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1966 ENVIRONMENTAL MONITORING RADIATION LEVELS AT BROOKHAVEN NATIONAL LABORATORY

A.P. HULL AND J.T. GILMARTIN

September 1969

BROOKHAVEN NATIONAL LABORATORY
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ABSTRACT

Measurements of "natural background" radiation levels and of increments attributable to Laboratory operations obtained on site and in the vicinity of Brookhaven National Laboratory during 1966 are summarized in this report. These increments include contributions from the gaseous and particulate effluents from the stack serving the Brookhaven Graphite Research Reactor and the High Flux Beam Research Reactor, from multicurie field γ sources, and from the discharge of low-level liquid wastes from the Laboratory's sanitary waste treatment plant into the headwaters of the Peconic River.

The natural background external radiation levels declined to an average of 1.90 mR/wk during 1966. The highest yearly on-site level attributable to Laboratory operations was 8.51 mR/wk (for 168 hr), well within established radiation protection standards for individuals in controlled areas. The highest yearly average radiation level at the perimeter was 2.49 mR/wk, to which the ecology forest source contributed 1.60 mR/wk, the remainder being from ^{41}Ar. The total was 25% of the established yearly standard of 500 mR for individuals in uncontrolled areas.

No airborne radioactivity attributable to Laboratory operations, other than ^{131}I, was detectable at ground level. The yearly average gross β concentration of samples counted after a 54-hr delay (to allow for the decay of natural radioactivity) was 0.15 pCi/m^3, with a 1-day maximum of 2.9 pCi/m^3 on May 18.

Stack effluent dispersion studies utilizing the routine emission of ^{131}I from the Graphite Research Reactor were continued during 1966. The highest yearly average was 0.0042 pCi/m^3, which may be compared with the radiation protection standard of 100 pCi/m^3 in uncontrolled areas. Fallout ^{131}I from foreign weapons tests was apparent in an average concentration of 0.0420 pCi/m^3 between May 14 and 27 and of 0.0200 pCi/m^3 between Oct. 28 and Dec. 2.

The gross β activity in precipitation declined slightly to a monthly average of 7.3 nCi/m^2 and the average concentration to 111 pCi/liter. The largest daily collection, 22.3 nCi/m^2 in a concentration of 3560 pCi/liter, was made on Nov. 6.

Liquid wastes totaling 35.4 mCi were discharged to the headwaters of the Peconic River in an average gross β concentration of 32 pCi/liter. This was 3% of a calculated radiation protection standard which assumed that the ^{90}Sr fraction was 20% and that the other isotopes present were "unknown" β or γ emitters. In addition, 3.5 Ci of tritium was discharged in an average concentration of 3.2 nCi/liter. This was 0.1% of the applicable radiation protection standard. The average gross β concentration of monthly "grab" samples from downstream on the Peconic ranged from 15 to 4 pCi/liter, while those from off-site control locations averaged 7 pCi/liter. The average tritium concentrations for the Peconic River and control locations were all <1 nCi/liter. The highest concentration of individual isotopes in bottom sediment, 10.2 pCi/g of ^{60}Co and 12.0 pCi/g of ^{137}Cs, were found at the Laboratory's perimeter. The highest concentrations in one species of vegetation *(Vallisneria americana)*, 4.2 pCi/g of ^{60}Co and 30 pCi/g of ^{137}Cs, were found on site near the perimeter. Concentrations of ^{60}Co in both sediment and vegetation declined to near-background beyond a point about a mile downstream from the Laboratory's perimeter. The situation for ^{137}Cs was not as defined in vegetation and turtle samples.

The concentrations of ^{131}I in milk were generally less than the minimum level of detection (2 pCi/liter) except for a few weeks after the May and October foreign weapons tests. The applicable radiation protection guide, assuming an intake of 1 liter/day, is 100 pCi/liter.

The Environmental Monitoring Program has established that during 1966 radiation levels attributable to Laboratory operations were maintained well below the established radiation protection standards of the AEC for external exposures and for concentrations of radioactivity in air and water. Radiation levels attributable to fallout were also well below established standards.

1966 ENVIRONMENTAL MONITORING RADIATION LEVELS AT BROOKHAVEN NATIONAL LABORATORY

INTRODUCTION

Brookhaven National Laboratory is situated on Long Island, about 70 miles east of New York City. Its location with regard to surrounding communities is shown in Figure 1. Except for shoreline communities, most of the land area within ten miles is either forested or under cultivation. Environmental monitoring data have been obtained in the vicinity of the Laboratory since 1949. Annual reports[1-4] of this information were instituted in 1962 to make both the fallout data and the results of the investigations of local effects available to interested persons.

The evaluation of radiation levels in the vicinity of the Brookhaven National Laboratory site is performed by the Environmental Monitoring Section of the Health Physics Division. Laboratory operations contribute three principal additions to the local natural background radiation: gaseous and particulate radioactivity contained in the effluent cooling air of the Brookhaven Graphite Research Reactor (BGRR), the High Flux Beam Research Reactor (HFBR), the Medical Research Reactor (MRR), and the off-gas of the Hot Laboratory (discharged from the BGRR–HFBR stack); radiation from two multicurie field γ sources; and low-level radioactivity contained in liquid wastes released to a small stream that forms one of the headwaters of the Peconic River.

Natural background and radiation levels attributable to Laboratory operations during 1966 are summarized in this report. Although substantially reduced from the record 1963 levels, some residual fallout from the atmospheric testing of nuclear weapons during 1961 and 1962 was observed during 1966 in many types of environmental samples. Some fresh fission products were also evident for several months after the Chinese weapons tests in May and October.[5,6] While fallout is measured primarily to separate it from the Laboratory's contribution to the environment, such information about fallout radioactivity levels as has been obtained is also summarized.

Among the data reported are external exposures, air particulate concentrations, rain and settled dust collections, milk and grass concentrations, liquid effluent concentrations, and water, silt, and vegetation concentrations in off-site streams.

EXTERNAL EXPOSURE MONITORING

Environmental radiation levels, including natural background (as influenced by fallout) and the increments attributable to reactor cooling-air effluent and to the multicurie field γ sources, were monitored continuously at six fixed monitoring stations and seasonally at five additional stations. As shown in Figure 2, one of these continuous stations was on site and four were at the perimeter. Off-site station O-6, at 8.7 km and 168° downwind from the BGRR–HFBR stack, is not shown. The seasonal stations were located in a line downwind from the stack for the prevailing southwesterly wind from May to September and for the prevailing northwesterly wind from November to March. Each seasonal line included one continuously operated perimeter station.

Included in each station's equipment was an ion chamber and dynamic capacitor electrometer assembly, described in detail elsewhere.[7] These units are capable of accurately measuring <10 μR/hr and of detecting changes of the order of 1 μR/hr. Although information about the instantaneous dose rates up to about 0.5 mR/hr may be obtained from these units, normally the integrated radiation over 4-hr periods was used to obtain weekly averages, and these in turn were used to compute the monthly data tabulated in this section.

Monthly average gross external radiation levels are set forth in Table 1. For convenience in making comparisons in this and immediately following summaries, the stations have been grouped according to location on site, at the perimeter, and off site.

Since the established radiation protection standard[8] of 500 mR/yr for individuals living in the vicinity of the Laboratory is in addition to natural

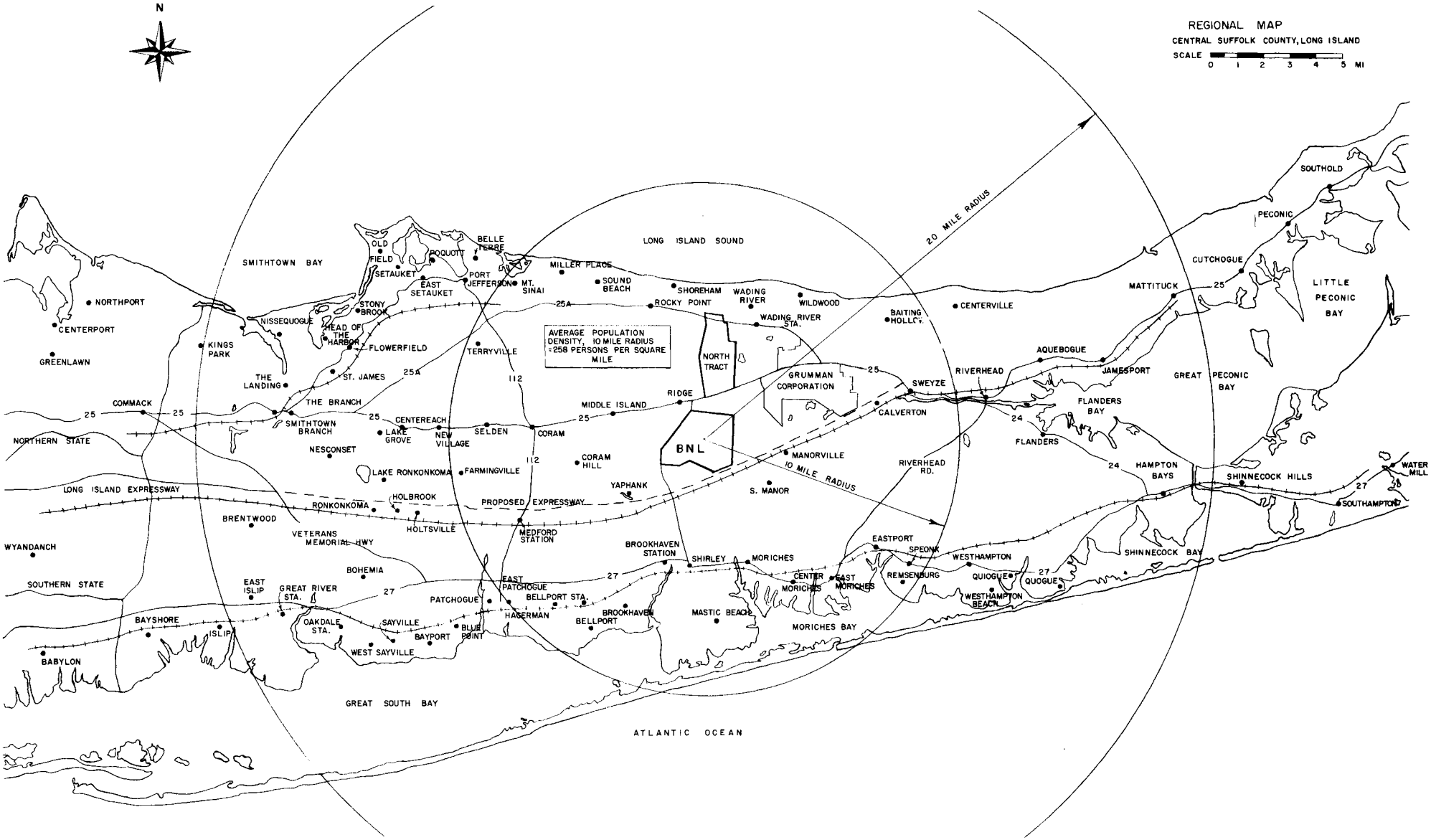

Figure 1. Central Suffolk County, showing the area around Brookhaven National Laboratory.

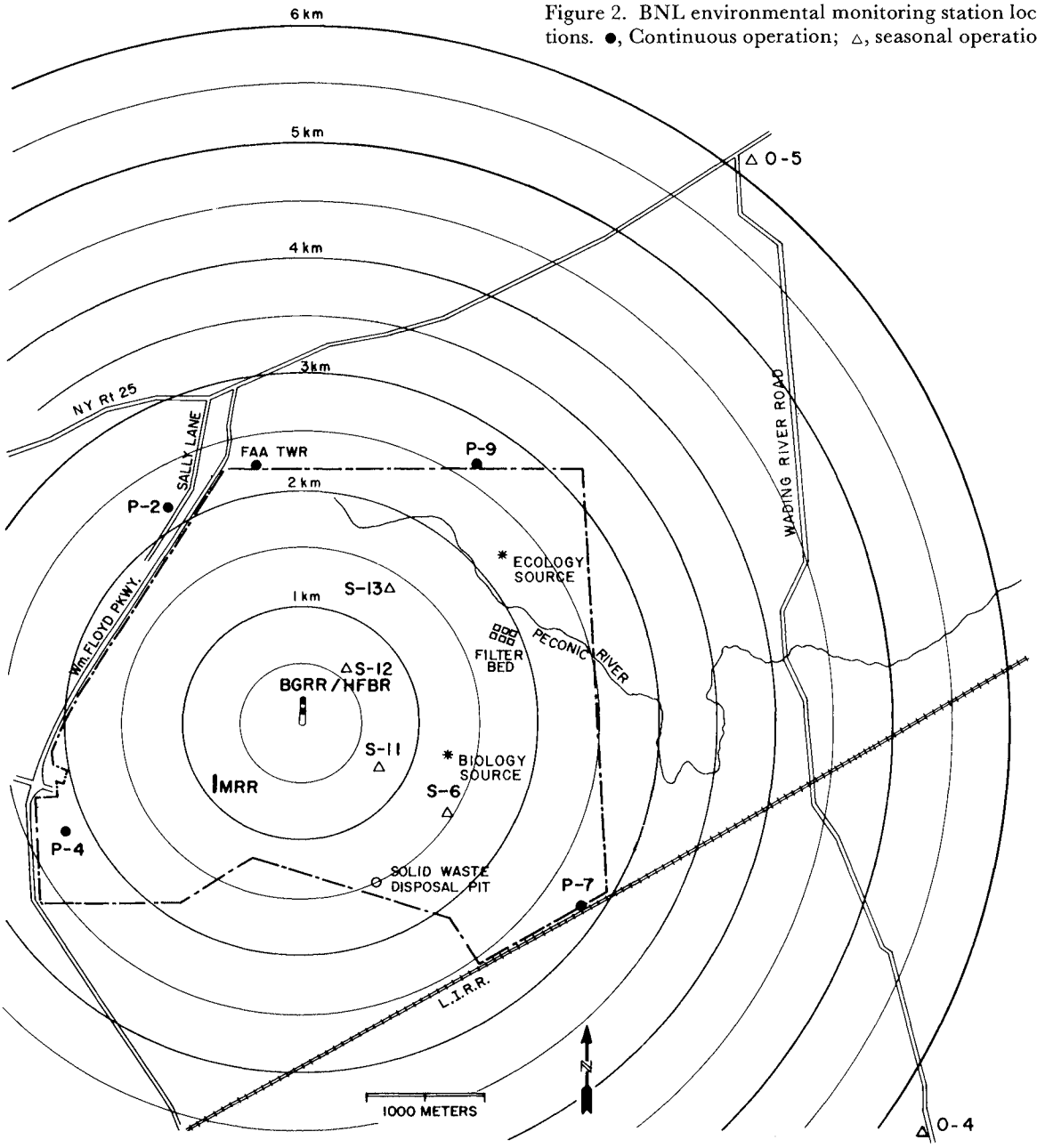

Figure 2. BNL environmental monitoring station locations. ●, Continuous operation; △, seasonal operation.

background, determinations of the latter are routinely made. Natural background levels, as measured by 6-liter atmospheric-pressure ion chambers which reflect some deposition of fallout radioactivity, are reported in Table 2. Yearly natural background levels (including fallout) from the initiation of observations at the Laboratory in 1949 to the present are indicated in Figure 3. The data prior to 1964 have been adjusted to take into account the change in elevation of the ion chambers from 6 in. to 2 ft above the roof of each monitoring station. Background radiation levels declined to the lowest level observed since 1961.

Natural background at a given station was determined from the radiation level prevailing when no obvious Laboratory contributions were detectable at a station. The subjective error in making this determination was minimized by reference to meteorological data (to establish the direction of the reactor plume) and to the log indications of down hours of the field γ sources.

The only measurable increase above natural background attributable to Laboratory operations at most of the monitoring stations was caused by the activated ^{41}Ar component of the BGRR–HFBR effluent cooling air. As indicated in Table 3, Kanne chamber measurements showed an average ^{41}Ar stack concentration of 1.84×10^{-3} $\mu Ci/cm^3$ during 1966. The daily discharge of 110-min half-life ^{41}Ar was 19,300 Ci/day when the BGRR was in operation at close to 20 MW. As of July 1, 1966, the BGRR was scheduled to shut down every weekend beginning at 1800 hr on Friday and to start

Table 1

1966 BNL Environmental Monitoring
Monthly Average Gross Radiation Levels, mR/wk

	On site				Perimeter				Off site		
Month	S-6	S-11	S-12	S-13	P-2*	P-4	P-7	P-9	O-4	O-5	O-6
Jan.	89.3	12.42	—	—	1.95	1.95	3.10	3.57	—	—	1.78
Feb.	87.2	10.82	—	—	2.01	1.69	2.24	3.80	—	—	1.61
Mar.	94.3	9.45	—	—	2.06	1.75	2.08	3.84	1.60	—	1.74
Apr.	87.3	9.72	—	—	2.10	1.82	2.20	4.00	1.61	—	1.74
May	—	11.12	—	—	2.46	2.10	2.42	4.43	—	—	1.88
June	—	12.46	—	—	2.21	2.12	2.17	5.73	—	2.83	1.85
July	—	11.82	5.04	5.57	2.29	1.92	2.27	5.78	—	2.38	1.97
Aug.	—	10.93	5.36	5.34	2.33	1.97	2.25	5.76	—	2.38	2.04
Sept.	—	10.61	3.55	3.80	2.32	2.40	2.05	4.57	—	2.19	1.90
Oct.	—	11.33	3.42	3.62	2.26	2.04	2.47	4.01	—	2.11	1.80
Nov.	—	8.46	—	4.53	1.77	1.95	1.89	4.55	—	—	1.73
Dec.	—	8.33	—	3.31	1.78	2.04	1.87	3.67	—	—	1.70
Av	89.5	10.62	4.34	4.36	2.13	1.98	2.25	4.48	1.60	2.38	1.81

Estimated error (monthly average): ±3%.
*Station was shut down Oct. 14, moved from Sally Lane to FAA Tower location, and started up Nov. 4.

Table 2

1966 BNL Environmental Monitoring
Monthly Average Background Levels, mR/wk

	On site				Perimeter				Off site			All stations,
Month	S-6	S-11	S-12	S-13	P-2*	P-4	P-7	P-9	O-4	O-5	O-6	av**
Jan.	2.0	2.22	—	—	1.90	1.76	2.03	2.03	—	—	1.78	1.95
Feb.	1.9	2.23	—	—	1.85	1.65	1.84	2.00	—	—	1.61	1.86
Mar.	1.8	2.03	—	—	1.80	1.66	1.83	1.89	1.52	—	1.68	1.82
Apr.	1.8	2.00	—	—	2.02	1.74	1.92	2.04	1.53	—	1.72	1.91
May	—	2.09	—	—	1.87	1.68	1.88	1.83	—	—	1.72	1.84
June	—	2.08	—	—	2.03	1.73	1.88	1.93	—	1.89	1.79	1.91
July	—	1.96	1.93	2.01	2.21	1.82	2.08	2.12	—	1.89	1.96	2.02
Aug.	—	1.97	1.97	2.04	2.23	1.80	2.03	2.10	—	1.86	1.97	2.02
Sept.	—	1.89	2.01	1.94	2.11	1.83	1.92	2.08	—	1.95	1.86	1.95
Oct.	—	1.76	2.05	1.96	2.12	1.90	1.90	1.98	—	1.93	1.79	1.91
Nov.	—	1.80	—	1.99	1.71	1.87	1.87	1.94	—	—	1.73	1.82
Dec.	—	1.75	—	1.89	1.61	1.80	1.80	1.91	—	—	1.67	1.76
Av	1.9	1.98	1.99	1.99	1.96	1.77	1.92	1.99	1.52	1.90	1.77	1.90

Estimated error: ±0.15 mR/wk.
*Station was shut down Oct. 14, moved from Sally Lane to FAA Tower location, and started up Nov. 4.
**Seasonally operated stations not included in monthly averages.

up at 0001 hr Monday morning, with nominal 20-MW operation attained by noon on Monday. The MRR stack concentration of ^{41}Ar is 3.0×10^{-4} $\mu Ci/cm^3$, and the discharge is 75 Ci/24-hr day at full power (3 MW); however, the MRR was infrequently operated at this power level or duty cycle. About 5 Ci/wk were discharged from its stack, and it was insignificant as a source of ^{41}Ar when compared with the BGRR. The yearly average radiation levels, in mR/wk, attributable to ^{41}Ar at each of the monitoring stations are shown in Table 4. A decrease in the monthly ^{41}Ar levels was apparent at most stations during the second half of the year. The overall yearly average at the six continously operated stations was 94% of that for 1965, while the number of MWd of reactor operation was 95% of that for 1965. The percentage frequencies of wind directions to the nearest 10° during the years 1961–1963, tabulated by the BNL Meteorology Group, were published in the 1964 report.[3] The seasonal patterns apparent from these wind roses can be correlated reasonably well with the monthly variations in the ^{41}Ar reported at the individual monitoring stations.

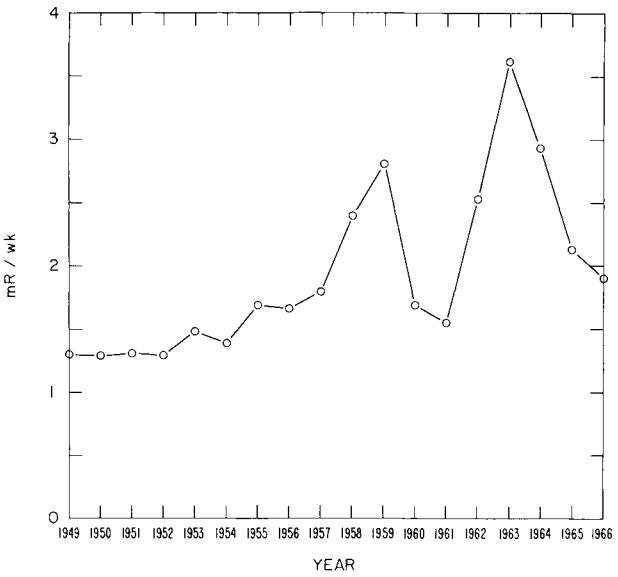

Figure 3. Yearly average background at elevation of 3 ft, 1949–66.

Two multicurie field γ sources are routinely exposed 20 hr/day. One, a ^{60}Co source that contained 3080 Ci on Jan. 1, 1966, and was restored to 3600 Ci on June 1, is used primarily for plant irradiations in a cultivated plot. The other, a ^{137}Cs source that contained 8000 Ci as of Jan. 1, 1966, is used to irradiate an otherwise undisturbed wooded area for ecological studies. The ^{137}Cs source produced a measurable dose rate at stations P-9 and S-13, and the ^{60}Co source dose rate was evident at station S-11. Monthly average radiation levels at these stations attributable to the sources are listed in Table 5. With use of a method suggested by Cowan and Meinhold[9] and the observed monthly mean temperatures, monthly dose rates have also been calculated. Attenuation by the shield plugs and by

Table 3

1966 BNL Environmental Monitoring
BGRR–HFBR Stack Emission

Month	BGRR MWd	Air volume, cm^3	^3H (HFBR) Ci	^3H (HFBR) $\mu Ci/cm^3$	^{131}I mCi	^{131}I $\mu Ci/cm^3$	^{41}Ar Ci	^{41}Ar $\mu Ci/cm^3$	Particulate Ci	Particulate $\mu Ci/cm^3$
Jan.	458	2.29×10^{14}	—	—	189	8.23×10^{-10}	3.8×10^5	1.66×10^{-3}	30	1.31×10^{-7}
Feb.	357	1.79×10^{14}	—	—	180	10.01×10^{-10}	3.6×10^5	2.03×10^{-3}	26	1.46×10^{-7}
Mar.	455	2.43×10^{14}	0.3	0.12×10^{-8}	511	21.00×10^{-10}	4.7×10^5	1.93×10^{-3}	33	1.36×10^{-7}
Apr.	443	2.54×10^{14}	0.5	0.20×10^{-8}	777	30.60×10^{-10}	4.5×10^5	1.77×10^{-3}	27	1.06×10^{-7}
May	496	2.78×10^{14}	0.8	0.29×10^{-8}	160	5.75×10^{-10}	4.7×10^5	1.69×10^{-3}	34	1.22×10^{-7}
June	556	3.25×10^{14}	3.0	0.95×10^{-8}	170	5.74×10^{-10}	5.3×10^5	1.63×10^{-3}	39	1.20×10^{-7}
July	296	1.50×10^{14}	3.6	2.40×10^{-8}	80	5.32×10^{-10}	2.9×10^5	1.93×10^{-3}	21	1.40×10^{-7}
Aug.	384	2.04×10^{14}	7.3	3.57×10^{-8}	90	4.42×10^{-10}	3.8×10^5	1.87×10^{-3}	27	1.33×10^{-7}
Sept.	300	1.56×10^{14}	5.2	3.23×10^{-8}	75	4.82×10^{-10}	2.9×10^5	1.86×10^{-3}	27	1.73×10^{-7}
Oct.	304	1.58×10^{14}	8.6	5.45×10^{-8}	90	5.75×10^{-10}	2.9×10^5	1.83×10^{-3}	19	1.20×10^{-7}
Nov.	327	1.67×10^{14}	4.5	2.72×10^{-8}	75	4.55×10^{-10}	3.1×10^5	1.88×10^{-3}	20	1.21×10^{-7}
Dec.	301	1.50×10^{14}	5.9	3.84×10^{-8}	69	4.60×10^{-10}	3.0×10^5	2.00×10^{-3}	20	1.33×10^{-7}
Annual total										
	4677	24.93×10^{14}	39.7		2466		45.2×10^5		323	
Av				2.28×10^{-8}		9.23×10^{-10}		1.84×10^{-3}		1.32×10^{-7}

Table 4

1966 BNL Environmental Monitoring
Monthly Average ^{41}Ar Radiation Levels, mR/wk

Month	On site				Perimeter				Off site		
	S-6	S-11	S-12	S-13	P-2*	P-4	P-7	P-9	O-4	O-5	O-6
Jan.	1.4	4.50	—	—	0.05	0.19	1.07	0.32	—	—	0.01
Feb.	0.6	2.93	—	—	0.16	0.04	0.40	0.62	—	—	0
Mar.	1.2	1.53	—	—	0.26	0.09	0.25	0.63	0.07	—	0.07
Apr.	2.7	2.54	—	—	0.08	0.08	0.29	0.50	0.08	—	0.02
May	—	2.78	—	—	0.59	0.42	0.54	1.08	—	—	0.16
June	—	2.84	—	—	0.18	0.39	0.28	2.03	—	0.94	0.07
July	—	1.38	2.82	2.35	0.08	0.10	0.19	1.47	—	0.49	0.01
Aug.	—	1.27	3.14	2.14	0.10	0.17	0.22	1.62	—	0.52	0.07
Sept.	—	0.98	1.28	0.79	0.21	0.57	0.14	0.55	—	0.23	0.04
Oct.	—	2.35	1.13	0.61	0.14	0.14	0.57	0.30	—	0.18	0.01
Nov.	—	0.32	—	1.70	0.06	0.08	0.02	1.21	—	—	0
Dec.	—	0.29	—	0.68	0.17	0.24	0.07	0.40	—	—	0.04
Av	1.5	1.98	2.09	1.38	0.17	0.21	0.34	0.89	0.08	0.47	0.04

Estimated Monthly Average Error

mR/wk	Error, %
<0.02	±100
0.02–0.05	±50
0.05–0.25	±25
>0.25	±10

*Station was shut down Oct. 14, moved from Sally Lane to FAA Tower location, and started up Nov. 4.

Table 5

1966 BNL Environmental Monitoring
Monthly Average Radiation Levels From Ecology Forest Source at Stations P-9, S-13, and S-11, mR/wk

Month	Mean T		P-9[a]			S-13[b]			S-11[a]		
	°F	°C	Obs.	Calc.	Obs./Calc.	Obs.	Calc.	Obs./Calc.	Obs.	Calc.	Obs./Calc.
Jan.	27.8	−2.3	1.22	1.85	0.66	—	—	—	5.70	7.18	0.79
Feb.	29.9	−1.2	1.18	1.84	0.64	—	—	—	5.56	7.34	0.76
Mar.	37.7	3.2	1.32	1.95	0.68	—	—	—	5.64	7.74	0.73
Apr.	42.5	5.8	1.47	2.12	0.69	—	—	—	5.19	8.19	0.62
May	53.0	11.7	1.52	2.33	0.65	—	—	—	6.24	9.75	0.64
June	66.0	18.9	1.77	2.68	0.66	—	—	—	7.37	12.30	0.60
July	72.4	22.4	2.19	2.93	0.75	1.24	2.28	0.56	8.16	12.90	0.64
Aug.	70.0	21.1	2.04	2.82	0.72	1.14	2.25	0.51	7.69	12.40	0.62
Sept.	60.5	15.8	1.95	2.80	0.70	1.07	2.06	0.52	7.27	11.34	0.64
Oct.	48.6	9.2	1.73	2.22	0.78	1.05	1.88	0.56	6.91	10.00	0.70
Nov.	44.0	6.7	1.39	2.10	0.66	0.84	1.41	0.60	6.34	9.34	0.68
Dec.	31.0	−0.5	1.36	1.80	0.75	0.75	1.36	0.55	6.28	8.14	0.77
Av	48.6	9.2	1.60	2.29	0.70	1.02	1.87	0.55	6.53	9.72	0.68

Estimated error (observed data): ± 7.5%.

[a]Distance from source, 815 m.
[b]Distance from source, 840 m.

Table 6

1966 BNL Environmental Monitoring
Ion Chamber Comparison, mR/hr

Location	BNL shielded chamber (wall 2825 mg/cm^2 thick)	NYS Dept. of Health chamber (wall ≈2500 mg/cm^2 thick)
7th St. and Brookhaven Ave.	0.020	0.020
Sewer plant	0.010	0.011

the surrounding woods is suggested as the most probable explanation for the lower radiation levels observed. The reason for the difference between the average ratio of observed to calculated dose at stations at comparable distances from the sources is not obvious but is perhaps related to the limitations of the method of calculation.

Some radiation from the ^{60}Co source also reaches on-site station S-12, but the amount is too small to be measured accurately in the presence of the much higher ^{41}Ar levels usually observed at this location. A calculated correction for the source effect was applied to obtain the natural background measurements at station S-12.

The cylindrical ion chambers used in making the above measurements have a sensitive volume of 6 liters and operate at atmospheric pressure. They have Bakelite side walls ≈400 mg/cm^2 thick. The ends are much thicker and may be considered essentially β-opaque. In November 1965 an intercomparison between the BNL ion chamber and an 8-liter, high-pressure, Ar-filled chamber with a 2500-mg/cm^2-thick steel wall belonging to the New York State Department of Health indicated that about 30% of the background dose rate measured by the BNL chamber was attributable to β or soft-γ radioactivity not detectable by the high-pressure chamber.

In February 1966 the response to ^{60}Co and ^{226}Ra sources of the standard chamber (400-mg/cm^2-thick wall) was compared with that of a chamber having a 2825-mg/cm^2-thick wall and an outer lining of steel. Background averages inferred from the two sources were virtually identical (10.3 μR/hr for ^{60}Co and 10.2 μR/hr for ^{226}Ra). The background as measured with the thick-walled chamber averaged 90% of that of the thin-walled chamber with ^{60}Co calibration, and 96% with ^{226}Ra calibration.

On Aug. 24, 1966, measurements were made of the external background radiation levels at the BNL ion chamber, shielded by ⅛-in. steel, and the high-pressure chamber being used by the New York State Department of Health for field surveys in the BNL area. The results are compared in Table 6. The agreement is quite satisfactory and strongly suggests that previously observed discrepancies between the New York State Department of Health observations of background in this vicinity and those made by the BNL Environmental Monitoring Section are principally attributable to the difference in ion-chamber wall thickness.

Table 7

1966 BNL Environmental Monitoring
Average Concentrations of ^{82}Br, ^{131}I, and ^{133}I, 10^{-9} μCi/cm^3

Month	^{82}Br	^{131}I	^{133}I
June	4.13	0.58	1.36
July	6.55	0.50	4.50
Aug.	5.85	0.42	3.42
Sept.	3.55	0.40	1.74
Oct.	4.84	0.52	3.69
Nov.	4.86	0.34	2.76
Dec.	3.94	0.32	1.21
Av conc.	4.82	0.44	2.67
Emission rate, μCi/sec	0.60	0.05	0.32

STACK-EFFLUENT AND GROUND-LEVEL AIR PARTICULATE AND RADIOIODINE MONITORING

Routine monitoring of the BGRR–HFBR stack effluent is conducted by the Reactor Health Physics Group. The equipment used includes an air particulate sampler with a continuous tape of filter medium (HV-70), which moves past a β scintillation detector at 20 min post collection, to determine the air particulate gross β concentration; a Sill-type charcoal cartridge[10] which was routinely changed every other day and counted in a NaI well detector 1 wk post collection to determine ^{131}I effluent concentrations; and a silica-gel trap to collect water vapor for weekly liquid scintillation analysis for ^{3}H. The average monthly gross β, ^{131}I, and ^{3}H concentrations in the BGRR–HFBR stack effluent, as established by this routine sampling program, are shown in Table 3.

In June 1966, the Environmental Monitoring Section undertook the daily γ analysis of an independently obtained stack air particulate and charcoal sample pack. This was done primarily to determine the feasibility of detecting some of the shorter lived stack effluent nuclides at ground level and thereby to establish their usefulness as tracers

Table 8

1966 BNL Environmental Monitoring
Average Concentrations of Intermediate and Long-Lived γ-Emitting Isotopes in BGRR Stack Effluent, pCi/m³

Sample component	Activation isotopes									
	^{60}Co		^{65}Zn		^{75}Se*		^{124}Sb		^{203}Hg	
	Conc.	%	Conc.	%	Conc.	%	Conc.	%	Conc.	%
Particulate	1.2	94	7.6	95	0.4	8	2.1	85	1.0	6
Charcoal	0.1	6	0.4	5	3.3	91	0.3	15	14.7	94
Total	1.3	100	8.0	100	3.7	100	2.4	100	15.7	100

	Fission product isotopes													
	^{95}Zr-^{95}Nb		^{103}Ru		^{106}Ru		^{131}I		^{137}Cs		^{140}Ba-^{140}La		^{141}Ce		^{144}Ce	
	Conc.	%	Conc.	%	Conc.	%	Conc.	%	Conc.	%	Conc.	%	Conc.	%	Conc.	%
Particulate	1.4	83	2.5	61	1.1	83	27	5	2.4	91	11.2	26	1.0	13	1.7	19
Charcoal	0.3	17	1.6	39	0.2	17	504	95	0.3	9	32.1	74	7.1	87	7.3	81
Total	1.7	100	4.1	100	1.3	100	531	100	2.7	100	43.3	100	8.1	100	9.0	100

*Identification tentative.

Table 9

1966 BNL Environmental Monitoring
Monthly Average Gross β and γ-Emitting Isotope Concentrations, Air Particulate Filters, pCi/m³

Month	Gross β	Max	Min	^{7}Be	^{54}Mn	^{125}Sb	^{95}Zr-^{95}Nb	^{103}Ru	^{106}Ru	^{131}I	^{137}Cs	^{140}Ba-^{140}La	^{141}Ce	^{144}Ce
Jan.	0.067	0.135	0.014	0.112	0.002	0.002	<0.001	<0.001	0.010	<0.001	0.008	<0.001	<0.001	0.004
Feb.	0.054	0.112	0.006	0.081	0.001	0.002	<0.001	<0.001	0.004	<0.001	0.005	<0.001	<0.001	0.002
Mar.	0.081	0.163	0.022	0.141	0.002	0.003	<0.001	<0.001	0.004	<0.001	0.008	<0.001	<0.001	0.006
Apr.	0.087	0.210	0.036	0.145	0.002	0.003	<0.001	<0.001	0.006	<0.001	0.010	<0.001	<0.001	0.007
May[a]	0.108	0.146	0.075	0.173	0.003	0.006	<0.001	<0.001	0.016	<0.001	0.020	<0.001	<0.001	0.012
May[b]	0.393	2.94	0.147	0.156	0.003	0.006	0.029	0.026	0.016	0.042	0.019	0.057	0.017	0.012
June	0.272	0.726	0.078	0.150[c]	0.001	0.004	0.027	0.018	0.009	0.006	0.012	0.037	0.011	0.014
July	0.189	0.296	0.081	0.150[c]	0.001	0.004	0.023	0.015	0.015	<0.001	0.012	0.011	0.013	0.008
Aug.	0.098	0.200	0.033	0.141	0.001	0.001	0.005	<0.001	0.011	<0.001	0.005	<0.001	0.004	0.004
Sept.	0.100	0.314	0.023	0.147	0.001	0.001	0.004	<0.001	0.006	<0.001	0.006	<0.001	0.002	0.004
Oct.	0.053	0.196	0.018	0.084	<0.001	0.001	0.001	<0.001	0.005	0.001	0.003	<0.001	<0.001	0.006
Nov.	0.325	1.174	0.026	0.100[c]	<0.001	<0.001	0.027	0.023	0.003	0.020	0.002	0.061	0.014	0.005
Dec.	0.070	0.229	0.030	0.115	<0.001	<0.001	0.006	0.007	0.001	0.002	0.001	0.005	0.003	0.002
Av	0.146	0.526	0.053	0.124	0.001	0.003	0.010	0.007	0.008	0.006	0.008	0.014	0.005	0.007
Estimated error, %		±10	±10	±25	±10	±50	±50	±25	±25	±25	±50	±25	±25	±50	±25

[a]April 29–May 13.
[b]May 14–27.
[c]Estimated.

to supplement previous longer term studies of stack-effluent dispersion phenomena which utilized its ^{131}I component.

From examination of the data, it appeared that 21-hr ^{133}I and 35-hr ^{82}Br were the only nuclides with useful half-lives (several hours to a few days) that were present in the stack effluent in sufficient concentrations to lead to quantifiable ground-level collections. Since initial counts of the complete pack showed little day-to-day variation in ^{82}Br and ^{133}I concentrations, representative samples were selected to establish monthly and long-term averages. These are indicated in Table 7, as are the concentrations of ^{131}I determined by this method. The latter are in good agreement with those determined by the Reactor Health Physics Group (Table 3).

The packs were subsequently disassembled and the individual components again analyzed to establish the concentrations of longer lived nuclides. Those >1 pCi/m^3 are shown in Table 8. Additional details and the results of a full year's study (June 1966 – May 1967) of stack effluent are to be published elsewhere.[11]

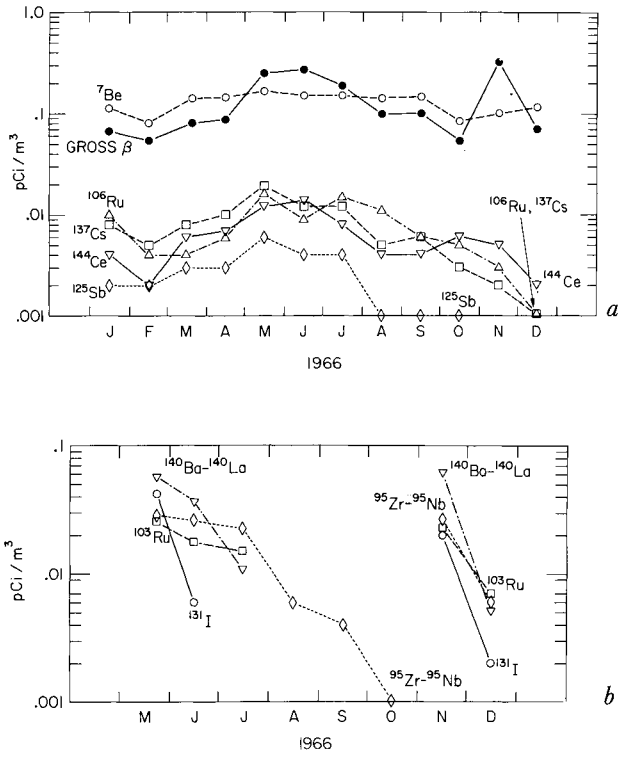

Figure 4. Monthly average concentrations: *a*, long-lived air particulates; *b*, short-lived air particulates.

During 1966 "high volume" (20 ft^3/min) positive displacement air pumps (Gast 3040) were operated at all the active monitoring stations (Figure 2). The air sampling media consisted of a 3-in.-diam air particulate filter (Jan.–July, MSA C-17651; Aug.–Dec., Gelman Type G) followed by a 3×1-in. bed of petroleum-based charcoal (Columbia Grade LC 12/28 X mesh) for sampling radioiodine. One particulate filter was changed and counted on a daily basis. All other samplers were routinely operated on a 2-wk change cycle.

Gross β counts of the air particulate samples were made with use of a 2-in.-diam end-window GM tube. A 2-in.-diam section of the filters was counted at about 54 hr post collection. This delay was introduced to minimize the contribution from the naturally occurring ^{212}Pb (10.6-hr half-life) thoron daughter. A γ analysis was routinely made on a composite of filter samples from the seasonally downwind stations, and another on a composite from the remaining stations. Monthly average 54-hr-delay gross β concentrations and those of all identifiable (concentration $>10^{-3}$ pCi/m^3) γ-emitting nuclides are listed in Table 9. The seasonal trend of concentrations of long-lived nuclides and the inputs of fresh shorter lived nuclides are evident from Figures 4*a* and 4*b*. Initial calculations of intermediate-lived isotopes have been adjusted for the presence of longer lived isotopes with overlapping photopeaks in the same spectrum. The longer lived isotopes were evaluated by a recount of composite monthly samples after a 1-yr delay. The number of photopeak transactions attributable to the amount of longer lived isotopes, such as those from 1-yr ^{106}Ru at 0.51 MeV and 285-day ^{144}Ce at 0.13 MeV, that should have been present in the initial count was then calculated and subtracted from the total initial photopeak count of the same energy (within the resolution of the 4×2-in. NaI detector). The concentrations of 39-day ^{103}Ru at 0.50 MeV and 33-day ^{141}Ce at 0.15 MeV were determined from the net initial photopeak count. When ^{140}Ba-^{140}La appeared to be present, a "stripping" procedure (using a magnetic tape of ^{140}Ba-^{140}La standard) was employed to remove the several interfering photopeaks of this isotope prior to evaluation of the amounts of other isotopes present in air particulate samples.

A "spring maximum" related to the exchange to the troposphere from the stratospheric reservoir of "aged" nuclear debris was apparent in the monthly concentrations of longer lived nuclides.

Table 10

1966 BNL Environmental Monitoring
Air Particulate Gross β Concentrations,
May 9–29 and Oct. 27–Nov. 16, pCi/m^3

Date	BNL	New York City (HASL)[a]	Date	BNL	New York City (RSN)
May 9	0.04	0.07	Oct. 27	0.06	<0.10
10	0.09	0.21	28	0.02[b]	<0.10
11	0.10	0.13	29	0.02[b]	<0.10
12	0.15	0.23	30	0.02[b]	<0.10
13	0.15[b]	0.07	31	0.02	<0.10
14	0.15[b]	0.16	Nov. 1	0.07	<0.10
15	0.15[b]	0.16	2	0.03	<0.10
16	0.43	0.52	3	0.03	<0.10
17	0.44	1.80	4	0.22[b]	<0.10
18	2.94	0.47	5	0.22[b]	0.15
19	0.14	0.33	6	0.22[b]	N.A.[c]
20	0.10	0.30	7	0.45	<0.10
21	0.68	0.78	8	0.68	0.19
22	0.17	0.14	9	1.17	0.28
23	0.22	0.17	10	0.97	0.66
24	0.28	1.1	11	0.36[b]	0.40
25	0.82	1.7	12	0.36[b]	0.11
26	0.80	2.1	13	0.36[b]	0.18
27	0.42[b]	1.1	14	0.27	0.27
28	0.42[b]	0.72	15	0.26	0.19
29	0.42[b]	0.08	16	0.70	0.15

[a] γ/min/m^3.
[b] Weekend.
[c] N.A. = not available.

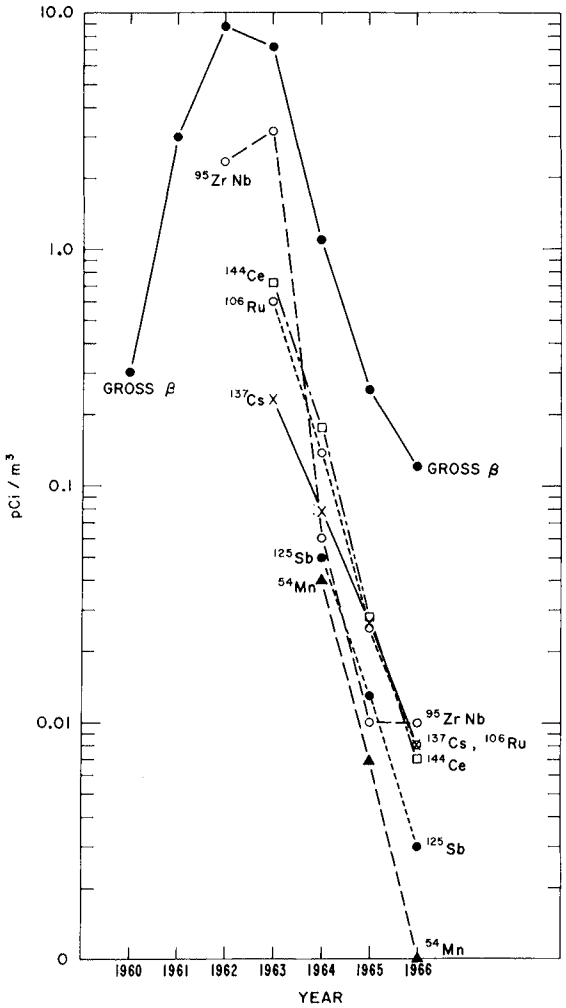

Figure 5. Yearly average air particulate concentrations, 1960–66.

An input of fresh fission products shortly after each of the reported May and October Chinese weapons tests was also apparent. Although a third Chinese test[12] was reported to have been conducted late in December, fission products attributable to this test did not appear in local air samples during 1966.

Since the preceding concentrations were minimal, the arrival of debris after each test was evident in daily measurements of gross β concentrations. Those for the three weeks after each reported test are indicated in Table 10, as are similar data obtained at New York City by the U.S. Atomic Energy Commission's Health and Safety Laboratory (HASL)[13] and by the U.S. Public Health Service Radiation Surveillance Network (RSN).[14] The May data are consistent with an analysis by Grundy and Snavely[15] of the intrusion pattern of fallout from the third Chinese test.

Although the arrival of a sharp peak in concentration took from 9 to 13 days, in both cases increases from the preceding background levels were apparent several days earlier. This is presumed to be the result of the gradual sifting down to ground level of material from the high-level clouds of weapons test debris, which appear to move from west to east several days earlier than the bulk of the material in the ground-level cloud.

Yearly average gross β air particulate concentrations since 1960, ^{95}Zr-^{95}Nb concentrations since 1962, and those of other identifiable long-lived γ emitters since 1963 are shown in Figure 5. Since there was no significant input from these long-lived nuclides after 1962, the rate of decrease of tropospheric concentrations would appear to reflect that of the stratospheric reservoir (assuming a constant fractional rate of the stratospheric to tropospheric transport per year). The mean strato-

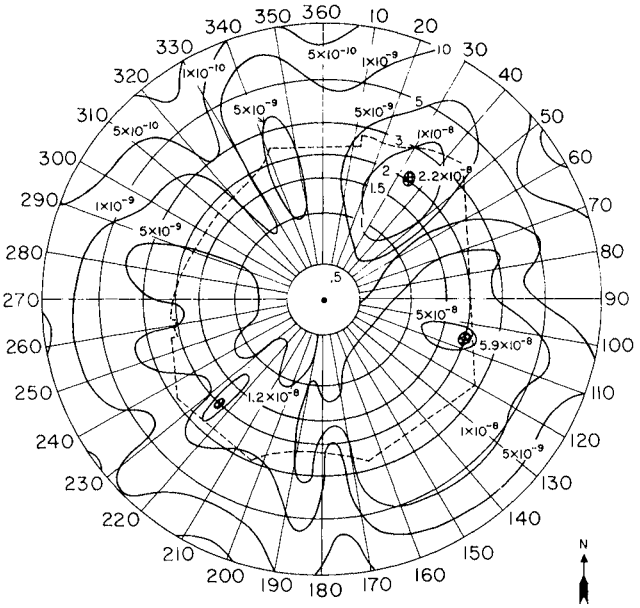

Figure 6. Average ground-level concentrations in units/m^3 for stack emission of 1 unit/sec, Season I (Jan.–Mar.).

spheric residence time suggested by the nearly exponential decrease of most nuclides between 1963 and 1966 is of the order of 1 yr. This is somewhat shorter than most of the estimates based on stratospheric sampling reported by Machta.[16]

Three 1-day samples were obtained in September and October when the dose-rate recorder at a field station indicated that unusually high radiation levels associated with reactor-plume ^{41}Ar had persisted at a location for several hours on the preceding day. The samples were analyzed within 24 hr for ^{82}Br and ^{133}I, and 24-hr average concentrations of the order of 5×10^{-14} $\mu Ci/cm^3$ were established for both isotopes in each sample. The calculated-to-observed ratios of ^{131}I and ^{133}I were almost identical (0.24 and 0.26). Although the higher concentrations of ^{131}I and ^{82}Br afford increased sensitivity, the necessity for frequent sampling and prompt analysis limits the practicability of this method for routine ground-level monitoring of stack effluents.

As indicated above, a charcoal canister for ^{131}I sampling was operated in sequence after the particulate filter in each of the continuous high-volume samplers for the same 2-wk sampling period as the particulate filter. After a delay of 2 or 3 days following the sampling period (to allow for the decay of radon and thoron progeny) a complete γ spectrum (from 0.1 to 3.0 MeV) was made for both filters.

At the BGRR–HFBR stack, about 1% of the emitted radioiodine has been found to be filterable on a 2-day particulate sample. Stack-emitted ^{131}I has not been found on routine field air particulate filters. The interference from other nuclides normally present on air particulate samples imposed a lower limit of detection of particulate ^{131}I of about 0.003 pCi/m^3, and it has been assumed on the basis of the stack sampling that all the stack-emitted ^{131}I passed through the particulate filter and was collected on the charcoal canister.

Interference from photopeaks of ^{214}Bi (RaC) originating from radium in the filter medium imposes a lower limit of sensitivity on γ analysis for ^{131}I. This effect is minimized by using petroleum-based charcoal, loaded into locally fabricated canisters. In the routine analysis procedure, an initial 5-hr net spectrum of the charcoal sample was obtained. The sample was set aside for about 1 mo and then recounted. The net difference in the 0.36-MeV photopeak region was interpreted as the amount of filtered ^{131}I that had decayed during the 1-mo interval.

As shown in Table 3, sampling devices operated by the BNL Health Physics Division indicated that a total of 2.47 Ci of ^{131}I was emitted from

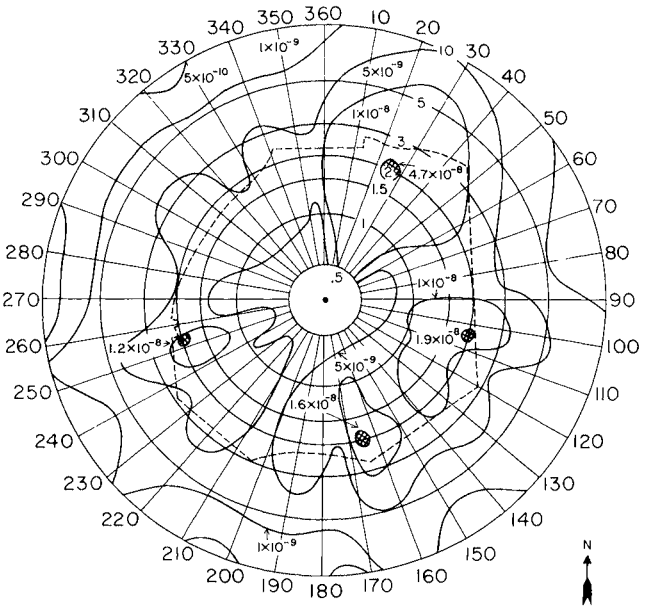

Figure 7. Average ground-level concentrations in units/m^3 for stack emission of 1 unit/sec, Season II (May.–Sept.).

the BGRR–HFBR stack during 1966 in an average concentration of 9.23×10^{-10} μCi/cm^3. Calculated ground-level isoconcentrations, based on a stack emission rate of 1 unit/sec, for each of four local seasons (of relatively uniform wind and stability conditions) are shown in Figures 6 to 9. These are revised from similar figures published previously,[4] in the light of increases in effective stack height suggested by a study[17] of the 1965 BNL ^{131}I environmental monitoring data.

The BGRR–HFBR stack emission data for each of these seasons are shown in Table 11. Calculated and measured ground-level concentrations of stack-effluent ^{131}I for each season are shown in Table 12. The former are derived by applying the reported seasonal stack emission rate of ^{131}I to the applicable plotted isoconcentrations (Figures 6 to 9).

The calculated ground-level concentrations are consistently low, especially for sampling locations close to the stack ($\approx$0.5 km). This is probably related to an overestimate of effective stack height. It appears that the formula utilized, which is one recommended for general use by Briggs,[18] may overpredict plume rise for relatively cool stack effluents such as that of the BGRR–HFBR.

Although the average yearly emission rate of ^{131}I was close to 0.1 μCi/sec, it was several times greater during March and April because of unusual releases from the Hot Laboratory off-gas system. These were terminated by the installation of a charcoal filter on Apr. 22. The rates of emission and the peak 2-wk ground-level concentrations of ^{131}I observed on site and at the perimeter are shown in Table 13. The average calculated concentration at the eight operating ground-level sampling stations was in good agreement (1.24, S.D. = 0.42) with the observed concentrations.

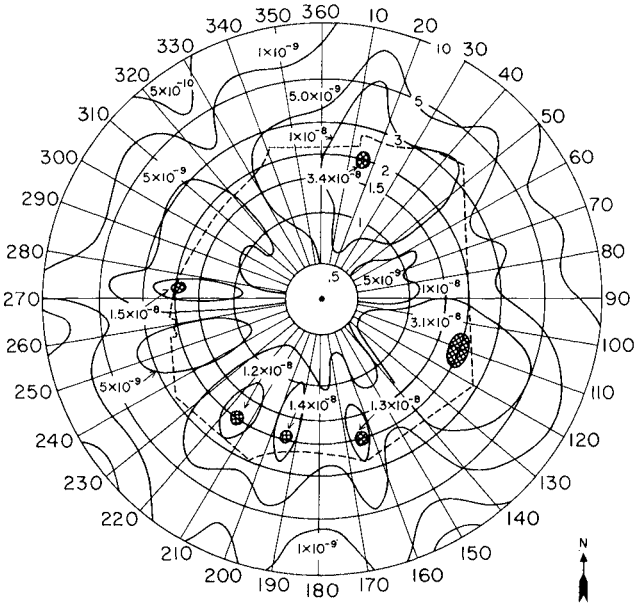

Figure 8. Average ground-level concentrations in units/m^3 for stack emission of 1 unit/sec, Season III (Apr. + Oct.).

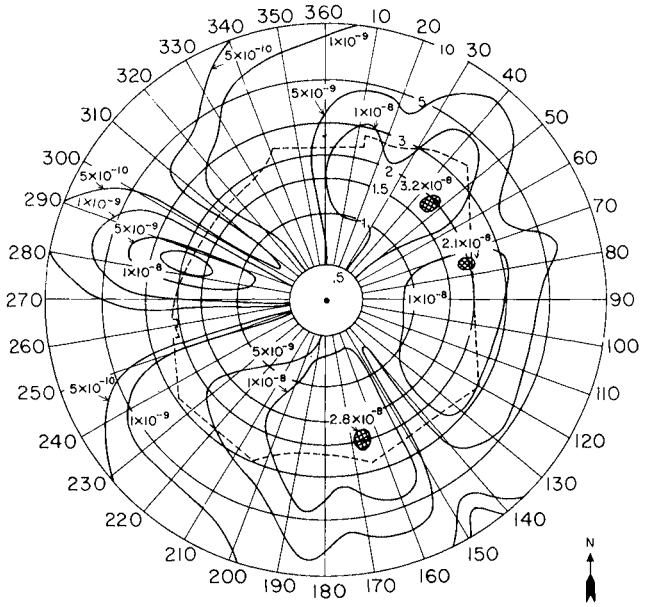

Figure 9. Average ground-level concentrations in units/m^3 for stack emission of 1 unit/sec, Season IV (Nov.–Dec.).

Table 11

1966 BNL Environmental Monitoring
Seasonal Emission of ^{131}I from BGRR–HFBR Stack

Season	Amount,* mCi	Av conc., nCi/cm^3	Av release rate, μCi/sec
I (Jan.–Mar.)	880	1.35	0.113
II (May–Sept.)	579	0.52	0.044
III (Apr. + Oct.)	868	2.11	0.165
IV (Nov.–Dec.)	144	0.46	0.027
Yearly total	2471		
Yearly av		0.99	0.078

*Sum of BGRR–HFBR and Hot Laboratory releases.

Table 12

1966 BNL Environmental Monitoring
Ground Level Concentrations of Stack Effluent ^{131}I, pCi/m^3

ta-on	Downwind from stack: Direction	Distance, m	Season I (Jan.–Mar.): Calc.	Obs.	C/O	Season II (May–Sept.): Calc.	Obs.	C/O	Season III (Apr. + Oct.): Calc.	Obs.	C/O	Season IV (Nov.–Dec.): Calc.	Obs.	C/O	Annual av: Calc.	Obs.	C/O
-2[a]	130°	1850	0.0003	0.0013	0.23	0.0002	0.0011	0.18	0.0008	0.0016	0.50	0.0001	0.0005	0.20	0.0005	0.0011	0.46
-2[b]	167°	2160															
-4	63°	2200	0.0007	0.0018	0.39	0.0004	0.0005	0.80	0.0008	0.0020	0.40	0.0001	0.0005	0.20	0.0005	0.0011	0.46
-11	300°	580	0.0011	0.0078	0.14	—	—	—	0.0017	0.0074	0.23	0.0003	0.0008	0.40	0.0010[c]	0.0057[c]	0.18[c]
-6	300°	1490	0.0051	0.0067	0.76	—	—	—	0.0045	0.0037	1.22	0.0004	0.0008	0.50	0.0036[c]	0.0042[c]	0.86[c]
-7	300°	2860	0.0034	0.0035	0.97	0.0003	0.0012	0.25	0.0041	0.0020	0.20	0.0003	0.0005	0.60	0.0010	0.0018	0.56
-12	218°	570	—	—	—	0.0005	0.0020	0.25	0.0012	0.0048	0.25	—	—	—	0.0007[c]	0.0028[c]	0.25[c]
-13	217°	1330	—	—	—	0.0018	0.0047	0.38	0.0033	0.0064	0.52	0.0007	0.0027	0.26	0.0019[d]	0.0046[d]	0.41[d]
-9	217°	2750	0.0017	0.0058	0.29	0.0016	0.0045	0.35	0.0025	0.0028	0.90	0.0005	0.0024	0.21	0.0018	0.0042	0.43
-5	217°	6100	—	—	—	0.0005	0.0030	0.17	—	—	—	—	—	—	0.0005[e]	0.0030[e]	0.17[e]
	Av				0.46			0.34			0.53			0.34			0.44

[a]At Sally Lane. [b]At FAA Tower. [c]Av, 7 mo. [d]Av, 9 mo. [e]Av, 5 mo.
Estimated error of observed concentrations: 0.0001 to 0.0005, ±100%; 0.0005 to 0.0025, ±50%; >0.0025, ±25%.

Air concentrations at the perimeter during this period averaged $1/10{,}000$ of the Radiation Protection Standard[8] of 1×10^{-10} μCi/cm^3. This standard is based on direct inhalation, and the perimeter air concentrations were 1/40 of a calculated acceptable concentration based on deposition and the resultant ^{131}I concentration in milk of a hypothetical cow pastured at the perimeter. (The nearest actual milk cows are 8 to 10 km from the BGRR–HFBR stack.)

Table 13

1966 BNL Environmental Monitoring
BGRR–HFBR Stack Release of ^{131}I, Mar. 4–Apr. 22

Sampling period	Emission rate, μCi/sec	Peak concentration: On site, Station	On site, pCi/m^3	Perimeter, Station	Perimeter, pCi/m^3
Mar. 4–18	0.26	S-11	0.010	P-9	0.005
Mar. 18–Apr. 1	0.25	S-11	0.014	P-9	0.011
Apr. 1–15	0.39	S-11	0.007	P-4	0.010
Apr. 15–22	0.51	S-13	0.022	P-9	0.010
Overall av	0.33		0.012		0.09

Estimated error: stack emission, ±10%;
field ^{131}I concentrations, ±15%.

A nonroutine change of air particulate and charcoal filter samples was made on Apr. 22 because of the unusually high stack concentrations of ^{131}I during the immediately preceding week. From Apr. 15 to 22 a total of 261.8 mCi of ^{131}I was released. The ground-level air particulate samples, as well as the charcoal filters, were recounted at the end of a month's storage in order to evaluate this ^{131}I component as accurately as possible. The average distribution of activity for all eight monitoring stations was 12% for particulate samples and 88% for charcoal filters. Although the value for the particulate sample was somewhat greater than anticipated from previous studies, it would seem that the error introduced by the routine procedure of neglecting the particulate fraction at lower overall concentrations (at which it could not be evaluated) has not been significant.

PRECIPITATION COLLECTION

Two pot-type rain collectors, each with a surface area of 0.33 m^2, are situated adjacent to the Meteorology Building, 1300 m and 90° downwind from the BGRR–HFBR stack. Two routine collections were made. A sample from one col-

lector was picked up at 0900 only if precipitation had been observed during the previous 24 hr (or weekend); the other was picked up each Monday morning, whether or not precipitation had occurred. A standard amount of distilled water was used to wash down the collector if no precipitation was falling at the time the sample was terminated.

Part of each collection was evaporated for gross β counting. The largest single rainout, 22.3 nCi/m^2 at a concentration of 3560 pCi/liter, occurred on Nov. 6, ten days after the second Chinese weapons test during 1966. The second largest, 19.9 nCi/m^2 in a concentration of 543 pCi/liter, occurred on May 19, ten days after the first 1966 Chinese test. Weekly samples were analyzed for identifiable γ-emitting isotopes, and monthly composite samples for ^{89}Sr and ^{90}Sr. The monthly averages for gross β activity and for individual isotopes in precipitation are given in Table 14. The monthly amounts of gross β activity and of the more prevalent isotopes are plotted in Figure 10. The increased gross β activity and the presence of fresh fission isotopes in the May, June, and July and again in the November and December samples appear to reflect the contributions from the Chinese tests.

The deposited gross β activity after each of the 1966 Chinese tests was several times greater than that collected at BNL shortly after the first (Oct. 1964) and second (May 1965) tests. The locally collected amounts were in general agreement with those reported by Rechen[14] for Public Health Service stations in northeastern U.S. As indicated previously, there was no perceptible increase in backgrounds attributable to deposition from either 1966 test.

Although the total amount of deposited gross β activity was comparable with that collected in 1965, the amounts of intermediate half-life nuclides such as 285-day ^{144}Ce and 1-yr ^{106}Ru were $<$½ of those observed in 1965, and the amounts of long-lived nuclides such as 28-yr ^{90}Sr and 30-yr ^{137}Cs were $\approx$½ of those observed in that year. This is consistent with the previously indicated 1-yr stratospheric residence time for high-level weapons-test debris and suggests that the Chinese tests to date have added very little to the

Table 14

1966 BNL Environmental Monitoring
Monthly Average Gross β Concentrations, Total Gross β Activity, and Principal Isotope Activities in Precipitation

Month	Amount, in.	Gross β conc., pCi/liter	Gross β activity, nCi/m^2	Isotope activity, nCi/m^2											
				^{7}Be	^{54}Mn	^{89}Sr	^{90}Sr	^{95}Zr-^{95}Nb	^{103}Ru	^{106}Ru	^{131}I	^{137}Cs	^{140}Ba-^{140}La	^{141}Ce	^{144}Ce
Jan.	2.05	35	1.69	2.67	<0.10	<0.05	0.12	<0.10	<0.10	0.58	<0.10	0.29	<0.10	<0.10	0.85
Feb.	5.19	24	3.33	6.51	0.15	<0.05	0.30	<0.10	<0.10	0.69	<0.10	0.48	<0.10	<0.10	0.68
Mar.	2.14	48	2.59	6.68	0.12	<0.05	0.32	<0.10	<0.10	0.39	<0.10	0.32	<0.10	<0.10	0.57
Apr.	1.04	71	1.96	3.28	<0.10	<0.05	0.30	<0.10	<0.10	0.34	0.07	0.49	<0.10	<0.10	0.35
May	8.27	265	34.03	22.00	0.22	0.71	0.79	5.15	2.88	1.19	3.12	1.17	8.39	2.19	1.34
June	1.04	218	6.44	3.30	<0.10	0.20	0.10	0.13	1.27	0.28	<0.10	0.25	1.17	0.35	0.40
July	1.13	151	4.45	8.13	<0.10	0.21	0.19	0.60	0.86	0.56	<0.10	0.38	0.88	0.54	0.38
Aug.	2.83	17	0.61	1.66	0.10	0.08	0.07	<0.10	<0.10	<0.10	<0.10	0.21	<0.10	0.06	<0.10
Sept.	4.52	19	2.13	5.68	<0.10	0.17	0.07	<0.10	<0.10	0.92	<0.10	0.30	<0.10	<0.10	0.54
Oct.	4.77	10	1.21	3.54	<0.10	0.44	0.11	0.31	<0.10	0.67	<0.10	0.28	<0.10	<0.10	0.34
Nov.	2.35	435	26.56	1.45	<0.10	0.77	0.06	1.87	2.10	0.15	1.75	0.10	4.20	1.23	0.37
Dec.	3.05	39	2.27	3.38	<0.10	0.13	0.13	0.13	<0.10	0.36	<0.10	0.26	0.17	0.17	0.35
Total	38.38	1332	87.27	68.28	—	2.81	2.56	8.49	7.51	6.18	5.39	4.53	15.16	4.84	6.22
Av	3.20	111	7.27	5.69	—	0.23	0.21	0.71	0.63	0.52	0.45	0.38	1.26	0.40	0.52
Estimated error, %	±0.10	±10	±15	±25	±0.10	±10[a]	±10[a]	±10[b]	±25[b]	±15[b]	±15[b]	±10[a]	±25[b]	±25[b]	±15[b]

[a]If >0.05. [b]If >0.10.

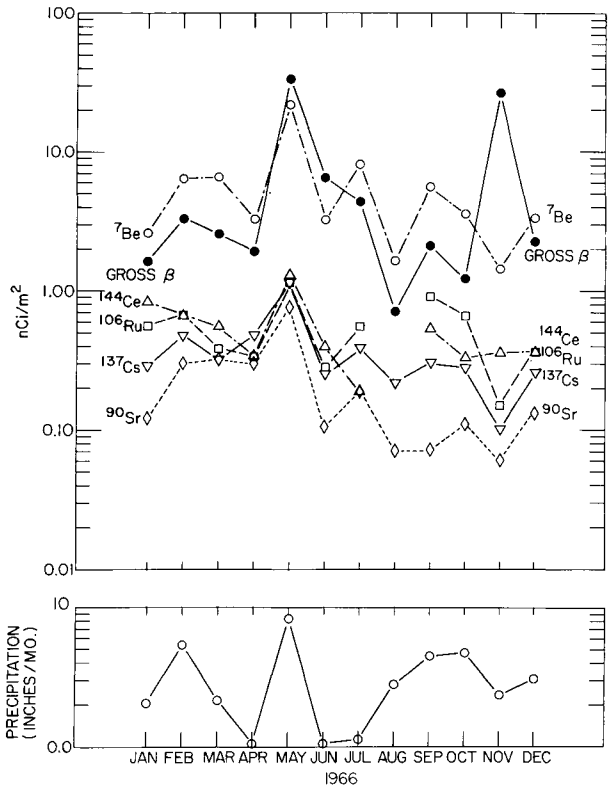

Figure 10. Monthly precipitation collection, gross β activity, and ^{7}Be, ^{90}Sr, ^{106}Ru, ^{137}Cs, and ^{144}Ce activities.

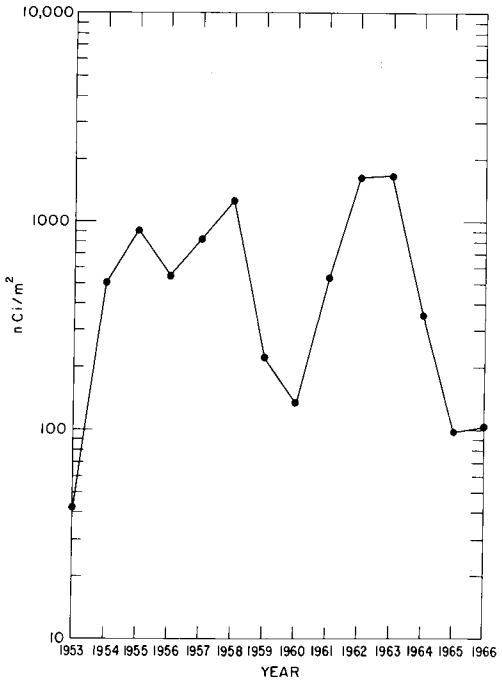

Figure 11. Yearly total gross β activity in precipitation, 1953–66.

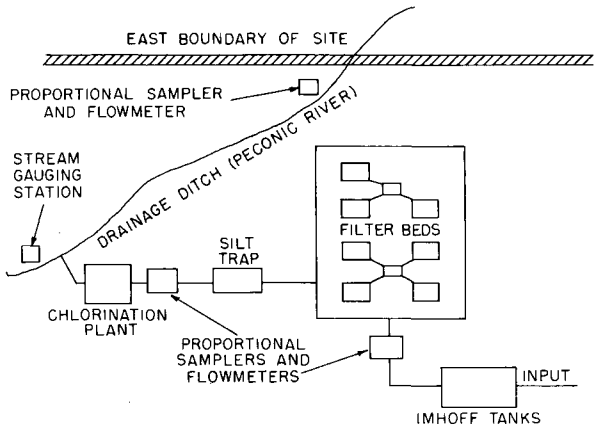

Figure 12. BNL sewage processing and monitoring system.

stratospheric inventory. The monthly amounts of the longer lived fallout isotopes, ^{90}Sr, ^{137}Cs, and ^{144}Ce, are in general agreement with those reported by the Health and Safety Laboratory[19] for New York City and for Westwood, N. J.

Rain and settled dust collections have been made by the Environmental Monitoring Section at Brookhaven National Laboratory continuously since the latter part of 1953. Total yearly activity is shown in Figure 11. The amount for 1953 is estimated from the Sept.–Dec. average.

LIQUID EFFLUENT MONITORING

Small amounts of low-level radioactive liquid effluents were routinely disposed of by release into the Laboratory's sanitary waste system, where they were diluted by a large volume of uncontaminated water. This liquid waste effluent passed through an Imhoff tank which removed most of the solids and then flowed onto sand filter beds, from which most of it was collected by an underlying tile field. The liquid effluent was then chlorinated and discharged into a small stream that forms one of the headwaters of the Peconic River.

The monitoring arrangements for the central sewage system are indicated in Figure 12. During May a new totalizing flowmeter (Leupold & Stevens, TF 61-2), which includes provision for actuating a sampler for each 2000 gal of flow, in combination with a positive-action battery-operated sampler (Brailsford DU-1), was installed at the perimeter sampling station. A proportional sample is obtained through use of an electronic circuit devised by the BNL Instrumentation Division. The circuit is arranged so that the pump

Table 15

1966 BNL Environmental Monitoring
Monthly Average Liquid Effluent Flow, Concentration, and Total Gross β Activity

Month	Imhoff tank			Chlorine house			Perimeter		
	Flow, gal/day	Conc., pCi/liter	Activity, mCi	Flow, gal/day	Conc., pCi/liter	Activity, mCi	Flow, gal/day	Conc., pCi/liter	Activity, mCi
Jan.	732,000	54	4.7	549,000	35	2.2	635,000	30	2.2
Feb.	747,000	72	6.3	594,000	61	4.3	741,000	49	4.3
Mar.	771,000	57	4.7	595,000	46	2.9	714,000	38	2.9
Apr.	951,000	21	2.4	701,000	35	2.9	787,000	31	2.9
May	1,084,000	48	5.9	792,000	34	3.1	850,000	32	3.1
June	1,232,000	235	33.9*	912,000	50	5.3	974,000	48	5.3
July	1,273,000	82	10.3	956,000	39	4.0	875,000	41	3.8
Aug.	1,410,000	43	7.1	943,000	31	3.8	910,000	28	3.3
Sept.	1,056,000	24	3.0	875,000	28	2.6	866,000	22	2.0
Oct.	1,060,000	15	2.1	838,000	22	2.4	825,000	21	2.3
Nov.	975,000	16	1.7	755,000	27	1.9	711,000	23	1.8
Dec.	904,000	31	3.2	589,000	23	1.5	587,000	23	1.6
Total			85.1			36.9			35.4
Av	1,015,000	60		757,000	35		800,000	32	
Estimated error, %		±10	±10		±10	±10		±10	±10

*$\approx$20-mCi release of 87.5-day ^{35}S + 245-day ^{65}Zn.

makes one full stroke following each 2000-gal signal from the flowmeter, during which it delivers $\approx$10 ml.

Values of the monthly average gross β concentration and total gross β activity for the input to the filter bed, discharge to the river, and at the site boundary are given in Table 15. The perimeter data prior to May are calculated from the concentrations at the chlorine house adjusted for the increase in flow at the boundary. The May–Dec. sampling results confirm the previous assumption that essentially 100% of the activity at the chlorine house passes off site at the perimeter. A calculated radiation protection standard concentration of 1070 pCi/liter, based upon an assumed 20% ^{90}Sr content, is applied at the boundary.

A γ spectrum and a ^{90}Sr analysis were performed on a monthly composite of samples taken from the input to the sand filter beds, the effluent from the beds, and at the perimeter (May–Dec.). The amounts and average concentrations of identifiable isotopes entering and leaving the beds and passing the perimeter are shown in Table 16. The latter are calculated data from January to April and measured data thereafter.

The amounts of radioactivity released as liquid waste by the Laboratory have decreased annually during recent years up to 1966. Information from internal BNL reports concerning the gross β liquid effluent activity going into and discharged from the sand filter beds since 1951 is presented in Figure 13.

The sand filter beds have been reported to be about 90% efficient for most isotopes.[20] A recapitulation of the unusual releases involving millicurie amounts of ^{32}P, ^{35}S, ^{60}Co, ^{65}Zn, and ^{131}I that occurred during the year is presented in Table 17. It appears that on a short-term basis all the isotopes involved were substantially retained on the filter beds or lost to groundwater. The excess of ^{90}Sr and ^{137}Cs in the filter bed effluent over the input during recent years, again apparent in 1966, indicates that these isotopes are not permanently retained in the filter beds. A delay mechanism with a long time constant appears to be operative.

Accumulations of dried sludge previously pumped from the Imhoff tank were disposed of to the BNL dump during January and November. Gross α and gross β concentrations, the concentra-

Table 16

1966 BNL Environmental Monitoring
Total Activities and Average Concentrations of Identifiable Isotopes

Month	Gross β	^{32}P	^{60}Co	^{65}Zn	^{90}Sr	^{131}I	^{137}Cs	^{144}Ce	^{3}H	^{35}S	^{54}Mn
						Imhoff Tank					
Jan.	5.1	2.1	0.3	0.2	0.3	1.1	0.6	0.5	$<0.2\times10^3$	<0.5	<0.1
Feb.	5.6	—	1.1	<0.1	0.3	1.8	0.3	0.2	$<0.2\times10^3$	2.0	0.2
Mar.	4.9	—	0.4	<0.1	0.2	4.2	0.5	0.1	$<0.2\times10^3$	<0.5	0.1
Apr.	2.1	—	0.2	<0.1	0.2	0.7	0.4	<0.1	$<0.2\times10^3$	<0.5	0.1
May	9.5	—	3.0	<0.1	0.5	0.6	0.9	<0.1	$<0.2\times10^3$	<0.5	<0.1
June	27.5	—	<0.1	6.4	0.3	0.3	0.6	<0.1	$<0.2\times10^3$	20.0	<0.1
July	10.3	—	<0.1	4.9	0.3	<0.1	0.8	<0.1	$<0.2\times10^3$	<0.5	0.2
Aug.	7.1	—	<0.1	2.4	0.3	2.2	0.9	<0.1	$<0.2\times10^3$	<0.5	<0.1
Sept.	3.0	—	0.3	0.7	0.2	0.5	0.5	<0.1	$<0.2\times10^3$	<0.5	<0.1
Oct.	4.4	—	0.6	0.5	0.1	0.4	0.7	0.1	1.5×10^3	<0.5	<0.1
Nov.	2.0	—	0.1	0.3	0.1	<0.1	0.6	<0.1	0.9×10^3	<0.5	<0.1
Dec.	3.6	—	<0.1	0.4	0.2	0.3	0.9	<0.1	1.9×10^3	<0.5	<0.1
Total, mCi*	85.1	—	6.2	16.0	3.0	12.2	7.7	1.3	5.2×10^3	24.5	1.0
Av conc., pCi liter	60	—	4	11	2	8	5	1	3.7×10^3	17	<1
						Chlorine House					
Jan.	2.7	0.1	0.6	<0.1	0.4	0.4	1.8	0.4	$<0.2\times10^3$	<0.5	<0.1
Feb.	3.9	—	0.9	<0.1	0.2	0.5	1.5	<0.1	$<0.2\times10^3$	<0.5	0.4
Mar.	3.0	—	0.7	<0.1	0.2	0.7	1.4	<0.1	$<0.2\times10^3$	<0.5	<0.1
Apr.	2.7	—	0.7	<0.1	0.3	0.1	1.4	<0.1	$<0.2\times10^3$	<0.5	0.1
May	3.6	—	0.4	<0.1	0.2	<0.1	2.0	<0.1	$<0.2\times10^3$	<0.5	<0.1
June	4.7	—	0.3	<0.1	0.2	<0.1	1.6	<0.1	$<0.2\times10^3$	2.4	<0.1
July	4.0	—	0.2	0.1	0.8	<0.1	1.9	<0.1	$<0.2\times10^3$	<0.5	<0.1
Aug.	3.8	—	0.3	0.2	0.5	0.5	2.0	<0.1	$<0.2\times10^3$	<0.5	<0.1
Sept.	2.6	—	<0.1	0.2	0.2	0.4	1.4	<0.1	$<0.2\times10^3$	<0.5	<0.1
Oct.	2.8	—	0.5	0.1	0.2	<0.1	1.5	0.1	1.2×10^3	<0.5	<0.1
Nov.	1.9	—	0.4	<0.1	0.1	<0.1	1.6	<0.1	0.8×10^3	<0.5	<0.1
Dec.	1.5	—	<0.1	<0.1	0.1	0.3	0.7	<0.1	1.1×10^3	<0.5	<0.1
Total, mCi*	37.2	—	5.1	1.0	3.4	3.2	18.8	1.0	4.0×10^3	5.2	1.0
Av conc., pCi/liter	35	—	5	1	3	3	18	1	3.8×10^3	5	<1
						Perimeter					
Jan.**	2.7		0.6	<0.1	0.4	0.4	1.8	0.4	$<0.2\times10^3$	<0.5	0.4
Feb.**	3.9		0.9	<0.1	0.2	0.5	1.5	<0.1	$<0.2\times10^3$	<0.5	<0.1
Mar.**	3.0		0.7	<0.1	0.2	0.7	1.4	<0.1	$<0.2\times10^3$	<0.5	<0.1
Apr.**	2.7		0.7	<0.1	0.3	0.1	1.4	<0.1	$<0.2\times10^3$	<0.5	<0.1
May	2.1		0.4	<0.1	0.1	<0.1	1.3	<0.1	$<0.2\times10^3$	3.2	<0.1
June	5.6		<0.1	<0.1	0.2	<0.2	1.8	<0.1	$<0.2\times10^3$	<0.5	<0.1
July	3.8		<0.1	0.2	0.6	<0.1	2.0	<0.1	$<0.2\times10^3$	<0.5	<0.1
Aug.	3.3		<0.1	<0.1	0.4	<0.1	2.0	<0.1	$<0.2\times10^3$	<0.5	<0.1
Sept.	2.0		<0.1	<0.1	0.3	0.5	1.4	<0.1	$<0.2\times10^3$	<0.5	<0.1
Oct.	2.3		0.3	<0.1	0.2	<0.1	1.7	0.2	1.1×10^3	<0.5	<0.1
Nov.	1.8		0.3	<0.1	0.1	<0.1	1.5	<0.1	0.6×10^3	<0.5	<0.1
Dec.	1.6		<0.1	<0.1	0.1	0.2	0.6	<0.1	1.0×10^3	<0.5	<0.1
Total, mCi*	34.8		4.2	0.8	3.1	2.8	18.4	1.1	3.5×10^3	6.0	1.0
Av conc., pCi/liter	32		4	1	3	3	17	1	3.2×10^3	6	<1
Estimated error, %	±10		±25	±25	±10	±10	±10	±25	±25	±25	±50

*"Less than" amounts summed as half the indicated amount.
**Values given are estimates based on chlorine house data.

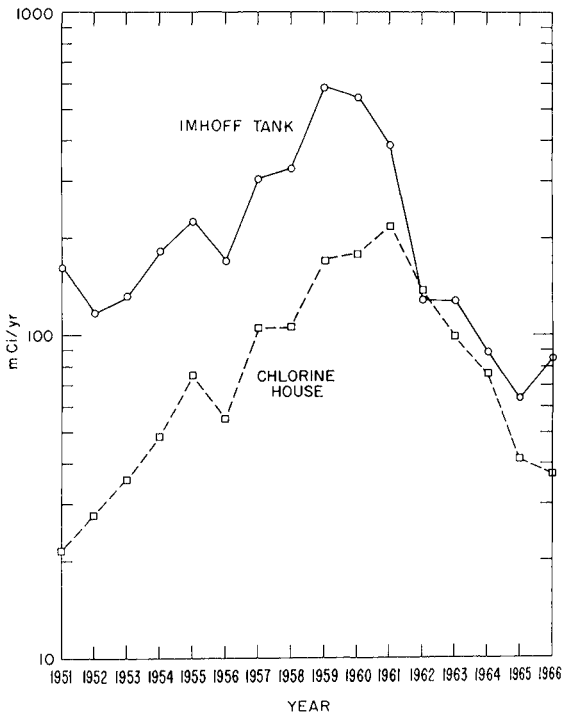

Figure 13. Yearly gross β activity in liquid effluent, 1951–66.

tions of the principal nuclides present, their estimated amounts, and the approximate fractions of total input to the Imhoff tank removed by the sludge are shown in Table 18. The total quantity of sludge removed from the drying beds is not well defined. There is also a delay of several months between the time it is pumped from the tank to dry and its removal. The previous removal of sludge from the drying beds was in October 1964. The approximate fractions removed have therefore been based on the assumption that they represent settling in the tank during 1964 and 1965. With the exception of ^{60}Co, it appears that $<25\%$ of an incoming radionuclide is removed by the sludge. The physical removal of suspended solids in the Imhoff tank is estimated by the BNL Plant Engineering Division[21] to be about 50%.

STREAM SAMPLING

Monthly "grab" water samples were obtained at on- and off-site locations along the upper tributary of the Peconic River, into which the Laboratory routinely discharges low-level wastes. Reference grab samples were also obtained from other nearby streams and bodies of water outside the Laboratory's drainage area. The sampling locations (Figure 14) were as follows.

A. Peconic River at Schultz Rd., 15,900 ft downstream from chlorine house.
B. Peconic River at Wading River–Manorville Rd., 23,100 ft downstream from chlorine house.
C. Peconic River at Manorville, $\approx$35,500 ft downstream from chlorine house.
D. Peconic River at Calverton, $\approx$46,700 ft downstream from chlorine house.
E. Peconic River, upstream from BNL effluent outfall.
F. Peconic River at north tributary (independent of BNL drainage).
G. Carman's River at Middle Island.
H. Carman's River at outflow of Yaphank Lake.
I. Artist Lake (maintained by water table, no surface outflow).
J. Lake Panamoka (maintained by water table, no surface outflow).
K. Peconic River, just below BNL effluent outfall.
L. Peconic River, 1300 ft below effluent outfall.
M. Peconic River, 2600 ft below BNL effluent outfall (at BNL boundary).
Q. Peconic River, 6900 ft downstream from BNL effluent outfall.

Stream-water sample gross β concentrations found during 1966 are summarized in Table 19. To facilitate comparisons, the samples are divided into two groups, one comprising locations in sequence

Table 17

1966 BNL Environmental Monitoring
Apparent Retention Efficiency of Sand Filter Beds

Isotope	Date	Imhoff tank (in), mCi	Chlorine house (out), mCi	Retention on filter beds, %
^{32}P	Dec. 27	2.15	0.09*	96
^{35}S	Jan. 31–Feb. 6	$\approx$2.00	$<$0.50	$>$75
^{35}S	June 3–4	20.0	2.4	88
^{60}Co	May 23–31	2.97	0.44	85
^{65}Zn	June	6.39	0.34	95
^{65}Zn	July	4.89	0.05	99
^{131}I	Mar. 8–9	4.23	0.67	84

*Estimated from gross β concentrations for Dec. 27 and 28 samples.

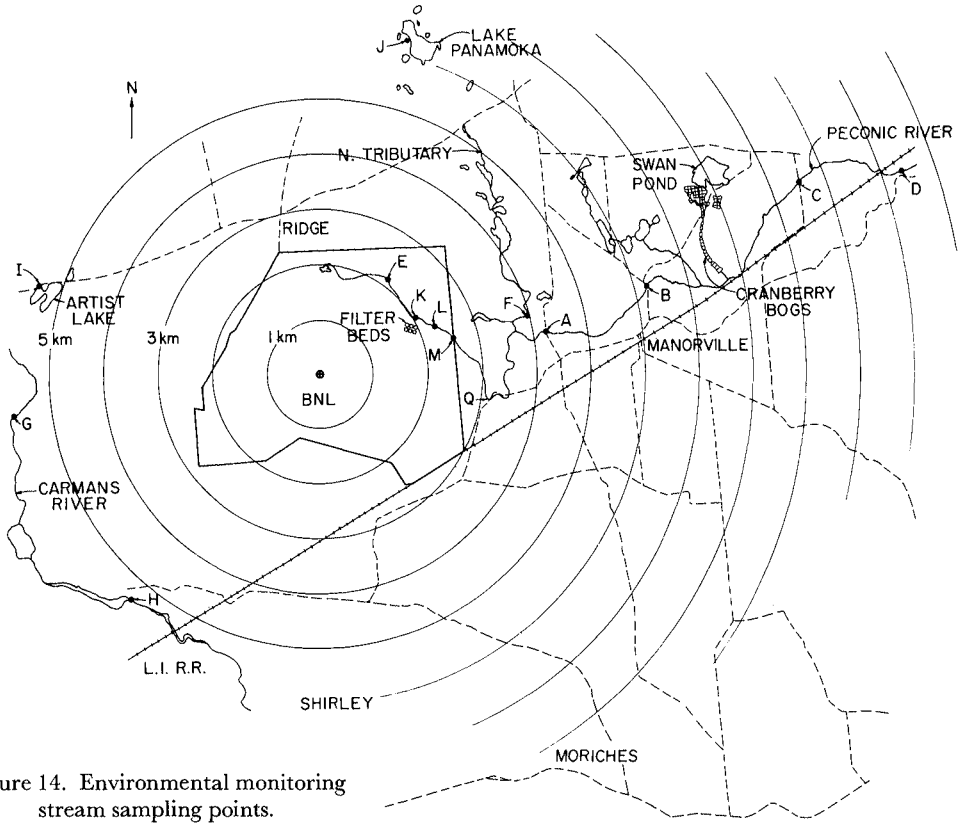

Figure 14. Environmental monitoring stream sampling points.

from upstream to downstream on the Peconic, and the other, control locations. Off-site stream sampling was initiated in 1960. Yearly averages since that time are also given in Table 19. There appears to be relatively little dilution by tributaries in the upper reaches of the stream. Three separate measurements made by the Water Resources Division of the U.S. Geological Survey[22] during 1966 indicated that the average daily flow of the Peconic River at Schultz Rd. (sampling location A) was about 11% of that at the perimeter (sampling location M), while continuous flow measurements made at the Riverhead Gauging Station, near the mouth of the river, averaged 1.04×10^7 gal/day, about 15 times that at the perimeter. The fraction of the gross β concentration in downstream water samples attributable to BNL effluent appears to fall off quite rapidly in the river's upper reaches. Stream bottom sampling was initiated in 1963 to obtain a profile of the distribution of radioactivity along the river downstream from the chlorine house outfall. Two sets of sediment samples were obtained in 1966. During an extensive summer program of stream sampling, effort was also directed toward the collection of identifiable species of bottom-growing plants and of turtles. A few fish and one snake were also obtained. All

Table 18

1966 BNL Environmental Monitoring
Concentrations in Sludge From Imhoff Tank, pCi/g

Date removed from bed	^{60}Co	^{90}Sr	^{137}Cs	^{144}Ce	Gross α	Gross β
Jan. 1966	148	N.A.	38	26	26	550
Nov. 1966	230	10	63	25	23	418
Estimated error, %	±15	±15	±15	±25	±15	±15
	Estimated Activity, mCi					
Jan. 1966[a]	3.0	N.A.	0.8	0.5	0.5	11.0
Nov. 1966[b]	11.5	0.5	3.2	1.3	1.2	20.9
Estimated error, %	±30	±30	±30	±35	±30	±30
	Fraction of Total at Imhoff Tank Removed by Sludge					
Collection period (1964-65)	0.44	0.11	0.21	0.06	—	0.17
Estimated error	$^{+0.06}_{-0.10}$	±0.03	$^{+0.04}_{-0.06}$	±0.03	—	±0.05

N.A. = not available.
[a]Total estimated amount, in grams, $2 \times 10^7 \pm 25\%$.
[b]Total estimated amount, in grams, $5 \times 10^7 \pm 25\%$.

samples were analyzed for γ-emitting isotopes. The turtles, with numbers engraved on their shells for identification, were returned to the stream at the point of collection so that they would be available for future sampling. The only nuclides detectable in most samples were ^{60}Co and ^{137}Cs; however, measurable amounts of ^{65}Zn were detected in one species of stream vegetation (*Vallisneria americana*) as far downstream as the eastern boundary. These appear to be related to the input of ^{65}Zn to the filter beds in June 1966 (see Table 17).

The bottom sediment profile appears in Figure 15. Profiles for a species of underwater vegetation (*Vallisneria americana*), which was found throughout the stream, appear in Figure 16, together with concentrations found in miscellaneous vegetation species obtained on the Laboratory site.

The stream-sediment and vegetation data are generally comparable with those shown in the reports for 1964 and 1965 and confirm that most of the radioactivity contained in the Laboratory liquid effluent released to the Peconic is retained within a distance of a few miles downstream from the point of release.

The concentrations of γ-emitting nuclides in turtles from the Peconic are summarized in Table 20. Although many eastern painted turtles were easily obtained on site, too few were collected

Table 19

1966 BNL Environmental Monitoring
Monthly Stream Water Samples and Yearly Averages for 1960–1966, Gross β Concentrations

(Values for ^{3}H in nCi/liter; all others in pCi/liter.)

	Peconic River locations, proceeding downstream from chlorine house								Control locations					
Month, 1966	K	L	M	Q	A	B	C	D	E	F	G	H	I	J
							Gross β							
Jan.	31	28	50	8	—	5	2	<2	—	7	—	<2	13	8
Feb.	23	21	62	45	15	10	4	3	5	8	—	<2	12	3
Mar.	65	50	15	26	13	5	13	6	—	13	—	<2	16	16
Apr.	29	25	32	55	27	7	6	4	—	3	—	11	15	9
May	35	36	—	42	20	10	4	5	—	14	—	2	16	7
June	22	—	—	46	23	9	9	5	—	18	—	6	20	13
July	43	51	—	48	—	5	6	—	—	—	—	1	21	3
Aug.	18	17	—	33	—	6	6	3	—	9	—	<1	23	3
Sept.	20	31	21	31	19	15	3	3	—	9	—	2	3	7
Oct.	17	15	12	24	11	14	7	4	—	9	—	2	16	7
Nov.	20	29	13	12	13	24	15	10	—	8	—	7	25	8
Dec.	17	18	17	15	10	7	5	4	—	7	—	3	13	3
							^{3}H							
Nov.	5	5	5	1	<1	<1	<1	<1	—	<1	—	<1	<1	<1
Dec.	10	10	14	4	<1	<1	<1	<1	—	<1	—	<1	<1	<1
							Yearly Average Gross β Concentration							
1966	29	29	28	32	17	10	7	4	—	10	dry	3	16	7
1965	39	41	39	56	18	10	10	8	14	10	10	7	17	15
1964	115	83	49	52	30	25	19	14	15	19	13	10	25	18
1963	61	74	39	—	46	42	59	40	36	37	13	25	50	35
1962	—	—	—	—	47	31	39	33	38	35	23	36	44	38
1961	—	—	—	—	34	19	—	17	17	10	6	9	14	16
1960	—	—	—	—	20	13	—	11	8	5	7	9	13	6

Estimated error: <10 pCi/liter, ±2 pCi/liter; 11 to 25 pCi/liter, ±15%; >25 pCi/liter, ±10%.

off site to provide a meaningful profile of concentration vs distance downstream. Except in a few of these turtles obtained at the perimeter, ^{137}Cs was the only detectable radionuclide. The highest concentration (14.3 pCi/g) was found in one obtained just below the chlorine house outfall, but concentrations almost as high (10.7 and 11.0 pCi/g) were found in two turtles obtained 5 miles downstream.

The data for three turtles that were "repeaters" from the 1965 sampling are shown in Table 21. It appears from the two originally trapped off site and placed in the Peconic River on site in 1965

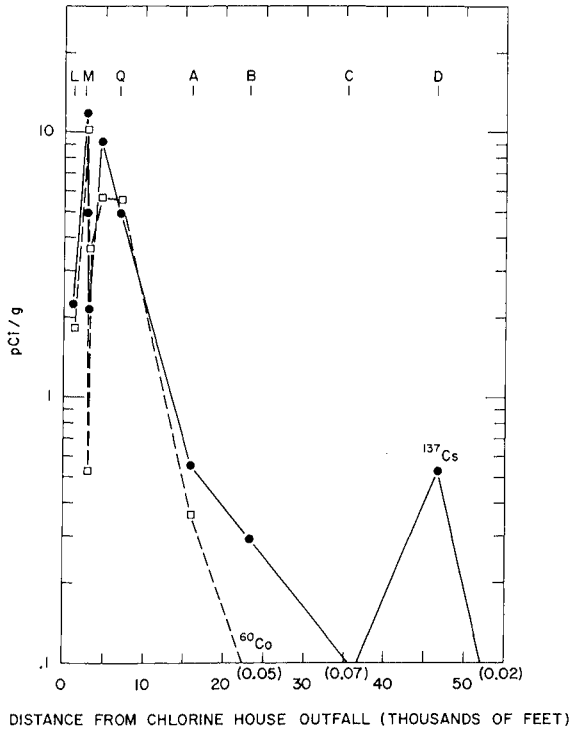

Figure 15. Peconic River bottom sediment samples.

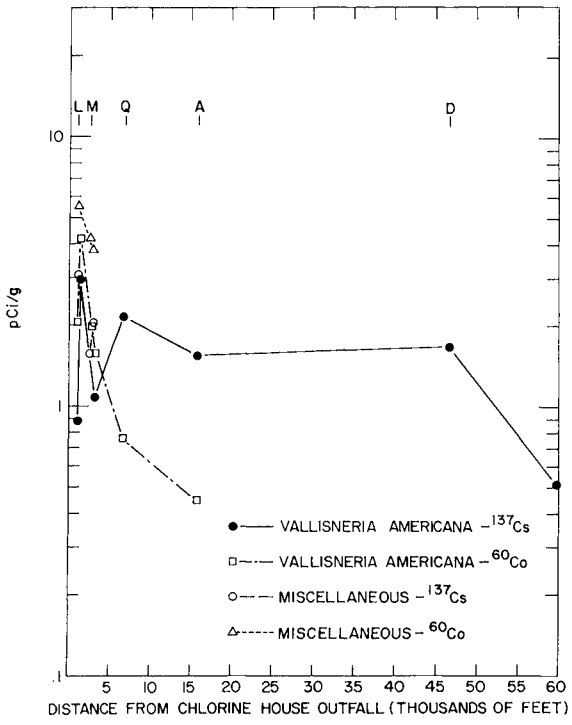

Figure 16. Peconic River vegetation samples.

Table 20

1966 BNL Environmental Monitoring
Average Concentrations of ^{60}Co, ^{65}Zn, and ^{137}Cs in Peconic River Turtles, pCi/g

Trap location (ft downstream)	Stream station	Species: Eastern painted ^{137}Cs	Eastern painted ^{60}Co	Eastern painted ^{65}Zn	Snapping ^{137}Cs	Snapping ^{60}Co
150	K	*(1) 14.3	<0.1	<0.1	—	—
1,300	L	(4) 5.6	<0.1	<0.1	(1) 3.1	0.1
1,800	—	(4) 2.7	<0.1	<0.1	—	—
2,600	M	(12) 5.1	0.1	0.1	—	—
23,100	B	(2) 10.9	<0.1	<0.1	—	—
35,500	C	(2) 2.2	<0.1	<0.1	—	—

*Parentheses indicate number of samples.

Table 21

1966 BNL Environmental Monitoring
Comparison of Turtles Sampled in 1965 and 1966

Specimen No.		Trap location (ft downstream)	Weight, g	Conc., pCi/g ^{137}Cs	Conc., pCi/g ^{60}Co
HP-3	1965	2600	240	6.3	<0.1
	1966	1300	240	3.9	<0.1
HP-5	1965	Off site	553	*	*
	1966	1860	547	3.9	0.9
HP-13	1965	Off site	275	0.1	<0.1
	1966	1300	270	1.3	<0.1

*Not analyzed in 1965; obtained from same off-site location as HP-13.

Table 22

1966 BNL Environmental Monitoring
Concentrations of ^{137}Cs, ^{65}Zn, ^{60}Co, and ^{40}K in Miscellaneous Peconic River Fauna

(Values for K in g/kg; all others in pCi/g.)

	Location (ft downstream)	^{137}Cs	^{65}Zn	^{60}Co	^{40}K
Snapping turtle	1300	3.10	—	0.07	—
Bullhead	2600	1.64	—	—	—
Snake (Eastern racer)	2600	6.90	—	0.14	—
Bluegill	2700	6.00	0.38	0.04	3.74
Bluegill	2700	6.09	0.65	0.75	3.47
Catfish	6900	4.60	—	0.20	3.38

that this species came to near equilibrium with the ambient concentrations within 1 yr. Similar data on the γ-emitting nuclides in other animals obtained in the Peconic are summarized in Table 22.

Through the cooperation of the Suffolk Health Department a sample of clams from the mouth of the Peconic River was obtained on July 18. The results of the assay for γ-emitting isotopes are shown in Table 23. No activity attributable to the Laboratory effluent could be detected.

Since there is an abundant underground supply of water on Long Island, the Peconic River is not used to supply drinking water or for irrigation. Its waters are occasionally used to flood the lower bogs of a commercial cranberry operation eight miles downstream. Although they were not so used in 1966, one sample of berries from the lower bogs of this farm was obtained in October. The only identifiable γ-emitting isotope found was ^{137}Cs (1.04 pCi/g).

Table 23

1966 BNL Environmental Monitoring
γ-Emitting Radioactivity in Clams at Mouth of Peconic River, July 18

(Values for K in g/kg; all others in pCi/kg.)

	^{54}Mn	^{137}Cs	U	Th	K
Meat	30	90	230	110	2.13
Shells	30	80	390	80	0.93
Estimated error, %	±10	±10	±50	±50	±0.2

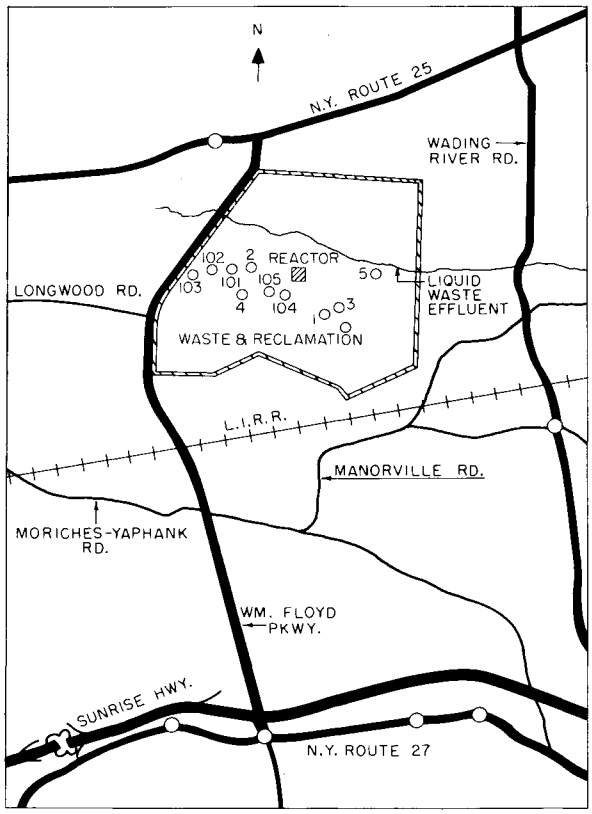

Figure 17. Location of BNL water supply wells.

WELL SAMPLING

The Laboratory's potable water wells and cooling water supply wells are about 100 ft deep or 50 ft below the water table in the Long Island surface layer of glacial outwash sand and gravel. They are also generally west to northwest and up-

Table 24

1966 BNL Environmental Monitoring
Gross β Concentrations in Deep Well Samples, pCi/liter

	Potable water well no.							
Month	1	2	3	4	5	6	7	W&R*
Jan.	<1.6	<1.5	<1.6	2.4	2.9	1.5	3.7	1.2
Feb.	—	—	—	2.4	<1.1	<1.1	<1.1	<1.2
Mar.	<1.1	<1.1	<1.1	<1.1	<1.1	—	—	<0.8
Apr.	<1.0	<1.0	<1.0	5.4	2.7	2.1	<1.0	<1.0
May	1.8	2.5	<0.9	2.2	1.2	<0.9	0.9	<0.9
June	<1.0	1.2	1.0	2.0	1.1	2.0	<1.0	1.0
July	<1.0	2.1	<1.0	1.4	<1.0	<1.0	2.0	<1.0
Aug.	1.6	<1.0	1.4	<1.0	1.6	2.1	<1.0	<1.0
Sept.	<1.0	<1.0	<1.0	1.1	<1.0	1.5	<1.0	<1.0
Oct.	2.2	<1.0	<1.0	<1.0	<1.0	1.5	<1.0	<1.0
Nov.	—	1.2	1.1	1.6	1.5	<1.0	1.1	1.1
Dec.	2.0	1.4	5.6	2.5	1.4	1.6	1.1	0.9
Av	1.1	1.1	0.7	1.8	1.3	1.3	1.1	0.7

	Cooling supply well no.				
Month	101	102	103	104	105
Jan.	—	<1.5	<1.5	<1.8	<1.5
Feb.	<1.1	<1.1	<1.1	1.2	<1.1
Mar.	<1.1	<1.1	<1.1	<1.1	<1.4
Apr.	—	<1.0	<1.0	—	5.1
May	—	<0.9	<1.0	<1.0	<1.0
June	—	<1.0	6.9	4.5	1.3
July	<1.0	1.9	<1.0	1.9	2.1
Aug.	<1.0	1.4	1.9	2.0	2.0
Sept.	<1.0	<1.0	2.3	1.4	<1.0
Oct.	<1.0	<1.0	2.1	<1.0	2.0
Nov.	<1.0	1.0	1.0	<1.0	2.0
Dec.	1.7	<0.9	1.4	—	1.0
Av	0.7	0.8	1.6	1.4	1.5

*Waste disposal and reclamation well.

stream from most of the Laboratory's facilities. The exceptions are principal potable water wells Nos. 1 and 3, the smaller well (No. 5) at the sewage plant, and the one at the waste and reclamation area (see Figure 17). Monthly gross β results are summarized in Table 24. Less-than-background values have been assumed to be 50% of the detection limit in calculating yearly averages. No significant differences from the previous sampling were apparent except for well No. 5 at the sewage plant, which averaged 1.3 pCi/liter compared with 5.3 in 1965.

VEGETATION AND SOIL SAMPLING

In addition to routine sampling early and late in the summer, a number of grass samples were secured from nearby farms (at most of which milk and soil samples were also obtained) to ascertain the levels of fallout nuclides during the few weeks after the May and October Chinese weapons tests. Most of the fallout activity observed in these samples appears to have been deposited during several periods of light to moderate precipitation late in May and early in June and November.

Table 25

1966 BNL Environmental Monitoring
Concentrations of γ-Emitting Isotopes in Pasture Grass

(Values for K in g/kg; all others in pCi/g.)

Location	Month	No. of samples	^{7}Be	^{54}Mn	^{95}Zr-^{95}Nb	^{103}Ru	^{131}I	^{137}Cs	^{140}Ba-^{140}La	^{141}Ce	^{144}Ce	K
Farm A,	May	3	873	<100	620	350	137	190	320	288	—	5.87
3 km NW	June	1	N.A.	<100	500	<250	—	116	343	<250	—	5.16
	July	1	—	<100	440	—	—	—	<100	250	—	6.60
	Aug.	1	1872	<100	638	<250	—	332	—	<250	—	4.03
	Oct.	1	3260	<100	217	—	—	107	—	—	1240	3.60
	Av		2002	<100	483			186				5.05
Farm B,	May	2	<1000	<100	606	196	168	<250	497	225	—	5.24
6 km SW	June	1	N.A.	<100	229	<250	N.A.	<100	172	<250	—	7.03
	July	1	2910	<100	220	—	—	190	420	210	—	9.30
	Aug.	1	1215	<100	842	252	—	100	—	<250	—	6.34
	Nov.	2	768	<100	<250	—	—	400	<100	—	<250	4.95
	Av		1348	<100	404			173				6.57
Farm C,	May	1	<1000	<100	665	178	116	250	347	<250	—	4.54
10 km SE	June	1	N.A.	<100	2940	465	N.A.	N.A.	1074	316	—	3.96
	July	1	—	<100	2240	—	—	370	<100	600	—	12.70
	Oct.	1	1090	<100	<250	—	—	78	—	—	547	3.45
	Nov.	1	9650	<100	3120	—	1310	400	9300	1135	—	—
	Av		3747	<100	1818			243				6.16
Farm D,	May	1	<1000	<100	407	<250	197	<250	776	<250	—	4.36
15 km NW	June	1	N.A.	<100	313	544	<50	N.A.	343	<250	—	4.95
	July	1	3940	<100	<250	—	—	180	1380	470	—	8.50
	Oct.	1	749	<100	<250	—	—	85	—	—	381	4.77
	Av		1730	<100	242			130				5.64
Farm F, 30 km E	July	1	2210	<100	250	—	—	100	730	250	—	2.50
Farm H, 6 km NE	July	1	5410	<100	1110	—	—	520	790	250	—	4.50
BNL site	Apr.	4	4327	295	<250	—	64	1317	—	—	401	3.80
	May	1	<1000	<100	735	<250	277	500	1205	702	—	N.A.
	July	1	7620	<100	4340	—	—	1065	300	525	—	7.80
	Aug.	6	5970	<100	3583	<250	—	1101	—	348	—	4.15
	Sept.	2	1724	<100	<250	—	63	152	—	—	<250	5.88
	Oct.	1	671	<100	<250	—	—	400	—	—	<250	3.50
	Av		3469	91	1506			756				5.03
Estimated error of individual sample			±25% or ±500*	±100%	±10% or ±50	±50% or ±250	±25% or ±50	±10% or ±100	±25% or ±100	±25% or ±250	±25% or ±250	±0.5

N.A. = not available.

*Whichever is greater.

Table 26

1966 BNL Environmental Monitoring
Concentrations of γ-Emitting Isotopes in Soil

(Values for K in g/kg; all others in pCi/kg.)

Location	Month	^{137}Cs	U_{nat}	Th_{nat}	K
Farm A	Mar.	440	N.A.	N.A.	5.5
	July	<250	"	"	5.7
Farm B	Oct.	530	940	740	7.5
Farm C	July	<250	1700	1600	6.2
	Oct.	1110	690	550	4.5
Farm D	July	<250	2200	2200	8.4
	Oct.	<250	1350	1080	9.5
Farm F	July	960	1200	1800	2.9
	Oct.	<250	1290	1120	12.5
Farm H	July	1995	1200	1800	7.7
Av		566	1321	1361	7.0
Estimated error (individual sample)		±250	±500	±500	±1.0

N.A. = not available.

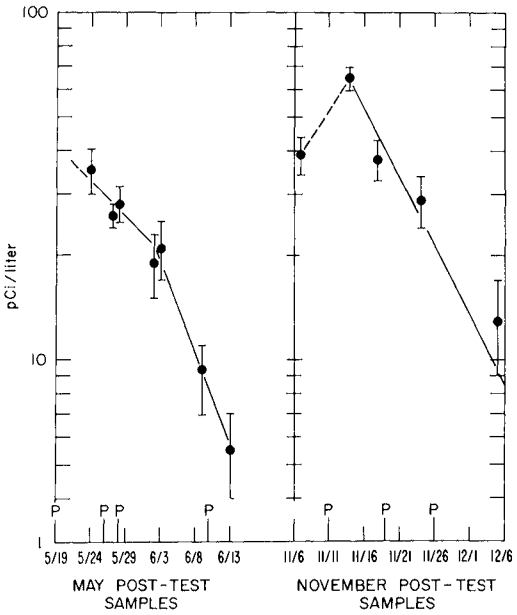

Figure 18. Post-test concentrations of ^{131}I in milk, May and November, 1966. P = measurable precipitation.

About 25% of the ^{131}I deposited in precipitation on May 19 and 22 and about 35% of that deposited on Nov. 6 appear to have been retained on the grass.

Concentrations of identifiable γ-emitting isotopes in these pasture samples are summarized in Table 25. The concentrations of these isotopes in both precipitation and pasture vegetation declined markedly in comparison with 1965 data.

The average ^{131}I deposition of two grass samples, obtained on Apr. 22 (at stations S-6 and S-13) in connection with the ^{131}I release from the Hot Laboratory, was 75 pCi/kg. The corresponding calculated deposition velocity was about 0.5±0.3 cm/sec.

Samples of the top 6 in. of soil were obtained in July and October from most of the farms in the vicinity of the Laboratory from which vegetation samples were secured. The concentrations of identifiable γ-emitting isotopes present appear in Table 26. The concentrations of natural uranium and thorium were determined by comparison with the γ spectrum of calibrated ore samples.

MILK SAMPLING

Meteorological predictions of average ground concentrations of ^{131}I emitted from the BGRR, with reasonable assumptions about its deposition and about the relationship between grass and milk concentrations, led to the conclusion that the concentration of Laboratory-released ^{131}I in the milk from cows pastured in the vicinity would generally be <1 pCi/liter, or well below the lower limit of detection. This expectation was confirmed by the measurements.

The concentrations of ^{137}Cs and the amounts of potassium in routine monthly samples are shown in Table 27. For locations sampled more than once, the number of samples is shown in parentheses and the ^{137}Cs and K values are averages. Samples with a concentration of ^{131}I >2 pCi/liter are also listed by date and location. The applicable radiation protection guide for ^{131}I, assuming an intake of 1 liter/day, is 100 pCi/liter.

Measurable concentrations of ^{131}I were generally evident shortly after the arrival of debris from the May and late October Chinese tests. The data for the several milk samples collected during and shortly after the largest depositions of ^{131}I late in May are shown in Figure 18. Weekly precipitation samples indicate that about 4 nCi/m^2 of ^{131}I was deposited in each of the last two weeks in May. Measurable precipitation was collected on May 24 and 26. Only trace amounts occurred between then and June 10. The decline in ^{131}I concentra-

Table 27

1966 BNL Environmental Monitoring
Concentrations of ^{131}I, ^{137}Cs, and K in Milk Samples

(Values for K in g/liter; for ^{137}Cs, in pCi/liter.)

Month	Game farm (A), 3 km NW		Suffolk County farm (B), 6 km SW		Thees farm (C), 10 km SE		Randalls farm (D), 15 km NW	
	^{137}Cs	K	^{137}Cs	K	^{137}Cs	K	^{137}Cs	K
Jan.	58	1.6	113	1.6	81	1.2	67	1.2
Feb.	44	1.5	62	1.0	48	1.9	57	1.6
Mar.	52	1.1	32	1.5	70	1.5	37	1.1
Apr.	(2) 40	1.3	(2) 58	1.3	71	1.5	45	1.5
May	(2) 52	1.4	(3) 45	1.5	52	1.3	(2) 46	1.4
June	(2) 46	1.4	(2) 64	1.4	(2) 62	1.4	(2) 45	1.5
July	—	—	41	1.4	72	1.6	44	1.5
Aug.	40	1.0	61	1.4	38	1.4	28	1.4
Sept.	—	—	52	1.6	34	1.3	41	1.1
Oct.	—	—	41	1.6	33	1.6	59	1.5
Nov.	36	1.5	(4) 48	1.7	(4) 46	1.6	(2) 30	1.4
Dec.	41	1.3	47	1.6	65	1.6	46	1.7
Yearly av	45	1.3	55	1.5	56	1.5	46	1.4

Estimated error (individual samples): ^{137}Cs, ±15 pCi/liter; K, ±0.2 g/liter.

Date	^{131}I Farm: A	B	C	D
Jan. 10	—	—	2.5	—
Feb. 17	—	2.8	—	—
May 13	9.0	2.0	—	—
24	42.0	28.0	—	—
26	—	—	26.0	26.0
27	—	28.0	—	—
June 2	25.0	—	19.0	13.0
3	—	21.0	—	—
9	13.0	6.0	—	—
13	—	—	3.0	8.0
July 1	—	—	3.0	—
11	—	—	—	16.0
Aug. 1	—	—	4.0	4.0
10	9.0	2.0	—	—
Sept. 12	—	—	6.0	5.0
26	—	6.0	—	—
Oct. 3	—	—	9.0	14.0
11	—	4.0	—	—
Nov. 2	—	7.0	—	—
7	—	—	39.0	16.0
10	—	13.0	—	—
14	—	—	65.0	—
15	—	13.0	—	—
17	7.0	—	—	—
18	—	—	38.0	6.0
24	—	—	29.0	—
Dec. 5	—	—	13.0	10.0
14	5.0	4.0	—	—

Estimated error: 2 to 5 pCi/liter, ±50%; 5 to 25 pCi/liter, ±35%; >25 pCi/liter, ±20%.

Table 28

1966 BNL Environmental Monitoring
Gross β and Tritium Concentrations in Recharge Basins

(Values for ^{3}H in nCi/liter; for gross β, in pCi/liter.)

Month	Location		
	North of AGS	East of BGRR	Medical complex
	Gross β		
Jan.	3	1	2
Feb.	13	<2	<2
Mar.	5	3	2
Apr.	5	5	—
May	5	3	<1
June	5	2	1
July	8	2	<1
Aug.	5	2	2
Sept.	4	<1	1
Oct.	3	2	<1
Nov.	6	2	2
Dec.	4	2	15
Av	6	2	2
	^{3}H		
Nov.	<1	<1	<1
Dec.	<1	3	4

tions in milk obtained during this period suggests an effective half-time of about 5.5 days. The concentrations of ^{131}I in milk from the one farm at which cows were on pasture throughout November are also shown in Figure 18. The sampling data do not reflect the maximum concentration, which was probably about 100 pCi/liter about Nov. 10. The half-time appears to be about 8 days, but this may reflect the several small precipitation depositions during November.

The May and November data are generally consistent with those reported for this region by the U.S. Public Health Service.[23] It is readily apparent from Table 27 that during the latter period only the herd at Farm C was consistently on pasture. This suggests that during marginal pasture conditions, differences in feeding practices can produce order-of-magnitude differences in the amount of ^{131}I reaching dairy cows in the same milkshed area.

ON-SITE SUMPS

Monitoring for the possible entry of radioactivity into the ground water included three recharge

Table 29

1966 BNL Environmental Monitoring
Dump Disposal of Contaminated Waste, 1964–66

Year	Month	Activity, μCi		
		Class I ($T_{1/2}$, <100 days)	Class II ($T_{1/2}$, 100 days–5 yr)	Class III ($T_{1/2}$, >5 yr)
1964				
	Jan.	225	35	28
	Feb.	1,274	714	8,379
	Mar.	56	89	5,263
	Apr.	598	2,687	7,631
	May	1,258	716	5,770
	June	90	540	3,984
	July	518	420	859
	Aug.	223	480	3,218
	Sept.	163	162	5,188
	Oct.	264	67	10,312
	Nov.	1,473	34	13,343
	Dec.	46	109	6,502
	Total	6,188	6,053	70,477
	Av	516	504	5,873
	% of allowable limit	0.069	0.605	70.4
1965				
	Jan.	145	186	12,281
	Feb.	536	62	8,030
	Mar.	148	0	5,610
	Apr.	279	27	7,272
	May	3,788	30	890
	June	174	224	4,012
	July	51	97	7,880
	Aug.	0	0	0
	Sept.	327	174	20,063
	Oct.	20	0	9,808
	Nov.	215	0	14,256
	Dec.	35	1	9,311
	Total	5,718	801	99,413
	Av	520	73	9,038
	% of allowable limit	0.063	0.08	99.4
1966				
	Jan.	311	233	14,027*
	Feb.	177	1,168	823
	Mar.	927	3,262	480
	Apr.	456	12,114	505
	May	1,290	6,377	370
	June	0	0	0
	July	0	0	0
	Aug.	365	7,937	507
	Sept.	5,375	556	1,027
	Oct.	1,976	3,323	1,925
	Nov.	583	880	366
	Dec.	1	6,163	2,632
	Total	11,461	42,013	22,662
	Av	1,146	4,201	2,266
	% of allowable limit	0.13	4.20	22.6

*During January $\approx$9900 μCi of activity was moved from sludge bed to dump.

basins, one north of the Alternating Gradient Synchrotron, one east of the BGRR, and one south of the Medical complex, into which secondary cooling water from these facilities is discharged. These sumps are also open to surface runoff, and, as shown in Table 28, their gross β concentrations appear to follow the concentration trends reported in the section on stream sampling. Analysis of these samples for ^{3}H was initiated in November, and these data are also shown in Table 28.

ON-SITE SOLID WASTE DISPOSAL

Small quantities of solid radioactive wastes may be disposed of in the ground locally under an AEC approved policy[24] that allows a total of 10 Ci of radioactivity a year to be placed in the open-pit burial ground located in the southeastern part of the Laboratory site (see Figure 2). However, further restrictions are imposed on the basis of half-life, as follows.

(1) Of the 10 Ci total activity, no more than 1 Ci may have a half-life >100 days.
(2) Of this 1 Ci, no more than 100 mCi may have a half-life >5 yr.
(3) No more than 1 mCi of radium and plutonium may be disposed of in this manner per year.

The amounts of radioactive solid waste with the percentages of allowable activity per class that have been disposed of on the Brookhaven open-pit dump since 1964 are listed in Table 29.

SPECIAL PROJECTS

Whole-Body Burden and 24-hr Elimination of ^{137}Cs

In mid-1964 a program in cooperation with the Medical Department was initiated to gather data for a comparison of human body burdens and 24-hr urine sample levels of ^{137}Cs. Because of the decline in prevailing concentrations, this program was concluded in mid-1966. A summary of the quarterly average body burdens, urine concentrations, and daily excretion is presented in Table 30. Quarterly average concentrations of ^{137}Cs in milk and air samples and the ^{137}Cs deposited in precipitation are also shown. The data obtained in 1966 indicate that the average concentration of ^{137}Cs found in the 24-hr urine samples was comparable with that found in milk samples during the same sampling period. Air and precipitation concentrations of ^{137}Cs continued to decline in 1966 in comparison with 1964 and 1965 levels. The measured 24-hr urine excretions of ^{137}Cs and corresponding body burdens of BNL employees

Table 30
1966 BNL Environmental Monitoring
Comparison of ^{137}Cs in Humans and in Environmental Media

				Urine		Milk	Air	Precipitation
Year	Quarter	No. of persons	Av body burden, pCi	Av conc., pCi/liter	Av daily excretion, pCi	Av conc., pCi/liter	Av conc., pCi/m^3	Activity, nCi/m^2
1964	1st	—	—	—	—	194	0.070	12.3
	2nd	—	—	—	—	148	0.150	12.3
	3rd	18	16,300	134	187	128	0.057	4.3
	4th	8	18,000	126	139	112	0.030	2.7
1965	1st	13	13,300	100	98	101	0.035	2.4
	2nd	7	18,900	107	89	76	0.041	4.5
	3rd	6	27,100	96	120	64	0.020	1.3
	4th	25	11,500	106	101	58	0.009	0.9
1966	1st	36	10,760	66	72	60	0.010	1.5
	2nd	28	8,710	63	64	52	0.019	1.1
	3rd	15	9,520	64	74	45	0.011	0.8
	4th	—	—	—	—	45	0.004	0.5
Estimated error, %						±10	±10	±10

who participated during 1964 and 1965 are shown in Figure 19. It is evident that a single urine sample does not indicate body burdens within a factor of 2.

Measurement of Radioactivity in an Oak-Pine Ecosystem

A project undertaken in cooperation with the Biology Department in the summer of 1966 involved γ-ray spectrometry on selected samples from the Biology Department's ecology forest to determine the distribution of γ-emitting radionuclides in an oak-pine ecosystem. The study is of particular interest from an environmental monitoring standpoint because radioactive fallout becomes accumulated in plant parts mainly by direct aerial deposition and persistence in the environment may be important in the determination of radionuclide concentrations. The data have been published elsewhere.[25]

Selection of Materials for a Low-Background Steel Shield Base

A large, low-background steel shield was acquired in June 1966. Its inner dimensions are 4×4×4 ft. The primary detector for this shield is a 5×8-in. NaI crystal. A second 5×8-in. crystal will be added to improve counting geometry.

Prior to erecting the shield, a brief survey was made to select suitable materials to minimize the external γ background from the concrete base now in use. Previous studies of the γ activity in materials selected for the new low-level counting facility at the Brookhaven Medical Research Center[26] and a study by Wollenberg and Smith[27] for the Lawrence Radiation Laboratory Facility were utilized. This survey was confined to local stores or to nearby available materials that these studies indicated would be worth considering for low background.

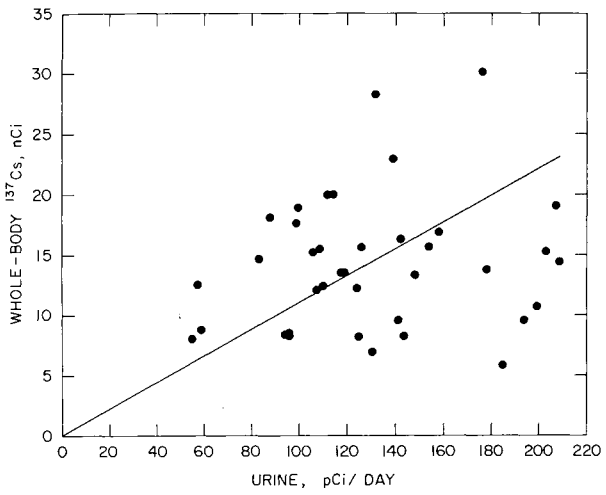

Figure 19. Human body burden vs 24-hr urine excretion of ^{137}Cs.

Cement purchased locally was compared, on the basis of Wollenberg and Smith's study, with cement remaining from a large amount obtained from the British Columbia Cement Co. for the low-level counting facility. The data are shown in Table 31.

A study was made of the activity in on-site sands and gravels, sands and gravels from the nearby source selected for the Medical Facility, and the local stores of limonite and ilmenite. During the study a sample of ferrophosphate was unintentionally counted. The data (Table 31) suggest that ferrophosphate (when protected from fallout, as that in the local store was not) ranks with the high-density materials investigated by Wollenberg and Smith as a low-background aggregate.

A comparison of the 600-min background spectra obtained with two 4×2-in. NaI detectors in a smaller 6-in.-thick pre-World War II steel shield and with an 8×5-in. NaI detector in the new large shield can be made from Figure 20. A small amount of ^{60}Co contamination is evident in the contemporary steel shield.

Radiocarbon Levels in the Immediate Air Environment of the BGRR

The BGRR produces ^{14}C by the (n,p) reaction with the ^{14}N in its cooling air. In the summer of

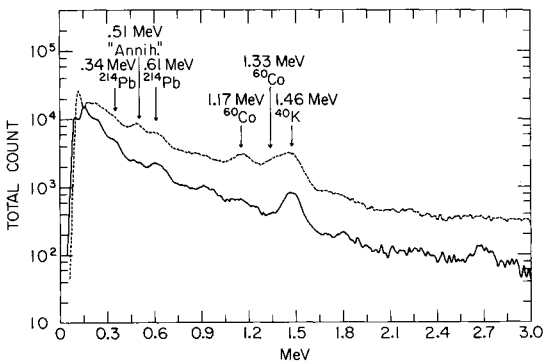

Figure 20. Background spectra obtained with two 4×2-in. NaI detectors in a 6-in.-thick pre-World War I steel shield (solid line) and with an 8×4-in. NaI detector in a 6-in.-thick contemporary steel shield (broken line).

Table 31

1966 BNL Environmental Monitoring
Comparison of Cement and Aggregate Backgrounds

Material	Date	γ/min/kg in principal photopeak regions							
		0.24	0.36	0.58 and 0.60	0.66	0.91	1.44	1.76	2.62
Gravel, BNL	3/20	126	210	183	<50	50	1125	93	43
Acme	4/19	187	153	138	<50	96	725	75	56
Sand, BNL	3/20	300	230	205	<50	182	675	100	137
Acme	4/19	169	153	157	<50	141	589	<50	92
Cement, BNL	3/20	531	420	324	<50	394	1000	120	194
ELK	5/6	131	115	222	<50	66	197	<50	<50
Limonite, BNL	4/6	87	113	217	<50	<50	180	121	<50
	5/2	354	740	750	<50	<50	490	530	<50
Ilmenite			60	76	326	<50	168	<50	<50
BNL	4/11	88	68	26	97	<50	105	<50	<50
Twin County, fine	4/27	82	35	31	136	<50	96	<50	<50
Twin County, medium	4/27	95	42	53	208	51	129	<50	<50
BNL, medium	4/27	133	<25	<25	88	<50	19	<50	<50
Ferrophosphate, BNL	4/27	<50	27	<25	86	50	32	<50	<50
	5/4	<50							

1966 a project[28] was conducted to investigate the feasibility of measuring the radiocarbon levels in the effluent cooling air and at ground level in the vicinity of the BGRR.

Air was drawn through glass fiber and halogen filters to remove particulates and halogens and then through a bubbler of the Greenberg-Smith type containing 0.5 N NaOH solution to trap CO_2. At the conclusion of the sampling period (24 to 72 hrs) $BaCO_3$ was precipitated from the sampling solution, dried, and powdered. It was then suspended in a scintillating gel and counted in a dual-channel liquid scintillation spectrometer.

Since this project was primarily a feasibility study, the sampling parameters were not carefully established. An apparent 24-hr average ^{14}C stack concentration, based on approximations of these parameters, was 2×10^{-8} $\mu Ci/cm^3$ as compared with a calculated concentration of 6×10^{-8} $\mu Ci/cm^3$ (based on the observed ^{41}Ar emission).

During the same 24-hr period an apparent downwind concentration of 1×10^{-10} $\mu Ci/cm^3$ was found at station S-13. While this S-13 concentration was about 1/1000 of the Radiation Protection Standard for uncontrolled areas, it was at least 1000 times that calculated on the basis of the stack effluent concentration and calculated diffusion. The reasons for this higher than anticipated ground-level concentration have not been established.

Waste and Reclamation Area Well Sampling

Samples of underground water were obtained from the well in the waste and reclamation (Igloo) area reported[29] to have been accidentally contaminated with between 1.5 to 6 Ci of old fission products in the summer of 1960. Samples were also obtained from a set of wells 80 ft downstream (southeast) for the apparent direction of groundwater flow in this region. The distance to the top of the water table in this portion of the Laboratory site is about 15 ft below grade. The original sampling data indicated that the maximum contamination was at 21 ft below grade, or only a few feet into the water table.

The gross β concentrations obtained between 1960 and 1966 in these wells are shown in Table 32. Some measurements of ^{90}Sr and ^{137}Cs concentrations were made in 1966, and these data are included in the table.

Table 32

1966 BNL Environmental Monitoring
Gross β Concentration in Igloo Wells, pCi/liter

Well No.	Distance, ft	Direction	Gross β Nov. 1960	Feb. 1961	Nov. 1961	Aug. 1962	July 1963	Apr. 1966	Apr. 1966 ^{90}Sr	Apr. 1966 ^{137}Cs
1	0	—	2.3×10^6	2.2×10^{6}*	3.3×10^5	3.6×10^5	3.2×10^5	1010	24	1205
10	80	155°	740	140	—	—	—	58	147	—
13	80	157°	7.6×10^4	1700	—	350	94	24	—	—
24	80	159°	—	3100	—	520	135	18	—	—
14	80	160°	5.6×10^4	1.2×10^4	770	—	208	36	—	—
23	80	162°	700	3.4×10^4	650	440	281	99	—	35
22	80	163°	360	440	820	120	297	550*	126	<10
33	80	168°	—	—	160	60	167	111	77	22

*Initial undisturbed sample, prior to pumping, 76 pCi/liter.

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