	15.0
Sugar	29.2	26.2	30.6	22.6 }	38.0
Jaggery	27.6	19.7	24.0	20.8 }	
Fats	31.4	30.0	32.4	25.9	31.0
Chillies	7.1	6.7	8.1	7.0	NA
Tamarind	13.3	7.8	14.9	10.5	NA
Total	1125.6	935.2	1014.4	1072.4	
Water (litres)	(3–5)	(3–5)	(3–5)	(3–5)	(3–5)

* Within 2.4 km from coast.
† Beyond 2.4 km from coast.
‡ Includes millets, wheat and other cereals (rice 108 g) (*Diet Atlas of India*, 1964).

Table 13. Stable Elements and Radioactivity in Meals served in Hotels

Location	Description	Ca g/meal	K g/meal	Sr mg/meal	Mn mg/meal	Zn mg/meal	P g/meal	^{90}Sr pCi/meal	^{137}Cs pCi/meal	Ra α pCi/meal
Tarapur	Rice plate	0.26	0.65	1.69	2.89	2.62	0.368	4.56	20.32	1.26
Chinchani	Vegetarian meal	0.28	0.29	2.60	2.20	1.50	—	5.80	7.80	—
Palghar	Vegetarian meal	0.27	0.29	0.81	3.50	—	—	7.10	20.30	—
Palghar	Vegetarian meal	0.14	0.52	1.40	1.90	1.81	0.217	5.58	11.46	1.18
Palghar	Non-vegetarian meal	0.47	0.50	2.95	4.29	4.76	0.216	—	—	—
Dahanu	Vegetarian meal	0.23	1.79	3.04	7.54	5.24	0.639	—	—	—

Table 14. *Daily Intake of Some Significant Elements and Radionuclides by Farmers*

Food material			Farmers near the coast						
	Ca	K	mg			µg	pCi		
	g	g	Sr	Mn	Zn	I	^{90}Sr	^{137}Cs	^{226}Ra
Rice	0.082	1.213	1.380	7.820	6.850	29.40	6.00	22.20	0.360
Wheat	0.028	0.197	0.443	1.470	0.560		1.12	1.53	0.046
Pulses	0.023	0.525	0.121	0.645	1.111	1.50	1.38	5.05	0.036
Vegetables	0.080	0.214	0.316	0.238	0.156	3.74	3.88	5.65	0.036
Milk	0.166	0.111	0.112	0.013	0.232	4.55	1.18	2.28	0.015
Fish	0.068	0.106	0.575	0.093	0.156	54.00	—	0.41	
Mutton	0.032	0.034	0.070	0.012	0.140	—	0.53	1.02	0.050
Chicken	0.006	0.008	0.019	0.007	—	1.12	0.06	0.12	—
Salt	0.036	0.039	0.446	—	—	1.55	1.12	0.26	—
Jaggery	0.022	0.264	—	0.125	0.305	—	—	—	—
Tamarind	0.004	0.024	0.028	0.017	0.029	—	0.32	0.32	—
Total	0.547	2.735	3.510	10.440	10.539	95.86	15.41	38.84	0.543

Table 15. *Daily Intake of Some Significant Elements and Radionuclides by Fishermen*

Food material	Fishermen								
	Ca	K	mg			µg	pCi		
	g	g	Sr	Mn	Zn	I	^{90}Sr	^{137}Cs	^{226}Ra
Rice	0.069	1.028	1.170	6.450	5.650		5.10	19.50	0.308
Wheat	0.046	0.324	0.727	2.420	0.920	27.00	1.84	2.52	0.075
Pulses	0.011	0.228	0.054	0.288	0.490	0.66	0.61	2.29	0.015
Vegetables	0.041	0.110	0.164	0.126	0.067	1.92	1.98	2.38	0.015
Milk	0.066	0.044	0.044	0.005	0.071	1.80	0.46	1.12	0.006
Fish	0.178	0.278	1.515	0.251	0.428	141.00	—	1.05	—
Mutton	0.018	0.019	0.039	0.006	0.065	0.62	0.29	0.57	0.107
Chicken	0.003	0.004	0.009	0.003	—	—	0.03	0.06	—
Salt	0.025	0.034	0.475	—	—	1.65	0.11	0.22	—
Jaggery	0.18	0.230	—	0.109	0.266	—	—	—	—
Tamarind	0.004	0.026	0.029	0.018	0.032	—	0.16	0.35	—
Total	0.479	2.325	4.226	9.676	7.987	174.65	10.58	30.06	0.528

Table 16. *Ca Intake from and* $^{90}Sr/Ca$ *Ratios in Different Food Groups of New York* (1965) *and Tarapur Diet*

Food groups	New York		Tarapur			
			Farmer		Fisherman	
	Ca % of total	$^{90}Sr/Ca$ pCi/g	Ca % of total	$^{90}Sr/Ca$ pCi/g	Ca % of total	$^{90}Sr/Ca$ pCi/g
Cereals and pulses	15.7	52.5	24.3	64.0	26.3	60.0
Vegetables	8.1	59.0	14.6	48.5	8.6	48.5
Milk and milk-products	61.3	19.3	30.3	7.1	13.8	7.1
Fish and meat	10.6	11.1	18.3	5.6	41.6	1.6
Total diet	—	28.3	—	28.0	—	22.0

York[5] and Tarapur diets are compared in Table 16. The *per capita* daily intakes of Ca and Sr in Tarapur are ~ 500 mg and ~ 4 mg respectively and the corresponding intakes in the Western diet[6] are ~ 1000 mg and ~ 1.3 mg.

In New York diet[5] ~ 50% of ^{90}Sr intake is accounted for by milk and milk products, and 30% is accounted for by cereals and pulses. In Tarapur diet, milk and milk products account for less than 10% of the intake, cereals and pulses account for ~ 70% of intake by fishermen and ~ 50% by farmer. The ratios of $^{90}Sr/Ca$ for the total intake in the two areas are very similar, viz. New York diet 28.3, Tarapur farmer's diet 28, and Tarapur fisherman's diet 22. Average intake of ^{90}Sr from New York diet is about twice that obtained in Tarapur diet. Major contribution of ^{90}Sr in the Tarapur diet comes from rice (~ 50% of total) and vegetables rank next in significance (~ 20%).

About 80% of total intake of stable Sr comes from cereals and pulses, and fish in farmer's and fisherman's diets. In the cereals and pulses group, rice is the major contributor to Sr intake (~ 70%). Intake of ^{90}Sr is highest through cereals because of higher ^{90}Sr activity and larger consumption of cereals. Fallout activity in rice is relatively high because of this being a rain crop (cf. Grummitt and Robertson[7]).

^{226}Ra

For the intake of ^{226}Ra, cereals and pulses account for 81% in farmers' diet and 75% in fisherman's diet, rice alone contributes 80% of the intake by farmers and 75% by fishermen from this food group.

^{137}Cs AND K

Approximately 70% of the total intake of ^{137}Cs and also of K is contributed by cereals and pulses (Table 17) of which rice contributed ~ 80% of the intake from this group. The K intake of 2.3–2.7 g/day in Tarapur diet compares with 2.3–3.4 g/day in U.S. diet.[5] In U.S. ~ 70% of ^{137}Cs intake is obtained from milk, fish and meat in contrast with Tarapur, where these groups contribute only about 10% to the daily intake of ^{137}Cs.

Total ^{137}Cs intake from New York diet[5] is three times that from Tarapur diet. ^{137}Cs intake in Tarapur would be approximately proportional to ^{137}Cs activity in cereals and pulses and in view of the fact that the bulk of the food is comprised of this group, the ^{137}Cs body burden in the population is largely determined by ^{137}Cs content in this food group; vegetables are next in significance.

An examination of four persons from the area showed that on an average they have a body burden of 1.9 nCi ^{137}Cs for an average body

Table 17. Contribution to Daily Intake from Major Food Group in Diet of Farmer and Fisherman

% of daily intake of \ Food groups	Cereals and pulses		Vegetable		Milk		Fish	
	Farmer	Fisherman	Farmer	Fisherman	Farmer	Fisherman	Farmer	Fisherman
Foodstuff	60.0	58.5	11.5	6.5	8.6	3.80	7.8	18.0
Ca	24.3	26.3	14.6	8.6	30.3	13.80	18.3	41.6
K	71.0	67.8	7.8	4.7	4.1	1.90	5.4	12.9
Sr	55.4	54.5	9.0	3.3	3.2	0.90	18.9	31.2
Mn	95.0	95.0	2.3	1.3	0.1	0.05	1.1	2.7
Zn	80.0	89.0	1.5	0.8	2.2	0.88	1.2	6.2
I	30.6	15.7	3.9	2.3	4.7	1.06	58.0	81.5
^{90}Sr	55.0	72.0	25.0	18.6	7.7	4.40	3.8	3.2
^{137}Cs	76.0	74.0	12.0	7.9	6.0	3.70	4.2	5.6
^{226}Ra	81.2	75.5	6.7	2.8	2.8	1.10	9.3	20.5

weight of 55 kg and 84 g body potassium.[1] These studies are being extended and will be useful in identifying build-up of body burden from sources other than fallout in the region.

Mn AND Zn

Trace elements like Mn and Zn are present in high concentrations in cereals (11–30 mg/kg) and again rice alone contributes about 70% of the total intake. Betel leaves (*Piper betel*) and radish leaves (*Raphanus sativus*) show high concentration of Mn. Gowar (*Cyanopsis psoraliodes*), onion and coconut kernel show somewhat high concentrations of Mn and Zn (cf. Table 8). There is significant concentration of Mn and Zn in fruits (cf. Table 7), but the daily intake of fruits is very small.

Oysters (cf. Table 9) are likely to be the significant carriers for radioactive Mn and Zn from station effluents as they are found near the shore and show high concentrations of the stable isotopes. The total intake of oyster meat in the diet, however, is small and most of the oysters harvested are exported to cities. Oysters having the highest cumulative concentration of Mn and Zn in soft tissue, among sea foods examined, would serve as a useful single indicator for build-up of induced ^{54}Mn and ^{65}Zn radioactivity in the shore waters of Tarapur.

PHOSPHORUS

Fishermen take on an average about 170 g of fish a day, i.e. 18% of the total diet. Survey data indicate that there are families of fishermen consuming as much as 250–300 g of fish a day. Among the poorer section of fishermen the fish intake is often 25–30% by weight of a day's total food intake.

High accumulation factors for ^{32}P coupled with high percentage intake of fish by a fisherman indicate that ^{32}P can contribute a high exposure, particularly when the diet abounds in sea foods like shrimps, fingerlings and intertidal organisms. If the bulk of P in the diet comes from cereals and vegetables which are rich in phytin phosphorus,[8, 9] then isotopic dilution of ^{32}P from fish will be reduced. It has been observed by other workers that Indian meals comparable to Tarapur diet, have a phytin P content as high as 42%[10] of the total P. It would therefore be necessary in assessing the significance of this element to characterise the source of supply and not judge only by the concentrations present in the dietary intakes.

IODINE

The environmental monitoring programme includes sampling of sea weeds and sheep thyroids for measurement of radioiodine contamination.

Monitoring of bovine thyroid under field conditions has shown that it is a sensitive method [13] for detection of environmental ^{131}I. Sheep thyroids under identical conditions of exposure have been reported to accumulate five times [14] more ^{131}I than bovine thyroids. [11]

For exposures resulting from the ingestion of radioiodine, milk has often been regarded as the most important source. [11] The British Medical Research Council, in setting up the acceptable level for ^{131}I contamination has considered exposure of a child's thyroid as critical. In rural Indian conditions [12] infants are mostly breast fed and are weaned only on medical grounds. Sometimes animal milk of some kind is given to supplement breast milk—the quantity rarely exceeding 200 ml/day. The supplementary foods for the infants are usually prepared from cereals, particularly rice.

Because of low intake, milk is not likely to be the critical food around Tarapur though there may be small groups of individual families (rich farmers), who may receive a higher exposure through consumption of milk.

The iodine content in food components given in Tables 14 and 15 has been calculated from reported iodine values for dietary components. [15, 16] The highest intake of iodine in Tarapur diet is from marine fish. Of the two population groups examined, iodine intake by fishermen is twice that by farmers. Approx. 80% of total iodine intake by fisherman and $\sim$ 60% by farmer is obtained from fish. Therefore restriction on milk consumption in emergency circumstances does not much affect the net intake of iodine. Under the circumstances, it is possible that the population would receive most of the ^{131}I exposure from fish consumption and fishermen would receive the highest.

Radioiodine intake through fish has been reported to be unimportant because of the short half-life of ^{131}I and delays involved in the uptake chains. [17] For most short lived activities, this point requires to be investigated in detail and particularly with reference to amounts of release and types of fingerlings and juveniles caught in the shore waters.

CRITICAL GROUP IN THE TARAPUR ENVIRONMENT

It is possible to predict from the information presented, the population group which will receive high radiation exposures through living in the vicinity of the power station and by eating food produced near the site.

Fishermen living in the near vicinity at Ghivali and Pophran ply their fishing gear in the coastal waters that would be receiving reactor effluents, and consume fish caught in these waters. The average intake of fish is 170 g per day by fishermen while that for farmers living in the interior it is only 40 g (cf. Table 12). Contamination of the land environment is not expected to be significant in normal operation and the exposure of farmers and fishermen from this source are expected to be very close to one another and as such the fish growing close to the shore and caught by fishermen may be the critical component in the diet. Oysters and shrimps grown in the area are likely to accumulate activation products and could be monitored as indicator organisms to follow any build-up of activation products from reactor effluents. Bombay duck (*Harpodon nehereus*) and shrimps are abundant and cheap and are consumed by local fishermen in large quantities. *Therefore the fishing population in the area could probably be the Critical Group in the environment.*

SOME SAMPLES FOR TERRESTRIAL MONITORING

High concentrations of Mn, Zn and P and relatively large ratios of $^{90}Sr/Ca$, $^{137}Cs/K$ in rice show that rice is a useful environmental sample to indicate terrestrial contamination. As a seasonal crop, its usefulness for round the year monitoring is limited. However, it contributes significantly to the body intake of trace elements and fallout contamination. Table 8 has shown that some vegetables (leafy ones because of high foliar absorption) are more selective than others to accumulate fallout contamination. None of them however, is likely to be a critical food because of small intake.

An interesting sample listed in Table 8 is the betel leaves, reputedly known as the "Indian Pan". Samples of betel leaves have consistently shown high concentrations of trace elements and radioactivity. Of the leafy vegetation examined, the betel and plantain leaves promise to be good indicators for terrestrial contamination.

COMMENTS IN CONCLUSION

In this study contributions from drinking water are not discussed, as contamination of main drinking water supply is most unlikely.

The search for the critical food through dietary surveys has shown that ^{90}Sr and ^{137}Cs contamination in the Tarapur diet is obtained from cereals and pulses (predominantly from rice) and the activation products are likely to be obtained through sea food harvested from the shore waters.

The ratios referred to in Table 16 for $^{90}Sr/Ca$ for Tarapur and New York diet (28.3 and 28.0) should be treated with caution since the bulk of Ca in the New York diet comes from milk and milk products, fish and meat and therefore largely available [8] while only 40% comes from these sources in the Tarapur farmer's diet. Cereals and vegetables in the Tarapur diet contain large amounts of phytin phosphorus which reduces considerably [8, 9] the availability of Ca.

This survey has brought out the typical features of the rural Indian diet in contrast to Western types of diet. Though it was anticipated in the beginning of the survey that possibly there would be a wide divergence in the dietary intakes of the different population groups in the area, because of different socio-economic conditions, the survey indicated that the general types of diets are very similar excepting for a small variation in the most easily available food stuffs for the group-like cereals and vegetables for the farmers and fish for the fishermen. These small variations and professional activities ultimately feature in the final selection of the possible critical group in the area.

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REFERENCES

1. I. S. Bhat, A. A. Khan and P. R. Kamath. Progress Report. AEET-242 (1965). Atomic Energy Establishment, Trombay, India.
2. K. Venkataraman, S. Somasundaram and S. D. Soman. An evaluation of radiation protection standards for Indian conditions. *Health Physics* **9,** 647–652 (1963).
3. *Diet Atlas of India.* Indian Council of Medical Research. Special Report Series No. 48. India, 1964.
4. A. S. Chhabra. Radium-226 in food in man in Bombay and Kerala State. *Br. J. Radiol.* **39,** 141–146 (1966).
5. *Radiological Health Data* **6,** No. 9, 503–505 (1965). U.S. Public Health Service.
6. C. L. Comar and F. Bronner. *Mineral Metabolism* **II,** Part A, 364–365 (1962).
7. W. E. Grummitt and R. Robertson. Strontium-90 and cesium-137 in Canadian wheat (1957–9). AECL Publication CRER-1000 (1960).
8. C. L. Comar and F. Bronner. *Mineral Metabolism* **II,** Part A, 251 (1962).
9. J. T. Irving. *Calcium Metabolism,* pp. 21–28. Methuen, London, 1957.
10. K. Mitra. The results of diet surveys in India (1935–48), ICMR Special Report No. 25 (1953).
11. *Hazards to Man of Nuclear and Allied Radiations—a Second Report to the Medical Research Council.* H.M.S.O. London, 1960.
12. Annual Report (1955–1956). Field Investigations: Protein malnutrition surveys in S. India. ICMR, 1956.
13. H. J. Baratta *et al* I-131 in bovine thyroids. *Radiological Health Data,* p. 575. U.S.P.H.S **6,** No. 10 (1965).
14. A. H. Wolff. Fallout and uptake of I-131. *Fallout from Nuclear Weapons Tests. Congressional Hearings.* U.S. Govt. Publ. Vol. 2, p. 1311. Washington, 1959.
15. J. McClendon. *Iodine and Incidence of Goiter.* University of Minesota Press, Minneapolis, 1939.
16. D. D. Sabu. *Determination of Iodine in Sea Water, Fresh Water and Marine Salt.* Indian Science Congress, 1963.
17. M. Eisenbud and M. E. Wrenn. Biological disposition of radioiodine—a review. *Health Physics* **9,** 1133 (1963.)

DISCUSSION

M. Delpla (*France*):

Je ferai deux remarques: la première de caractère général: la seconde, relative à un point très particulier.

1. M. Coulon étudie le contrôle de la pollution radio-active de la chaîne alimentaire en hygiéniste; il se place sur le plan de la santé publique et embrasse un vaste territoire, le pays tout entier. Il est aussi possible de considérer, à l'opposé, ce qui se passe à proximité d'une installation nucléaire, et utiliser la radio-analyse des produits de la chaîne alimentaire à la mesure de la contamination du milieu par cette installation. C'est suivant ces principes que nous surveillons nos sites nucléaires. Nous nous proposions de vous faire part de notre méthode—originale—et de nos résultats; nous ne pouvons que regretter qu'aucun des rapports que nous proposions sur ce sujet n'ait pu être retenu. Veuillez m'excuser, Monsieur le Président, d'avoir été aussi long.

2. M. Coulon cite à plusieurs reprises le ministère de l'agriculture. Bien d'autres ministères s'intéressent aussi, en France, à la pollution de la chaîne alimentaire. Il me paraît difficile, en cette matière, si l'on cite un ministère, de ne pas mentionner les efforts accomplis en cela par celui des affaires sociales (santé publique).

E. Di Ferrante (*Euratom*):

Les pH 5,9; 7,2; 8,25; 8,55 du sol mentionnés dans le mémoire sont-ils des valeurs naturelles, c'est-à-dire, trouvées dans les différents sols étudiés, ou bien les auteurs ont-ils corrigé le pH d'un même type de sol?

R. Kirchmann:

Ces différentes valeurs du pH ont été observées lors des expériences en serre, après apport d'hydroxyde de calcium à un même type de sol. En conditions naturelles la valeur $(pH)_{eau}$ du sol étudié est environ de 5,9.

T. L. Cullen (*Brazil*):

Have the authors considered any other soil parameters in their studies? For example there are 35 or 40 parameters used by the agronomer: particle size, pH in water, pH in KCl, oxides of metals, exchangeable cations. There are trace elements like Barium whose presence or absence is important.

It is proper in a laboratory to control all but one or two variables and let them vary. But in nature there are so many variables that influence uptake of the natural radioisotopes.

R. Kirchmann:

En ce qui concerne le facteur sol, nos expériences ont été limitées à la comparaison des niveaux de contamination, par Ra^{226}, d'une graminée cultivée sur quelques types de sols belges que nous connaissons bien grâce à nos travaux sur le comportement de Sr^{90} dans ces sols. Nous n'avons pas considéré séparément chacun des nombreux paramètres pouvant éventuellement influencer le taux de transfert du Ra^{226} du sol au végétal. Nous avons d'abord recherché si le type de sol jouait un rôle et ensuite, en examinant les caractéristiques différenciant les sols étudiés, nous avons constaté que la teneur en matériel sorptif donnait la meilleure corrélation avec les teneurs en Ra^{226} observées dans le végétal. Pour l'étude de l'interaction ionique, nous estimons que l'agriculture se prête le mieux à des tels travaux.

G. Joyet (*Switzerland*):

Je désire moi-même faire remarquer que ces auteurs ont trouvé une corrélation entre l'activité des herbages et l'activité du lait, corrélation qui paraît être assez sûre et que d'autres auteurs n'ont pas trouvée.

E. Van der Stricht:

Les conclusions diamétralement opposées des rapports présentés par M. Popović et par M. de Bortoli et al. peuvent à mon avis s'expliquer par l'étendue géographique très différente des zones surveillées.

M. Delpla (*France*):

Comme vous même, M. le Président, j'avais remarqué l'opposition des conclusions des deux rapports de MM. Popović et de Bortoli. Je signalerai que, de notre côté, nous ne trouvons pas de corrélation entre les activités, dans l'herbe et dans le lait, mesurées sur les éléments alcalino-terreux. En fait, l'établissement d'une telle corrélation n'est pas possible en raison de la variabilité des résultats obtenus sur l'herbe, variabilité due, sans doute, aux conditions expérimentales, en particulier, au fauchage successif de pièces juxtaposées délimitées dans une prairie naturelle.

R. B. Holtzman (*U.S.A.*):

I would like to ask these authors of the papers on ^{210}Po in tobacco why the ^{210}Po appears to be lower than that in the United States? Could it be due to differences in the curing process? I would also like to ask the Yugoslav authors how they treated their urine samples; that is were they wet-ashed?

D. Panov:

La première question concerne la concentration de polonium dans l'urine. Nous avons attaqué l'urine par HNO_3 et l'acide perchlorique; on a fait ensuite une déposition sur une plaque d'argent et le comptage par alpha.

La deuxième question est sur les résultats qui sont les mêmes à peu près dans le tabac et dans la cigarette: nous n'avons pas trouvé non plus de différences selon les différentes sortes de cigarette.

W. Kolb (*Germany*):

Im Auftrag der deutschen Zigarettenindustrie haben wir ebenfalls Messungen an Tabaken und Rauchkondensaten vorgenommen. Die spezifische ^{210}Po-Aktivität der Rauchkondensate (main stream smoke) lag zwischen 1,22 und 1,45 pCi/g ± 17%. Signifikante Unterschiede zeigten sich bei 12 verschiedenen Rohtabaksorten. Die ^{210}Po-Aktivität lag zwischen 0,30 und 0,71 pCi/g und unterschied sich damit extremal um den Faktor 2.

G. Joyet (*Switzerland*):

Je voudrais faire moi-même une remarque. Dans ce travail on a mesuré des totalités d'activité de césium de l'ordre de 1,9, c'est-à-dire environ 2 nanocuries par individu. J'ai vu les publications présentées par l'auteur à ce sujet et je voudrais signaler qu'en Suisse par exemple nous trouvons des activités pour l'homme et pour le sujet masculin de 20 ans qui sont exactement dix fois plus élevées. La valeur pour la femme est de 19 nanocuries pour le césium-137, et de 9,5 nanocuries pour la femme de 20 ans. Ces valeurs sont valables pour le printemps de cette année. Elles coïncident à peu près avec certaines valeurs américaines qui ont été trouvé à diverses periodes au Brookhaven National Laboratory. Je voulais signaler ces différences car je pense qu'ici il y a avant tout un effet de latitude.