SLAC-271

ANNUAL ENVIRONMENTAL MONITORING REPORT
JANUARY—DECEMBER 1983

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PREPARED FOR THE DEPARTMENT OF ENERGY
UNDER CONTRACT NO. DE-AC03-76SF00515

MARCH 1984

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1. INTRODUCTION

The Stanford Linear Accelerator Center (SLAC) is located two miles west of the Stanford campus in San Mateo County, California. Its boundaries include Sand Hill Road on the north, and San Francisquito Creek. The total length of the accelerator and experimental areas is approximately three miles, and is oriented almost east-west. Figures 1 and 2 locate SLAC with respect to the surrounding vicinity.

SLAC is a large research laboratory devoted to theoretical and experimental research in high energy physics and to the development of new techniques in high energy accelerator particle detectors.

Authorization of the project was given by the U.S. Congress in 1961. Construction of the accelerator started in 1962, and was completed in 1966. Research consisting of numerous and varied experiments has been underway since late 1966. The work is carried out under the sponsorship and financial support of the Department of Energy.

The main tool of the laboratory is a two mile long linear accelerator. This accelerator now produces beams of electrons with energies up to 31 billion electron volts (31 GeV). It can also accelerate positrons, the "antiparticles" of the electrons, up to 20 GeV. These beams can be used directly for experiments or they can be transported into either of two storage-ring facilities – SPEAR or PEP (see Fig. 2). These storage-rings are major laboratory facilities, roughly circular in shape, in which electrons and positrons brought from the accelerator are stored and circulated continuously in opposite directions. The energies are 4.5 and 18 GeV per beam for SPEAR and PEP, giving total collision energies of 9 and 36 GeV, respectively. SPEAR has been in operation since 1972 and PEP was first filled with beam on April 13, 1980.

The operation of PEP does not pose any greater hazards than those of the laboratory as it was previously operated. A high center-of-mass energy is achieved far more efficiently by colliding particles together than by having a single beam strike a stationary target. In a colliding beam storage-ring, the beam particles

are truly "recycled"; the same bunches of particles are brought into collision over and over again, rather than striking a target only once. For this reason, colliding beam devices produce much less radiation and residual radioactivity than do conventional accelerators. These statements are borne out by the monitoring data presented below.

Summary

Environmental monitoring results continue to demonstrate that environmental radiological impact due to SLAC operation is not easily distinguishable from natural environmental sources. During 1983, the maximum approximated neutron dose near the site boundary was 5 mrem. Results appear in Table 2.

There have been no measurable increases in radioactivity in ground water attributable to SLAC operations since operations since operation began in 1966. We plan to continue sampling wells W-23 and W-24 which are located near our two major beam dumps. If ground water activation did occur we would expect to find evidence at these locations long before the products migrated greater distances from the source. We have never found any evidence of radioactivity in ground water in excess of natural background radioactivity from uranium and thorium decay chains and potassium-40.

Airborne radioactivity released from SLAC continues to make only a negligible environmental impact, and results in a site-boundary annual dose of less than 0.3 mrem; this represents less than 0.3% of the annual dose from the natural radiation environment, and about 0.06% of the technical standard.

2. MONITORING TECHNIQUES AND STANDARDS

2.1 CONCENTRATION GUIDES FOR LIQUID EFFLUENT

Because of the nature of the radionuclides produced at SLAC, the appropriate Concentration Guide (CG) for liquid effluents is $3 \times 10^{-6}\ \mu Ci/m\ell$. This is true because none of the following isotopes are produced at SLAC:

^{90}Sr , ^{125}I , ^{126}I , ^{129}I , ^{131}I , ^{210}Pb , ^{210}Po , ^{211}At , ^{223}Ra , ^{224}Ra , ^{226}RA , ^{227}Ac , ^{228}Ra , ^{230}Th , ^{231}Th , ^{232}Th , ^{248}Cm , ^{254}Cf , ^{256}Fm , and natural thorium[1]

(1) Sample Analysis

All water samples collected are analyzed for gross beta activity and tritium by an independent laboratory. Analysis for alpha-emitting radioelements is not performed because we do not produce nor possess in unsealed form significant quantities of this type of radioactivity at SLAC.[2] In addition to routine gross beta analysis, SLAC examines aliquots of selected specimens by in-house gamma spectroscopy if necessary. Quality assurance procedures are described in Appendix C.

(2) Sample Preparation

When environmental water samples contain large amounts of insoluble solids, the solid fraction and filtrate activities are determined separately.

The total volume of each sample is measured and filtered. The origional sample bottle is rinsed with the filtrate and the activity in each fraction is determined separately.

For the solid fraction, the filter paper and solid are dried at $\sim 100°C$ and weighed after cooling. A 300 to 500 mg aliquot is counted.

The filtrate and water samples exhibiting low solid content are treated in the same manner. A 200 cc volume is taken from each 500 cc sample and evaporated to a smaller volume in a beaker. It is then transferred to a weighed planchet

with dilute acid and water rinses. The sample is evaporated gently, weighed, and counted.

(3) Gross Beta

The prepared samples are counted in a low-background proportional counter ($\leq$ 1.5 cpm). The results are normalized by comparison with the count of a known ^{137}Cs source.

Some samples may require a correction for naturally occurring ^{40}K. In that case, the total amount of potassium in the sample is determined by flame photometry. The amount of ^{40}K activity can then be calculated, based on the percent abundance of this naturally occurring radioelement and subtracted from the sample count. This correction is performed on water samples whose gross beta activity is greater than 1×10^{-7} $\mu Ci/m\ell$.

(4) Tritium

To determine the tritium concentration, a 2-3 $m\ell$ aliquot of the filtered solution from the gross beta sample preparation is accurately transferred to a liquid scintillation sample vial. The sample vial is placed in a liquid scintillation counting system. The limit of sensitivity at the 95% confidenced level is $\geq 3 \times 10^{-6}$ $\mu Ci/m\ell$.

2.2 Concentration Guides for Airborne Radioactivity

The Concentration Guides (CGs) for airborne radioactivity appear in Ref. 1. They were derived from dose standards which require that no individual in the general population be exposed to greater than 500 mrem in one year.

Airborne radioactivity produced as the result of operations is short-lived; i.e., the half-lives range from 2.1 minutes to 1.8 hours, and are in gaseous (not particulate) form. These isotopes include the following:

TABLE 1

Gaseous Radioactivity Released to Atmosphere

Isotope	Half-Life	CG μCi/mℓ
15_O	2.1 minutes	5×10^{-8} (*)
13_N	9.9 minutes	5×10^{-8} (*)
11_C	20.5 minutes	5×10^{-8} (*)
41_{Ar}	1.8 hours	4×10^{-8}

(*) Calculated from Ref. 3, assuming total submersion.

Since we do not routinely release airborne radioactivity while the beam is on, and require a waiting period before turning on the exhaustors, the only radioisotope released is ^{41}Ar. By far the greater proportion of exposure an individual may receive, under any circumstances, from the radioelements listed in Table 1 is from whole body immersion. Thus, for an individual to receive a whole body dose of 500 mrem annually requires a continuous exposure to a large cloud of ^{41}Ar whose average concentration equals 4×10^{-8} $\mu Ci/m^3$ (Ci/m^3) for an entire year.

2.3 Analysis Techniques for Airborne Radioactivity

The accelerator and beam switchyard (BSY) areas are vented by a total of 20 fans: the discharge point is just slightly above roof elevation. The total exhaust rate for the accelerator is 60 m^3/s, and for the BSY 40 m^3/s. Venting of PEP and its Interaction Regions (IR's) is accomplished by a total of 14 exhaust fans which vent just above grade level, with a total exhaust rate of 50 m^3/s. PEP is the only facility that is vented while the beam is on. If personnel entry has to be made during an operating cycle, the area is vented after the primary beam has been shut off for ten minutes prior to entry. The release of radioactivity is, there-

fore, infrequent, and only for brief periods of 30-60 minutes. The accelerator, SPEAR and PEP do not represent a measurable source of gaseous or particulate radioactivity due to low activating potential.

Each BSY ventilation fan is interlocked with a radioactive gas detector comprised of a Geiger-Mueller detector, power supply, rate meter, strip chart recorder and air pump are interlocked with the ventilation fan so that they operate only when the machine is being vented.

The gas monitors for the BSY collect particulate samples during venting and have revealed negative results; during this monitoring particulate radioactivity above background was detected. This is consistent with results of previous "grab" samples collected in the exhaust stream.

2.4 Penetrating Radiating Monitoring Techniques

Six Peripheral Monitoring Stations (PMS) provide continuously-recorded data concerning radiation levels (γ and n) near SLAC boundaries. Their positions are located in Fig. 3.

Radiation information is obtained with a Geiger tube for the ionizing component, and a paraffin-moderated BF_3 neutron detector calibrated with a Pu-Be neutron source. The resultant sensitivities are such that a γ dose of 1 mR from a radioactive ^{60}Co source would be recorded as $\sim 10^4$ counts on the Geiger tube channel, and a neutron dose-equivalent of 1 mrem would be recorded as $\sim 10^5$ counts on the BF_3 channel.

Calibration and quality assurance procedures are described in Appendix C. The hourly printout cycle of the Sodeco register is programmed by two clock motors with cam actuated switches and associated electronic circuitry. This programmer automatically interrupts data acquisition, generates a print command, resets the digits in parallel, and reverts to the normal condition of serial counting of incoming data pulses. Dead time per printout cycle is less than 20 seconds per hour, so that the related corrections would be negligible and are not made.

3. MONITORING RESULTS

3.1 PENETRATING RADIATION MONITORING

The measured annual dose to the general population coming from accelerator operations is almost entirely from fast neutrons and is characterized as skyshine from SLAC's research area. Estimates of individual and general population whole body doses can be calculated from the PMS data, based on estimates of distance and population density near SLAC. PMS-1 (formerly PMS-5) is located at the most sensitive location. Historically this station has always been used to calculate population dose since it records the maximum dose near our site boundary.

From demographic information and the measured radiation dose near the site boundary, we can estimate both the average individual dose and the population dose from SLAC operations. From 1974 data, we arrive at a population of 2040 persons who are included in the pool exposed to 1 mrem or more for any calendar year. A shift in the experimental program to low intensity experiments, including storage ring activities, is the primary reason for the decrease in site boundary measurements and calculated population dose.

3.2 MONITORING FOR AIRBORNE RADIOACTIVITY

During 1983, 0.44 Ci of short-lived gaseous radioactivity was released into the atmosphere from SLAC. Particulate samplers continue to demonstrate that radioactivity in particulate form is not released from SLAC. When corrected for dilution, this release resulted in an off-site concentration of $5.7 \times 10^{-11}\ Ci/m^3$. This concentration is compared to the CG for ^{41}Ar, which is $4 \times 10^{-8}\ Ci/m^3$.

We emphasized that the model used to calculate off-site concentration applies to the plume centerline, and is not corrected for vertical and horizontal plume spread. Also, the model is not corrected for wind direction or velocity. The estimate of off-sit concentration is, therefore, conservative and overestimates the actual concentration at the site boundary by factors of $2 - 10$.

4. NONRADIOACTIVE EFFLUENT

4.1 WASTE WATER

Waste water from SLAC is discharged in basically three directions:

(1) Sanitary sewer.

(2) Storm sewer effluent is released to natural open ditches. The ditches conduct this water to San Francisquito Creek by surface flow or by seepage. Both these liquid effluents (1) and (2) eventually reach San Francisco Bay, about six miles to the east.

(3) About 40% of the water leaves the site as water vapor via the four cooling towers.

Typical amounts are 7×10^4 m^3/year to the sanitary sewer; 1.5×10^5 m^3/year to the storm drains, and 1.5×10^5 m^3/year evaporated, for a total of 3.7×10^5 m^3/year. In addition, an average of 9×10^5 m^3/year fall as rain on the 472 acre site, also flowing to the creek. Thus, the SLAC effluent to the creek is diluted by an average factor of 6 by natural run-off.

The turn-on of PEP in April, 1980, has not changed these figures from those of previous reporting periods. This is because, as the PEP facility came into operation, other experimental programs were somewhat reduced so that there was no significant net change in water usage.

Because of PEP construction the sampling stations for both the sanitary sewer and strom drains have been relocated (see Fig. 3). These became operational in September, 1980. The sanitary sewer sampling station is now at Manhole No. 1, northeast of the PEP Interaction Region 12 (IR-12). Most of SLAC's sanitary sewage flows through this point. [1] A pump continuously samples the the effluent at the rate of 5 $m\ell$ per minute, which is stored in drums. At the end of each calendar quarter, the contents of the drums are mixed, and 1

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[1]There is a second sewer connection serving only PEP IR-4, 6 and 8. No gooling or process water is released via this connection which carries only small amounts of ordinary human wastes.

liter samples are removed for chemical-radiological analysis.

It should be noted that the sampling rate is constant at all times regardless of the flow rate, and thus tends to give relatively greater weight to the effluent at lower flow rates when concentrations are likely to be higher. Therefore, this method of sampling is likely to lead to an overestimate rather than an underestimate of concentration.

4.2 Sanitary Sewer Effluents

About 20% of SLAC's domestic water supply is released to the sanitary sewer; the remaining 80% leaves the site by evaporation or via storm drains to San Francisquito Creek. The sanitary sewer outlet at the northeast corner of the site is connected to the West Bay Sanitary District.

The quantity of discharge for 1983 was not measured because the Menlo Park Sanitary District had instrument problems that they have not solved. However, the amount normally discharged is not unusual for a facility employing about 1300 people, and does not constitute a burden on the Menlo Park Sanitary District. The amount is rather constant the year around, and relatively insensitive to the accelerator operating cycle.

4.3 Storm Drain Effluents

Water effluent discharged into the storm sewer is a combination of (1) cooling tower blowdown, (2) water run-off during the winter, and (4) miscellaneous uses, mainly once-through cooling of various small systems.

The largest potential source of chemical effluents discharged to San Francisquito Creek is from cooling tower blowdown discharged to three natural open ditches. There are four towers of the induced-draft counterflow type. The primary system in all cases is a closed-loop, low-conductivity system. Tower 101 is located at the Central Utility Building and provides cooling for laboratories and shops of the Campus Area. Tower 1201 is adjacent to the accelerator which cools the injector, positron source, and the first accelerator mile. Tower 1202, also adjacent to the accelerator, cools the second mile, while Tower 1701, near the Beam Switchyard and Research Area, provides cooling for these areas and

for PEP.

The cooling tower water is chemically treated with silica and organic algaecides. The blowdown water is basically source water whose solutes are concentrated by a factor of 4-6.

The cooling tower effluents are subject to control by the State of California, California Regional Water Quality Control Board, NPDES No. CA0028398, order No. 78-73, October 1, 1978. The discharge permit states the maximum permissible concentrations of settleable solids, oil and grease, chlorine residuals, and permissible range of pH. It sets forth a monitoring schedule describing the types of sampling and minimum frequency of analysis. Each tower's effluent is analyzed separately, except that effluent of tower 101 is combined with that of 1701.

5. MONITORING RESULTS

5.1 STORM DRAINS

Results of cooling tower blowdown monitoring for 1982 appear in Table 4.

APPENDIX A

ATMOSPHERIC DISPERSION MODEL

In 1966, an independent evaluation of meterological regimes at SLAC was performed.[4] From this study, an empirical mathematical model was developed. The model that is used predicts the centerline concentration very well, but overestimates the total dosage values.

$$\frac{\chi P}{Q} = \frac{G}{u}\left(\frac{X}{X_0}\right)^{-1.75+[b(1-C)/u]}$$

where χ_P = centerline concentration (Ci/m^3)
Q = source strength (Ci/s)
G = 8 m^{-2}
u = mean wind speed (m/s)
X = distance from source (m)
X_0 = 2 m
C = fraction of sky covered by low clouds
b = 0.5 m/s day ; b = -1.2 m/s (night) .

Figure 5 summarizes peak concentration per unit source strength as a function of wind speed and atmospheric stability at a fixed distance of 400 meters (roughly the distance from the source to SLAC's boundaries). To characterize atmospheric stability, the degree of cloud cover is indicated for day and night time regimes. This method is based upon Pasquill's data for cloud expansion for various stability categories.

For a wind speed of 2 m/s atmospheric dilution factors – for determining centerline concentrations – range between 2×10^{-5} and 1.5×10^{-3}. For purposes of estimating radiation dose at the site boundary, neutral conditions are assumed, and a generally conservative dilution factor of 4.5×10^{-4} s/m^3 is used in calculation of average concentration at the site boundary (see Fig. 4, curve 1.0).

APPENDIX B

MODEL FOR POTENTIAL DOSE ASSESSMENT

According to Department of Energy orders, an assessment of whole body man-rem dose to the general population within 50 miles (80 km) of SLAC is recommended. Our site boundary dose due to accelerator operation has generally been less than 10 mrem per year from penetrating radiation. Integrating a population dose of small values out to 50 miles becomes an exercise in numerical analysis that results in questionable dose estimates. This is true because assumptions must be made regarding the behavior of neutrons at large distances from the source. We have, therefore, modified the distance term to include individual annual doses down to 1 mrem, which corresponds to a distance of approximately one mile ($<$ 1700 meters) from a central point representative of the source of neutrons. The 1 mrem value is approximately 1% of the total natural background dose, and any further extrapolation is unjustified because the difference in population dose from natural background and SLAC operations cannot be reasonably determined. In any case the population dose thus ignored is very small.

There are three major pathways leading to human exposure from ionizing radiation: (1) airborne, (2) food chain, and (3) direct exposure to penetrating radiation. Of the three major pathways listed above, only direct exposure to pentrating radiation is of any measurable significance from SLAC operations. The source of this exposure is from neutrons resulting from the absorption of high energy electrons and photons in the experimental areas creating energetic particles, some of which escape from the heavily shielded enclosures.

In order to make an accurate and realistic assessment of radiation exposure to the public at low doses, it is necessary that exposure from the natural radiation environment be known. This is true because the instruments used respond to natural radiation sources as well as man-made sources, and the portion due to natural radiation must be subtracted from the total measurement. The

population exposure assessments appearing in this document are, in all cases, overstatements of the true impact. Hence, the resulting values are representative of an upper limit of the possible range.

While the annual neutron dose from accelerator operations at the site boundary has generally been measurable, it has always amounted to $< 25\%$ of the total annual individual dose from natural background radiation. According to an EPA report, the average dose from cosmic, terrestial, and internal radiation in California is 125 mrem.[5] For purposes of comparison, we have rounded this number off to 100 mrem.

Another quantity of interest is the population dose in units of man-rem. This is simply the product of the average individual dose and the total population exposed. For example, if there are 2000 people exposed to an average annual background dose of 0.1 rem (100 mrem), then the population dose is 0.1×2000, or 200 man-rem from natural background radiation. The annual variation of exposure to natural background radiation may vary by $\pm 20\%$, largely caused by the difference of naturally occurring uranium, thorium, and potassium present in the ground and in building materials where people live and work. This value is also affected by weather conditions which may increase or decrease the amount of radon/thoron present in the atmosphere at any given time.

There are two major problems associated with this determination that affect overall accuracy of the measurement. First, the conversion of neutron flux to dose requires that the spectrum of neutrons at the measurement point be known because the quality factor Q is a function of neutron energy. Because of the very low neutron fluences at the SLAC boundary and beyond it is impossible to measure the energy spectrum. Therefore we have selected a QF of 10 as a conservative choice. We feel that this choice leads to an overestimate of the neutron dose-equivalent by a factor of approximately 2. Until a useful experiment can be performed, with neutron yields of sufficient intensity, the quality factor cannot be determined with any better precision.

A second problem with this sort of extrapolation is the behavior of neutrons at large distances. Most of the high energy accelerator laboratories have made measurements. They are unique to each facility because of design differences, type of machine, and surrounding topography. Here, again, we have chosen a conservative formula for calculating the dose at distances other than the point of measurement. Lindenbaum[6] gave a method for evaluating skyshine neutrons which was later verified by Ladu et al.[7] using Monte Carlo techniques. Lindenbaum approximated the falloff by $e^{-R/\gamma}/R$, where R is in feet, and $\gamma = 830$ feet. This equation fits the SLAC data fairly well, and is the one used to predict doses beyond our measuring station (Fig. 5). In order to derive a correction for large distances unique for SLAC, we will need a much larger intensity to determine a more precise correction for distance. We feel that the methods used and reported in this document may overestimate the true population dose by at least a factor of 2 or more.

The population activity close to SLAC, i.e., within 1 mile, is a mixture of commerce and residential dwellings. The occupancy factor – the proportion of time throughout the year that these structures are occupied – is assumed to be 1/4 for business activities, and 1.0 for private dwellings. The number of people is estimated for each type of structure, multiplied by the occupancy factor, and summed to estimate the total population that might be continuously present.

APPENDIX C

CALIBRATION AND QUALITY ASSURANCE PROCEDURES

Peripheral Monitoring Stations (PMS)

The natural background radiation provides continuous verification that the monitoring equipment is connected and functioning properly. During accelerator downtime and any interrupted operation background radiation provides a calibration base-line as well.

A regular calibration procedure was initiated in 1984 using two small radioactive sources. The sources are placed at a measured distance to produce a known dose equivalent rate. The equipment is kept in normal operation during these checks. The printer is marked so the calibration data is not confused with normal measurements. This procedure is repeated twice each year and following equipment repair or maintenance.

Airborne Radioactive Monitoring Equipment

Dose-equivalent from gaseous radioactivity reaching the site boundary, if large enough, would be detected by the PMS, which has its own quality assurance procedures.

The separate radioactive gas monitors for each ventilation fan are inspected and calibrated at the beginning of each accelerator cycle. They are calibrated with a small radioactive source. During operation, the natural background radiation response assures that they are operating properly.

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TABLE 2

Annual Penetrating Radiation Dose Measured

Near SLAC Boundaries–Calendar 1983

PMS	Gamma (mrem)			Neutron (mrem)		
No.	Total	Background	Net	Total	Background	Net
1	70	72	(a)	18	13	5
2	47	48	(a,b)	12	11	(a)
3	46	47	(a,b)	15	14	(a)
4	100	101	(a)	17	16	(a)
5	69	70	(a)	14	12	2
6	70	75	(a)	10	10	(a)

(a) Within normal fluctuation of background radiation.

(b) Three calendar quarters only.

TABLE 3

Summary of Radiation Measurements by Pathway

During Calendar 1983

Exposure Pathway	Maximum Annual Dose mrem	Percent of Standard	Man-Rem Estimate SLAC	Man-Rem Estimate Background
Penetrating	5	< 1.0	10	200
Airborne	(a)	< 0.5	(a)	50 (b)
Total		< 0.5	10	250

(a) Within normal fluctuation of background radiation.

(b) 25 mrem person for internal dose from natural radioactivity[5] or $\sim$ 50 man-rem to population near SLAC.

TABLE 4

Nonradioactive Effluent Discharge Monitoring Report

(Cooling Tower Blowdown) — Calendar 1983

Parameter	Flow	pH	Settleable Solids
Sample Frequency	Continuous	Continuous	Monthly
Range or MDL (a)	Meter	0.1 to 14.0	$\geq$ 0.1
Units	Gal/d	NA (b)	mg/1/h
Standard	NA	6.5 to 8.5	0.1
Cooling Tower 1201			
Minimum (c)	0	7.1	$\leq$ 0.05
Maximum	34,000	7.8	1.0
Average	5760	NA	NA
Cooling Towers 101 and 1701			
Minimum (c)	0	7.6	$\leq$ 0.05
Maximum	96,990	8.4	1.0
Average	21,130	NA	NA
Cooling Tower 1202			
Minimum (c)	0	7.4	$\leq$ 0.05
Maximum	20,400	8.4	1.0
Average	6130	NA	NA

(a) MDL is minimum detectable level of concentration analyses.

(b) NA indicates not applicable.

(c) Cooling Tower Blowdown is activated by a conductivity controller, and this is intermittent.

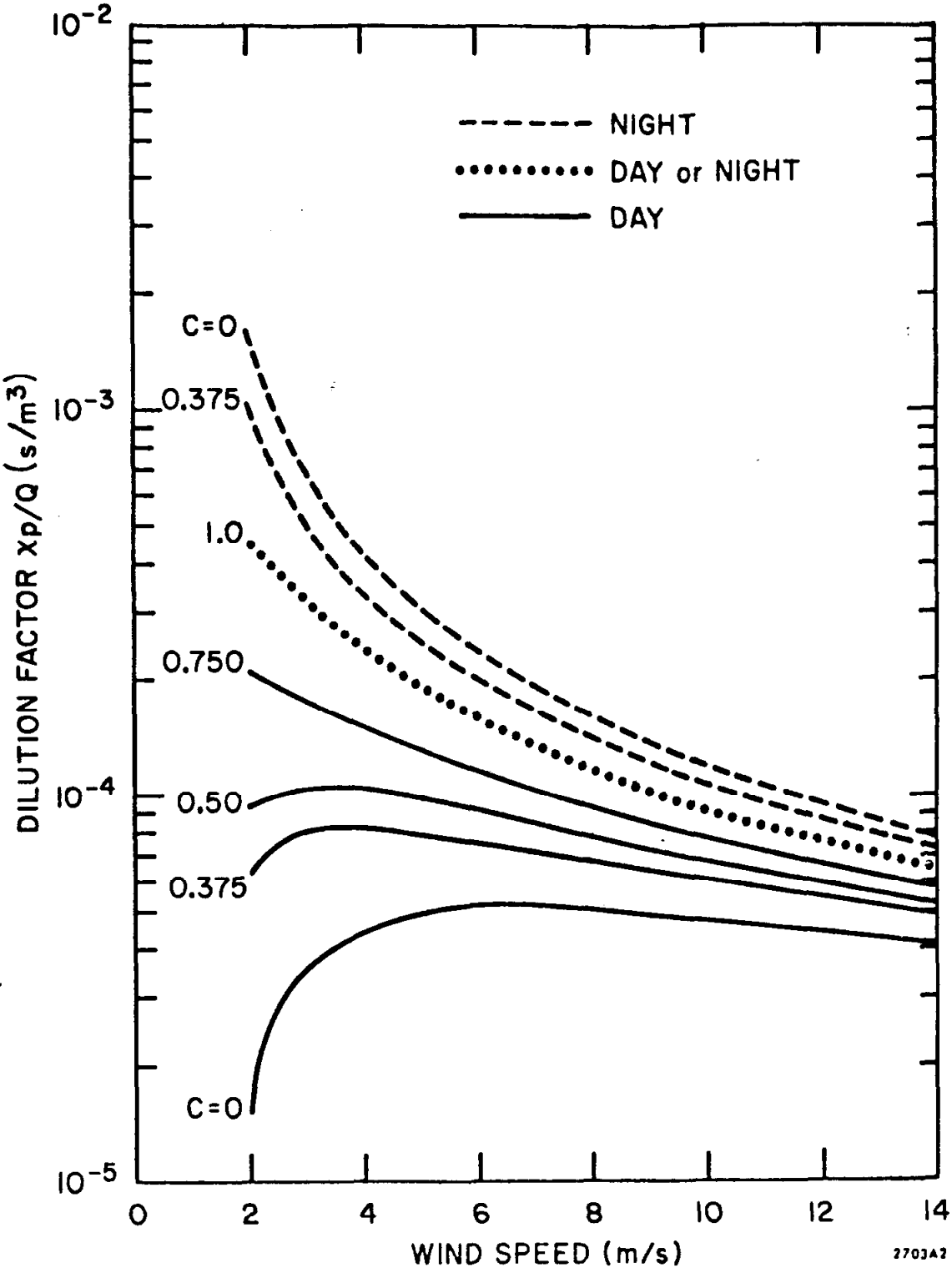

Fig. 4. Centerline dilution factor for various atmospheric conditions as a function of wind speed.

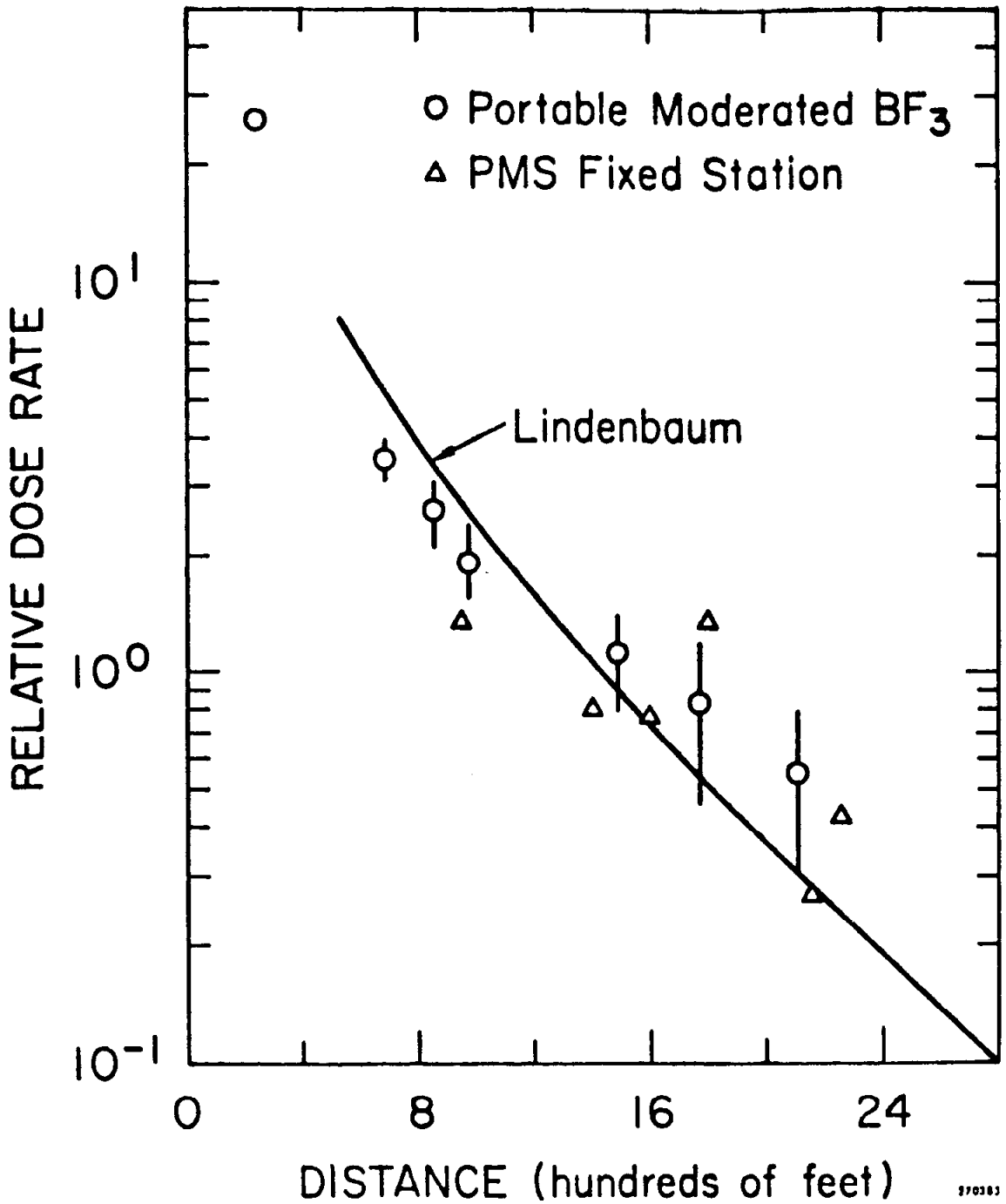

Fig. 5. Measurements made along a line between ESA and site boundary.