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Environmental Measurements Laboratory

LONG-TERM TLD MEASUREMENTS OF ENVIRONMENTAL BACKGROUND RADIATION IN THE NEW YORK CITY AREA

Mark Maiello
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DEPARTMENT OF ENERGY
NEW YORK, N. Y. 10014

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ABSTRACT

The results of month-long TLD measurements at seven locations within 150 km of New York City are reported for 12 years at a few locations and for up to 18 years at others. At some locations, multiple dosimeters were deployed to acquire concurrent indoor and outdoor measurements. The sites were varied and include an urban high-rise residence, three suburban backyards, a rural hillside, and the wooded outskirts of a nuclear power plant (nonoperational). Long-term mean dose rates in air ranged from 50.8 to 123.1 nGy h^{-1} (5.8 to 14.1 μR h^{-1}) across the area. The typical seasonal dose rate in air variations are presented for two of the sites and are briefly discussed in terms of soil conditions. The data indicate that it is possible to achieve monthly variations from the long-term mean as high as 20 to 40%. One of these locations was monitored for indoor (2 floors) and outdoor air dose rates. This allowed for a time series comparison to be performed illustrating the changing contribution of terrestrial radiation to the total dose rate relative to the steady building material-derived radioactivity. This site also permitted the calculation of indoor/outdoor ratios for two floors. Another suburban location yielded an indoor/outdoor ratio using ground floor dose-rate-in-air measurements. Also presented are mean annual dose rates in air showing a long-term decrease at some locations. A statistical Kendall test was performed to quantify the magnitude of the decrease. A definitive explanation of this trend requires further study.

Table of Contents

I. Introduction

The objectives of this report were to provide values of external indoor and outdoor dose rates in air from the combined cosmic-ray secondary and terrestrial radiation fields[1] as measured primarily in and around urban, rural and suburban structures using thermoluminescence dosimetry (TLD); and to illustrate the typical variations seen over time (seasonally and annually) in these measurements.

These data provide a reference background for many types of studies involving human exposure to radiation. Comparisons are always made with the natural radiation exposure in order to estimate potential man-made radiation health hazards. Further, a knowledge of the magnitude of natural variations is essential for institutional radiation surveillance programs such as those performed at scientific and industrial facilities using radionuclides.

A review of the data for the first 10 years was presented by Gulbin and de Planque (1984). These data were reproduced by the National Council on Radiation Protection and Measurements in its report regarding U.S. population exposure to natural background radiation (NCRP, 1987).

The present report presents results gathered at 12 sites from 1972 to 1990 during which monthly TLD measurements were made.

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[1]The exposure rate in $\mu R\ h^{-1}$ due to cosmic-ray secondaries and terrestrial radiation is multiplied by 8.76 $nGy\ h^{-1}$ per $\mu R\ h^{-1}$ to yield the dose rate in air.

II. Methods

TLD monitoring stations were established by the Environmental Measurements Laboratory (EML) in New York City and in the nearby suburbs of New Jersey, Long Island and Rockland County, NY (see Figure 1)[2]. The close proximity to the Laboratory facilitated monthly TLD exchanges. A list of the sites is presented in Table 1 and the following is a brief description of them.

The Union, Maplewood and Monsey sites were wood-frame, one-family, detached structures. At Maplewood and Monsey, both indoor and outdoor measurements were made. The outdoor measurements were obtained in backyards over grassy surfaces. The Manhattan residence is an 11th floor apartment of a 15-story building; only indoor measurements were possible here. The EML roof site is located on a 12-story building several city blocks south of the Manhattan residence. The Shoreham station was located on the grounds of a commercial nuclear power plant that was being constructed but never became operational. The most rural site is the Chester station, which is used by EML as a regional baseline station for field testing a variety of monitoring instruments. In all these locations, the radiation field consisted of terrestrial gamma radiation plus a cosmic-ray produced component and a small contribution from ^{137}Cs originating from weapons testing fallout. There was no other technological enhancement of the radioactivity.

The TLD methods used are described in the EML Procedures Manual (Maiello, 1992). The dosimeter consisted of Lif:Mg,Ti "TLD-700" chips (3.0 x 3.0 x 0.89 mm), encased in 3 x 3 x 1 cm Lucite holders (370 mg cm^{-2}) to shield environmental beta particles and sealed- in polyethylene to resist moisture intrusion. An in-house constructed TLD reader was used for the entire duration of the program. The reader is a manual pan-heater type with an electronically controlled heating ramp to produce a measurable integrated light signal from the TLD. A computerized analysis routine was used to subtract individual TLD backgrounds from the raw

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[2] A few measurement locations not discussed here were established early in the program but were abandoned when the TLD caretaker of the site (resident of the dwelling) moved away.

data, make corrections for storage exposures, and apply calibration factors. It was not necessary to correct for the insignificant transit doses to and from the sites. With five TLDs used per dosimeter, a standard deviation (SD) about the mean of the chip readings of about 3% was usually achieved. This was slightly improved at Chester where 15 TLDs were used to measure the site (two dosimeters in close proximity with 8 and 7 TLDs each).

The following procedures were applied to the data to account for the few instances when the regular dosimeter exchange method was interrupted:

1. where a monthly exposure rate value was missing due to loss of the dosimeter, the missing value was replaced with a mean determined by averaging all the other results for that month;
2. where consecutive 2-week measurements occurred, they were averaged to obtain the monthly, 4-week exposure rate value;
3. where overlapping 2-month and 1-month measurements were performed at a site, a subtraction of the total exposures was carried out to obtain the first month's exposure rate value;
4. where a 2-month measurement was performed without an overlapping 1-month measurement, the exposure rate value from the 2-month measurement was reported for both months;
5. the above procedure was also done for any 3-month measurements.

These changes were applied mainly to data from the first few years of the program when deviations from the simplified 30-day exchange protocol used later were more frequent. However, the corrections were relatively few in number. The deployment periods used throughout were ~ 30 days long, usually starting and ending within several days of the first of the month. No corrections were applied for this variation.

III. Results and Discussion

MEANS, RANGES AND SEASONAL VARIATIONS OF THE DOSE RATES

Table 2 summarizes the dose-rate-in-air results for all the sites. The means and medians are nearly identical indicating that outlying data are not skewing the results. For the most part, the outdoor dose rates in air are typical of the region. The site at Chester is somewhat atypical, having a dose rate about twice as high as all the other outdoor sites.

Individual monthly variations are reflected in the ranges of the dose rates. From the Chester range data, it is apparent that extremes of up to 40% of the long-term mean are possible. More generally, the ranges indicate monthly extremes of about 20% of the mean. The percent (1-sigma) SDs of the mean (not shown) are very small. The largest is associated with the outdoor Chester site (high variability expected) and not surprisingly, the smallest corresponds to the indoor, second floor Maplewood site (low variability expected).

The dose rate in air at Chester indicates that naturally enhanced concentrations of environmental radionuclides are present including a small contribution (2% of the total) from fallout ^{137}Cs (EML Chester Report, 1978). The higher variability is associated with the large terrestrial gamma-ray contribution which is estimated to be 70% of the total dose rate. This large fraction of the total dose rate can be affected by variations in the soil moisture levels and/or snow cover which explains the large SDs of the mean and the large spread in the range (similar changes occur at the other sites, though not to the same degree as at Chester). In Figure 2, we illustrate these changes using the smoothed, monthly dose rates at Chester (data was smoothed using the Minitab smoothing routine (Minitab, Inc., 1989)). As discussed by de Planque (1980), the highs and lows are associated with the seasons and reflect changes to the density of the soil due to the varying degrees of precipitation, evapotranspiration, and the levels of standing water or snow above the soil. This complicated relationship is further affected by the type of soil, the presence and types of vegetation, the water holding capacity of the soil, the soil temperature and the number of hours of sunlight. The apparent overall relationship is that dose rates in air rise in the summer months (months of higher temperatures, more daylight and sometimes, less rain) and are at minimums during the winter months when cold temperatures, less daylight, and periods of snow cover prevail. The results of a mathematical model, which estimates the monthly exposure rate variances by accounting for many of the factors mentioned above, is discussed by de Planque (1980).

Seasonal variations are also illustrated in Figure 3 where the results of the outdoor and indoor stations at Maplewood are presented. All three dosimeter stations show simultaneous temporal changes. The outdoor dose rate variations drive the changes observed indoors. The indoor radiation field is comprised of an outdoor radiation component modified by the shielding provided by the building. There is also a contribution from radioactivity present in the building materials. The second floor dose rate in air is always the lowest due to the amount of attenuating material between it and the source of the outdoor radiation field. These modifying factors explain why the indoor variations are smaller than those observed outdoors (refer to the SDs of the mean in Table 2).

In Figure 4, the Maplewood monthly dose rates are plotted on a relative scale after normalizing each rate to the station's long-term mean. Then, the outdoor rates were subtracted from the first floor rates, smoothed and plotted. This was also done for the second floor (2nd floor vs. outdoors) and between the first and second floors (2nd floor vs. 1st floor). In the topmost plot, the points > 0 indicate that the relative contribution of the first floor radiation field (vs. the outdoor field) has increased due to the attenuation of the outdoor dose rate associated with above normal precipitation. Especially noticeable peaks occurred in early 1977, 1978, 1982, 1983, and 1986 when precipitation for the first four months of each year was above normal (National Climatic Center, 1977, 1978, 1982, 1983, 1986). A similar explanation applies to the center plot where the relative contributions of the second floor radiation field vs. the outdoor field are compared. When the differences between the first and second floor normalized monthly air doses were small (see bottom plot for values near 0), the outdoor dose rates tended to be near minimal values (refer back to Figure 3). This occurred in early 1977, 1978, late 1979, early and late 1981, early 1983, early and late 1986 and 1987. Thus, the indoor dose rate is influenced by the outdoor soil conditions, but these variations occur against the relatively steady dose rate from building materials.

MEAN ANNUAL DOSE RATE CHANGES DUE TO DOSIMETER RELOCATION

The tabulated annual mean dose rates for all the monitoring sites are presented in Table 3. The average annual dose rates in air for selected outdoor stations and one indoor station (for comparison) can be examined in Figure 5. Abrupt changes in the mean annual dose rates caused by changes in the dosimeter location are very obvious. For example, the EML roof-top dosimeter was moved in December of 1986 to accommodate roof resurfacing. The new location was no further than 5 m away at the base of a very large air-conditioning cooling tower. An immediate decrease in the monthly dose rate is clearly seen in Figure 5. We postulate that the cooling tower partially shields the dosimeter from the radioactivity in the building materials and from the dose caused by cosmic ray-derived radiation. The data for this station was separated accordingly in Table 2 (the old roof surface at the new location was not immediately replaced). Also, previous investigators (Beck and de Planque, 1990) in this project reported that the dosimeter in the Manhattan residence was moved at the end of 1976, causing an increase of about 5.3 nGy h^{-1}. The dose rate has remained near this new level since then. Because small changes in dosimeter location can result in significant changes in the measured air dose rate, any changes in dosimeter location should be planned. The exposure rate of the proposed site can be measured for similarity to the old before implementing the change. Also, initial installation of a dosimeter should be away from structures that could shield the ambient radiation field.

LONG-TERM NEGATIVE TREND OF THE DOSE RATES IN AIR

The most obvious features of Figure 5 are the decreasing dose rates observed at most of the outdoor locations. Table 4 shows the results of applying trend analyzing statistics (Gilbert, 1987) to the monthly data in order to determine the estimated (Kendall) slopes. All the slopes were calculated with 95% confidence levels. Clearly, the estimated slopes are mainly negative (the Manhattan residence is a notable exception) and are interpreted as the decrease in dose rate in air per year. The magnitudes of the negative slopes are much higher than can be attributed to the decay of fallout.

As mentioned above, the indoor Manhattan residence location exhibits a rather steady annual dose rate which is reflected in the values of the slope estimate limits. The unvarying nature of the dose rate is expected for an indoor location at a height far from the ground surface and where the radiation field is mainly from building materials. In contrast, both the indoor Monsey and Maplewood sites (2nd floor) exhibit negative slope estimates comparable to outdoor locations.

Further statistical tests were conducted to verify the slope estimates. The Kendall test and the Sen test determine if the monthly data are independent of the time when they were obtained (the Sen test is somewhat more rigorous). The p-values (95% level and approximate due to autocorrelation of the data) for these two tests (Table 4) indicate that there is a high probability of falsely concluding that temporal dependence is present in the data at the Manhattan residence (1/77 to 12/89) and perhaps at Chester as well, when in fact they are independent. Therefore, it is safer to say that the Manhattan residence data is independent of the negative trend. The Chester p-values, considered with the estimated slope limits, indicate that the dose rates are more likely to be trend dependent.

Most of the other sites have very low or zero p-values implying that the negative slopes are real as well. The exceptions are the Manhattan Residence (1/72 to 12/89), the EML roof (1/87 to 12/89), and the Maplewood backyard and 1st floor stations. The dosimeter relocation may explain the Manhattan residence p-value. The abruptly increased dose rate probably introduced an artificial positive slope in the data. With the data prior to 1977 removed, the p-values approach levels indicating that no trend (positive or negative) is present. The EML roof data (1/87 to 12/89, after the dosimeter was moved) indicates that a trend is not present. However, the data from the preceding period (1/72 to 12/86) is apparently trending downward. Perhaps the downward trend has stopped after 1987 but the data of Figure 5 for this station and the other outdoor stations implies otherwise. If the roof data for the 1/87 to 12/89 period were extended beyond 12/89, the statistical analyses may produce different slope and p-value results. The backyard and 1st floor Maplewood stations apparently do not exhibit a decreasing slope. In contrast, the data from the 2nd floor Maplewood station does have a negative trend. Chi-square testing suggests that the slope varies from month to month at both the Maplewood backyard and 1st floor stations but the magnitude of the negative slope remains the same on a monthly basis at the 2nd floor station. This results in estimated Kendall p-values and slopes for the backyard and 1st floor sites which must be interpreted with caution due to this monthly variation (Gilbert, 1987). Only the Maplewood backyard and 1st floor sites exhibit this phenomenon and it is, at present, unexplained.

VERIFICATION OF NEGATIVE TRENDS

To determine if the negative trends could be attributable to a systematic error in the TLD system, concurrent monthly exposure rate data for the Chester site was obtained from an independently calibrated pressurized ion chamber (PIC) (EML Chester Reports, 1978-1982, 1984, 1985, 1988, 1991). The TLD station and the PIC are located about 1 m from each other at this location. The monthly exposure rates in air determined by each system were used to calculate the annual dose rate means for 13 separate years which are plotted in Figure 6. It is evident that both systems are in general agreement tracking year-to-year changes. The small differences in the absolute annual values between the two systems is believed to be an illustration of the LiF:Mg,Ti under-response to cosmic-ray produced charged particles (relative to a ^{137}Cs calibration) originally described by Lowder and de Planque (1977). This underestimate was determined to be about 15% (the TLD exposure rate measurements have not been corrected for this effect as it would be necessary to have concurrent charged particle ionization rate measurements for the calculation). The slope estimate for the PIC data is -0.44 nGy h^{-1} y^{-1}. The lower and upper limits are -0.59 and -0.22, respectively, which suggest a more negative trend than obtained with the TLD results. Supporting these numbers are the p-value results for both the Kendall and Sen tests which are both 0.000 verifying that a negative trend is present at Chester.

CAUSES OF NEGATIVE TREND

With systematic difficulties of less concern, the cause of the long-term decrease becomes more difficult to explain. The magnitude of the decrease at Chester, a site which is expected to show large variances (even long-term ones) because of the large terrestrial radiation component, is relatively small according to the TLD measurements. The EML roof site (data from 1/72 to 12/86) exhibits the decrease, but the radiation field there is mainly due to radioactivity from building materials which, when undisturbed, is a steady source of radiation. With the possible exception of Shoreham, the other sites were not subjected to long-term construction of structures that would shield a dosimeter. Such changes would, in any event, cause more abrupt changes in the dose rates than were observed.

Consideration was given to a change in the cosmic-ray produced charged particle ionization at the ground surface. During the years 1976 to 1989, two sunspot minimums and two maximums occurred or were approached (National Geophysical Data Center, 1989). Since sunspot activity is only a gross indicator of cosmic-ray variations (there is a rough inverse relationship), it cannot be ruled out that a steady decrease of the cosmic-ray produced component of the air dose rate has occurred. Unfortunately, the TLD measurements indicate that there is little if any trend in the harder components of the charged particle ionization (refer to Figure 7). These annual means of monthly data were obtained using a 5-cm thick lead sphere placed on the EML roof and a 9-cm thick cylindrical lead storage shield housed on the 5th floor of the EML building. Therefore, the TLDs should be responding mainly to the hard components of the particle flux and to the radioactivity of the lead (for the sphere data, the exposure contribution from the lead has been removed). The slope estimates of Table 5 indicate weak negative trends even for the softer spectrum detected in the sphere. The sphere ionization signal on the roof should show changes more readily than the harder spectrum measured on the fifth floor which is shielded by the seven floors above and by the thicker lead cylinder. Although there is more of an indication of a negative trend in the sphere data, the associated trend test p-values make it difficult to state unequivocally that a negative slope is present. Clearly, further measurements and study are required.

INDOOR/OUTDOOR DOSE-RATE-IN-AIR RATIO

The mean indoor/outdoor dose-rate-in-air ratio is easily determined from the data. The ratio for the Maplewood wood-frame home is 0.85 using the outdoor and first floor values (Table 1). This is well within the range quoted in NCRP Report No. 94 (1987) for U.S. wood-frame homes and is in agreement with a more recent survey (Miller, 1992). Using the Maplewood second floor mean dose rate, the ratio is 0.76. At the Monsey site, the indoor measurements were obtained in very close proximity to the terrestrial radiation source. This resulted in a relatively higher mean indoor dose rate. The indoor/outdoor ratio for this situation is 1.05. A rough estimate of the ratio for an urban high rise dwelling may be made using the mean dose rate for the 11th floor Manhattan residence and that for the 12-story EML roof site, yielding a value of 0.75. This estimate does not consider the possible variations between the two structures such as concrete exhibiting different gamma-ray exposure rates. The Manhattan residence is shielded from cosmic-ray secondaries by four floors which could be the reason for the lower dose rate relative to the EML roof measurement. However, the latter is primarily a 2π measurement geometry while the residence is 4π. It is possible that if the concrete gamma-ray exposures were similar, the residence could have had a higher gamma dose rate in air than the roof due to geometry factors alone. These measurements illustrate the variation of the indoor/outdoor dose rate ratio using floors at ground level and at greater heights - an interesting concept for a more thorough survey in the future.

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TABLE 1

TLD MONITORING SITES AND DATES BETWEEN WHICH DATA IS REPORTED

Dosimeter site	Type of site	Data used From	To
Chester, New Jersey	Rural, outdoor hillside	1/78	12/89
Maplewood, New Jersey	Suburban residence, wood-frame, 1st floor	1/75	12/89
"	2nd floor	1/75	12/89
"	Backyard	1/74	12/89
Union, New Jersey	Suburban residence, backyard	1/72	12/89
Manhattan (New York City)	11th floor apartment	1/72	12/89
EML (New York City)	Roof of 12-story building, outdoor site	1/72	12/89
Shoreham, New York	Outdoor, grounds of non-operational nuclear plant	1/78	12/89
Monsey, New York	Suburban residence, wood-frame, ground-level work room	1/72	12/86
"	Backyard	1/72	12/86

TABLE 2

MEANS, SDs OF THE MEAN, MEDIANS AND RANGES OF DOSE RATES IN AIR AT THE TLD MONITORING SITES (nGy h^{-1})

Site	Mean ± SD of Mean	Median	Range	No. of Measurements
Chester	123.1 ± 0.80	124.2	76.4-145.6	144
Maplewood 1st floor	56.6 ± 0.22	56.6	43.9- 67.9	180
" 2nd floor	50.8 ± 0.18	50.6	43.0- 59.4	180
" backyard	66.7 ± 0.31	67.0	49.5- 81.0	192
Union backyard	67.5 ± 0.29	67.4	52.7- 79.1	216
Manhattan apartment 1/72-12/89	59.0 ± 0.21	58.9	49.2- 69.1	216
Manhattan apartment 1/77-12/89	59.8 ± 0.22	59.6	51.9- 69.1	156
EML roof 1/72-12/86	78.3 ± 0.26	78.4	66.8- 88.1	180
EML roof 1/87-12/89	65.1 ± 0.50	65.3	57.9- 73.4	36
Shoreham	56.4 ± 0.32	56.2	47.5- 69.3	144
Monsey indoors	63.7 ± 0.25	63.5	56.0- 75.6	180
Monsey backyard	60.7 ± 0.30	60.6	49.5- 71.4	180

TABLE 3

ANNUAL MEANS ± 1 SD (nGy h^{-1})

Site	1972	1973	1974	1975	1976	1977	1978	1979	1980
Manhattan apt.	56.9 ± 2.3	56.8 ± 2.5	57.5 ± 4.2	56.5 ± 3.2	56.6 ± 3.1	62.0 ± 3.8	59.4 ± 1.9	60.1 ± 1.5	59.4 ± 2.2
EML roof	82.0 ± 3.6	78.6 ± 2.5	79.0 ± 3.5	79.6 ± 2.3	76.6 ± 4.1	81.2 ± 3.1	80.7 ± 1.8	78.4 ± 2.1	77.8 ± 2.9
Union, NJ	72.2 ± 3.6	71.4 ± 1.8	71.2 ± 4.5	68.6 ± 2.0	68.2 ± 4.0	70.6 ± 5.1	68.8 ± 6.7	66.4 ± 2.5	67.3 ± 1.4
Monsey, NY indoors	64.7 ± 3.0	66.3 ± 3.8	64.7 ± 4.9	64.5 ± 2.8	63.7 ± 4.3	65.7 ± 3.9	65.0 ± 3.3	63.2 ± 1.9	63.2 ± 1.8
Monsey, NY backyard	63.0 ± 3.9	61.2 ± 3.6	61.9 ± 4.3	61.8 ± 3.3	60.4 ± 4.8	63.5 ± 4.1	64.0 ± 5.9	60.0 ± 3.4	60.2 ± 3.3
Maplewood 1st floor	-	-	-	55.9 ± 2.4	55.4 ± 4.1	59.7 ± 4.5	57.1 ± 1.4	56.2 ± 1.8	56.8 ± 2.2
Maplewood 2nd floor	-	-	-	53.2 ± 2.7	50.4 ± 3.2	52.6 ± 1.9	51.9 ± 2.0	50.0 ± 1.6	50.1 ± 1.9
Maplewood backyard	-	-	68.4 ± 5.0	68.1 ± 2.4	66.2 ± 4.3	69.0 ± 5.5	64.7 ± 6.8	64.9 ± 3.8	67.2 ± 2.9
Shoreham, NY	-	-	-	-	-	-	62.0 ± 5.8	60.3 ± 2.5	58.5 ± 2.6
Chester,NJ	-	-	-	-	-	-	120.2 ± 21.9	21.2 ± 3.6	128.0 ± 6.1

TABLE 3 (Cont'd)

Site	1981	1982	1983	1984	1985	1986	1987	1988	1989
Manhattan apt.	59.8 ± 2.4	59.4 ± 2.6	59.8 ± 1.6	59.5 ± 2.8	59.8 ± 2.1	59.8 ± 2.3	58.9 ± 3.7	58.6 ± 4.0	60.2 ± 3.1
EML roof	77.6 ± 3.1	76.4 ± 2.3	76.7 ± 2.6	77.1 ± 3.0	77.1 ± 3.3	75.5 ± 4.5	64.4 ± 2.6	67.1 ± 2.7	63.7 ± 2.8
Union, NJ	67.2 ± 2.9	65.0 ± 4.0	66.9 ± 2.3	65.5 ± 3.1	65.4 ± 3.6	66.4 ± 2.9	65.7 ± 2.8	65.3 ± 3.2	62.8 ± 2.9
Monsey, NY indoors	62.0 ± 2.3	62.0 ± 1.8	62.3 ± 2.7	62.1 ± 2.4	62.5 ± 2.8	63.5 ± 3.9	-	-	-
Monsey, NY backyard	61.0 ± 2.0	59.2 ± 2.8	58.1 ± 1.8	57.9 ± 4.3	58.9 ± 3.4	58.8 ± 3.7	-	-	-
Maplewood 1st floor	56.1 ± 1.8	57.8 ± 1.8	57.9 ± 2.6	55.4 ± 2.6	56.2 ± 1.9	57.6 ± 2.4	55.9 ± 2.7	57.5 ± 2.3	53.3 ± 3.9
Maplewood 2nd floor	49.7 ± 3.0	50.8 ± 1.8	51.0 ± 2.2	50.1 ± 1.7	51.0 ± 1.5	51.6 ± 1.7	50.4 ± 2.4	49.9 ± 2.4	48.4 ± 1.9
Maplewood backyard	67.7 ± 3.2	67.4 ± 4.4	66.0 ± 2.8	65.4 ± 3.9	66.4 ± 2.4	68.0 ± 4.4	66.8 ± 3.3	66.2 ± 3.6	64.5 ± 6.0
Shoreham, NY	56.2 ± 2.7	56.3 ± 2.0	55.9 ± 2.0	55.0 ± 2.6	53.9 ± 2.6	55.1 ± 3.0	54.8 ± 3.1	55.8 ± 2.6	52.6 ± 1.5
Chester, NJ	125.8 ± 8.4	123.8 ± 8.2	123.4 ± 7.2	121.4 ± 6.7	121.4 ± 7.4	123.8 ± 10.	2121.0 ± 8.8	125.3 ± 9.1	121.2 ± 5.0

TABLE 4

ESTIMATED SLOPES OF THE MONTHLY DATA AT EACH SITE WITH TREND-TEST SIGNIFICANCE PROBABILITIES (P-VALUES)* (nGy h^{-1} y^{-1})

Site	Slope Estimate: Lower limit	Slope Estimate: Estimate	Slope Estimate: Upper limit	Kendall test, p-value	Sen test, p-value
Chester	-0.63	-0.27	+0.03	0.072	0.121
Maplewood 1st floor	-0.15	-0.05	+0.02	0.141	0.304
" 2nd floor	-0.23	-0.13	-0.05	0.000	0.000
" backyard	-0.24	-0.10	+0.01	0.077	0.039
Union backyard	-0.52	-0.43	-0.33	0.000	0.000
Manhattan apartment					
1/72-12/89	+0.09	+0.17	+0.25	0.000	0.000
1/77-12/89	-0.21	-0.07	+0.09	0.470	0.176
EML roof					
1/72-12/86	-0.40	-0.32	-0.22	0.000	0.000
1/87-12/89	-1.72	-0.58	+0.73	0.651	0.444
Shoreham	-0.77	-0.62	-0.47	0.000	0.000
Monsey indoors	-0.36	-0.23	-0.12	0.000	0.000
Monsey backyard	-0.46	-0.35	-0.21	0.000	0.000

*Slopes estimates were determined using monthly exposure rates in the TREND program and converting the results to nGy h^{-1} y^{-1} using the factor 8.76.

TABLE 5

MEANS, SDs OF THE MEAN, MEDIANS, LONG-TERM SLOPE ESTIMATES AND TREND TEST SIGNIFICANCE PROBABILITIES OF THE MONTHLY DOSE RATE IN AIR EQUIVALENTS DUE PRIMARILY TO COSMIC-RAY PRODUCED CHARGED PARTICLES*
(nGy h^{-1} y^{-1})

		Slope Estimate				
Mean ± 1 SD of mean	Median	Lower limit	Estimate	Upper limit	Kendall p-value	Sen p-value
Lead-sphere on EML roof (132 measurements)						
22.9 ± 0.15	23.0	-0.21	-0.09	-0.01	0.026	0.064
Lead-shield on EML 5th Floor (216 measurements)						
13.5 ± 0.06	13.5	-0.05	-0.04	-0.02	0.000	0.001

*Measured with TLDs shielded by a 5-cm thickness of lead (sphere) and a 9-cm thickness of lead (cylindrical shield). The sphere data has been corrected for radioactivity in the lead. See Figure 7 for years of coverage. Slope estimates were determind using monthly exposure rate measurements in the TREND program and converting the results to nGy h^{-1} y^{-1} using the factor 8.76.

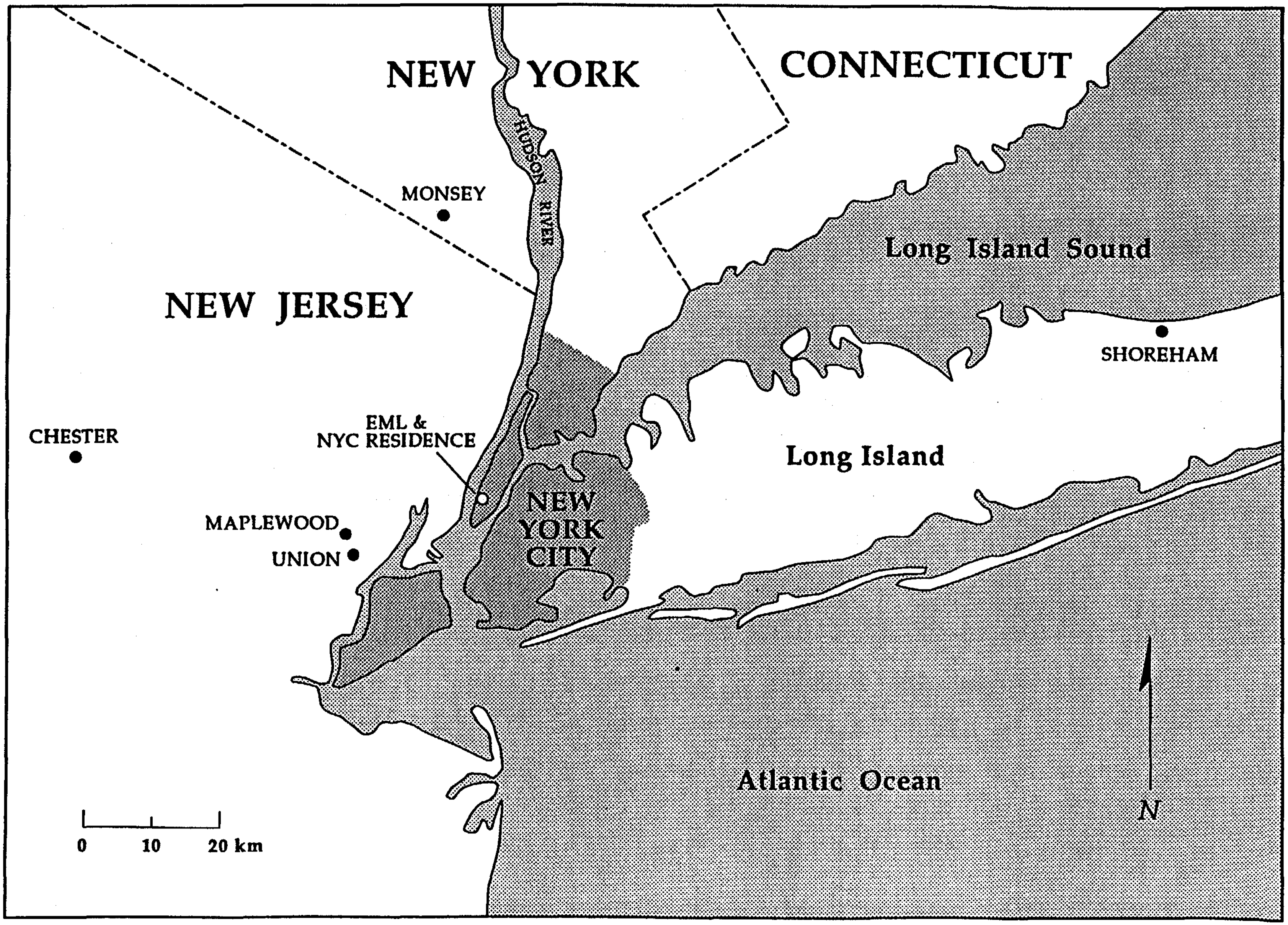

Figure 1. Relative locations of the TLD monitoring sites in the New York City area.

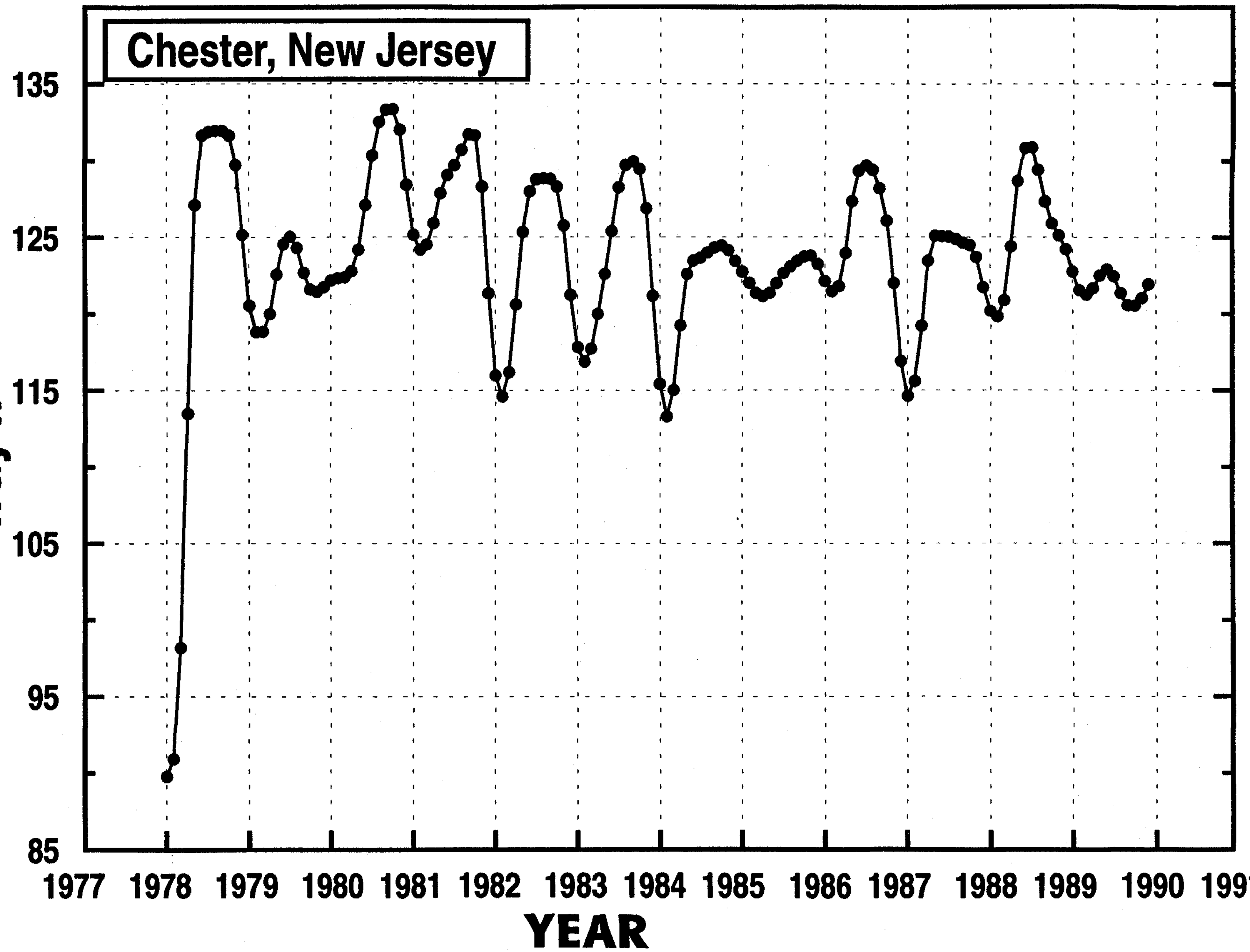

Figure 2. Time-series plot of dose rates in air at Chester, NJ. Data have been smoothed to clarify the presentation of the seasonal variations.

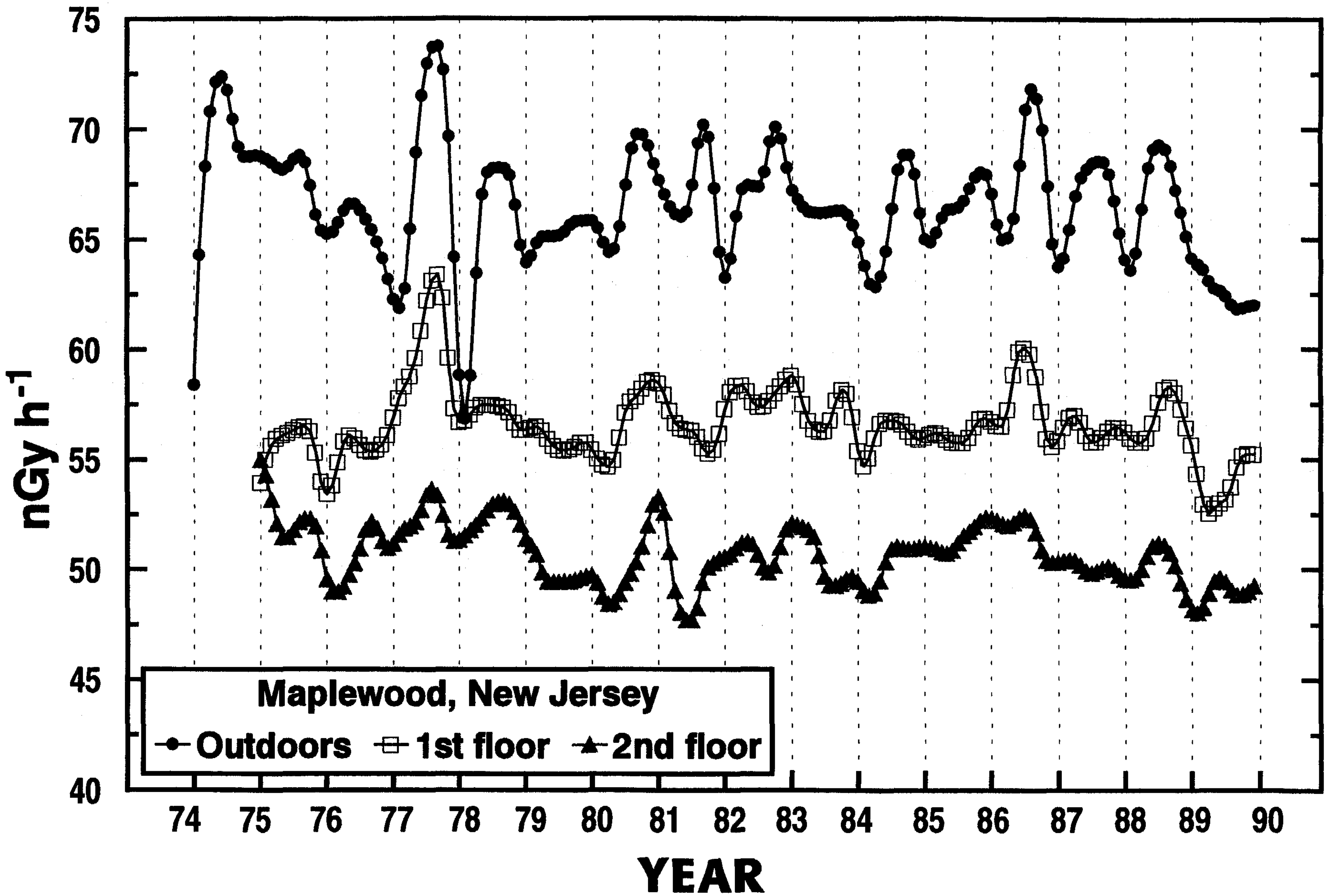

Figure 3. Time-series plot of dose rates in air at the Maplewood, NJ residence (backyard, first and second floors). Data have been smoothed for clarification of the seasonal variations.

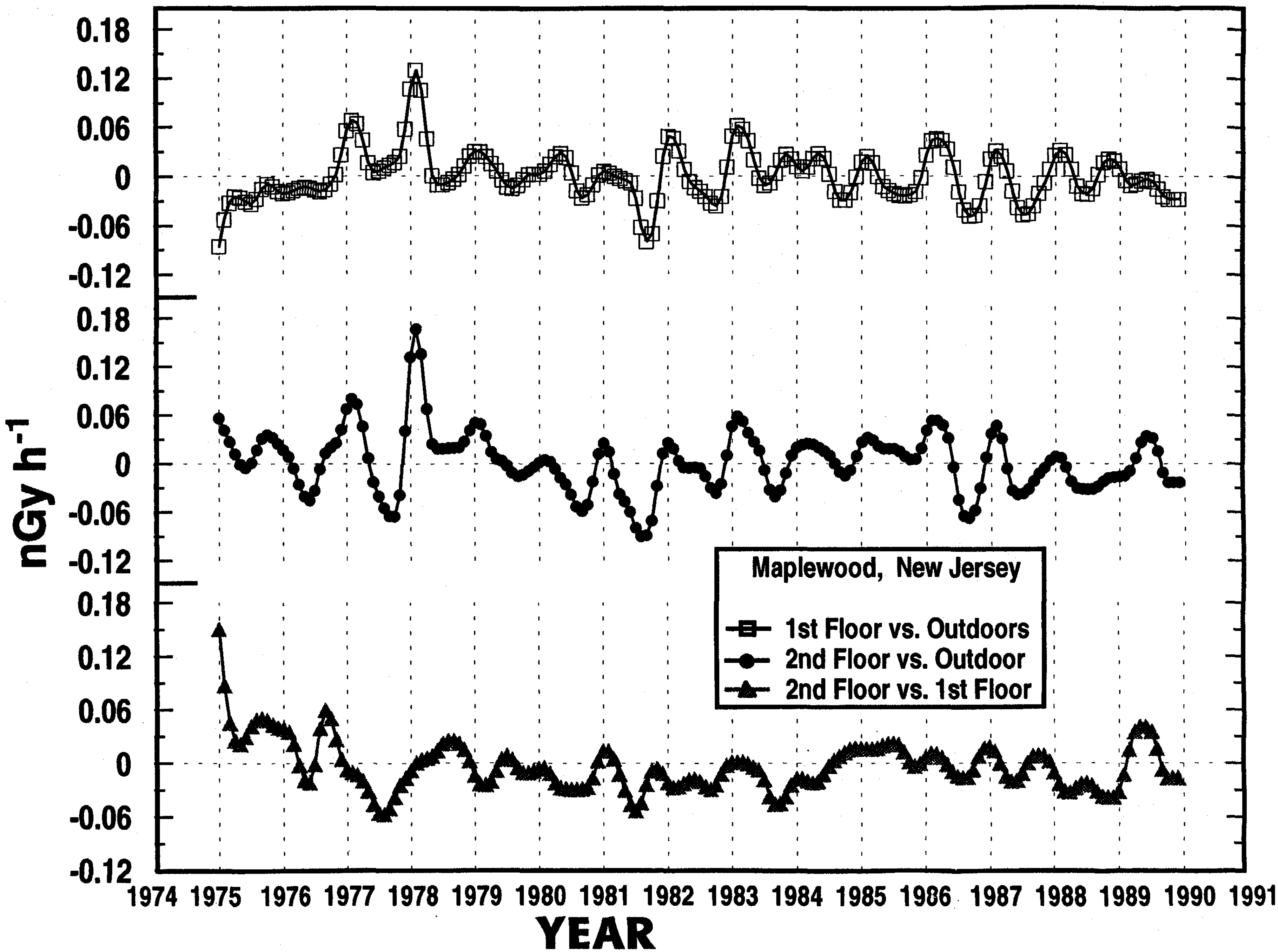

Figure 4. Differences between the normalized monthly dose rates in air of the outdoor, first floor and second floor stations plotted over time to show the changing relative contributions to the total dose rate of terrestrial and building material-derived radiation at different times of the year. The data have been smoothed for clarity of presentation.

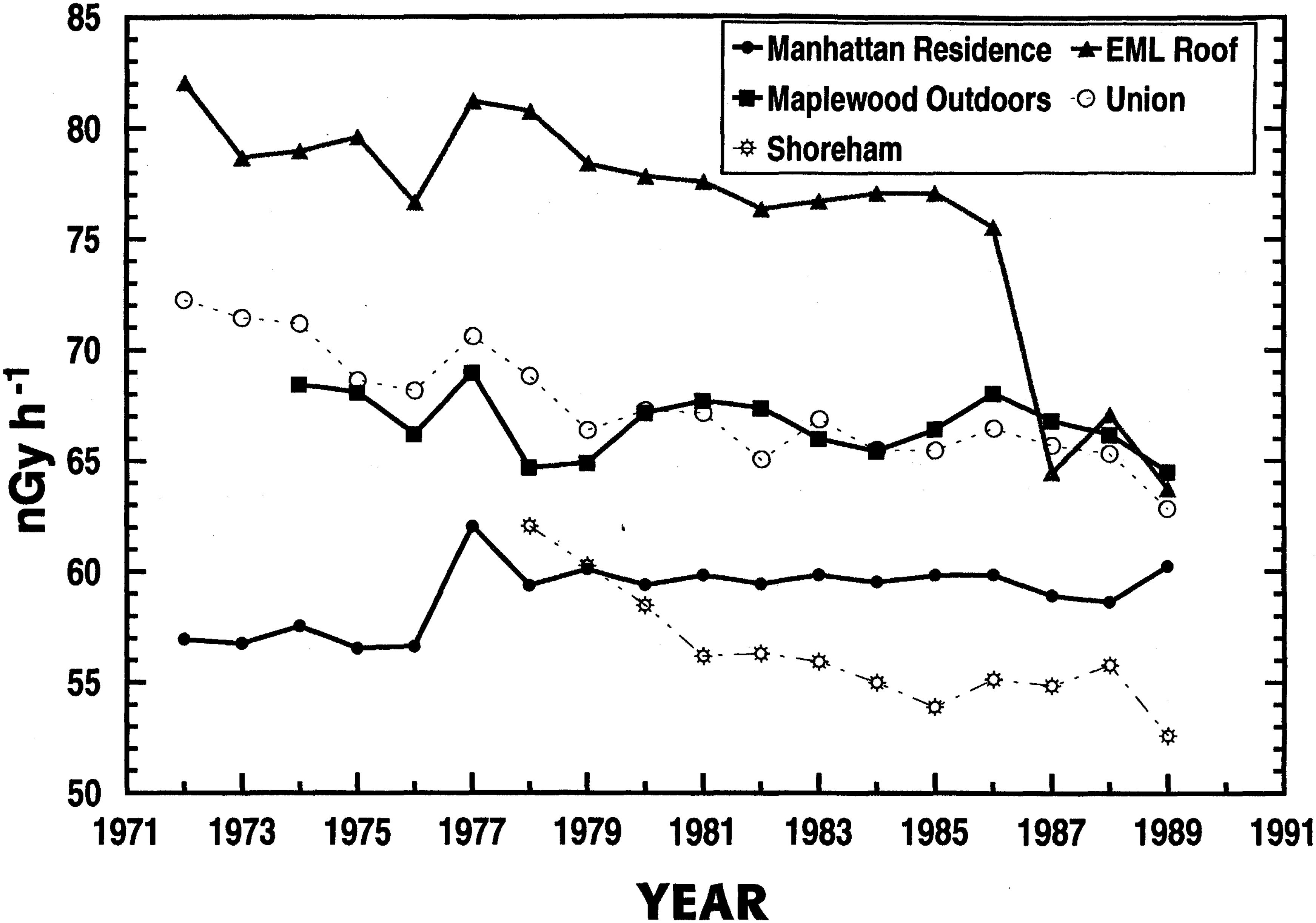

Figure 5. Annual mean dose rates in air for four outdoor sites and one indoor site.

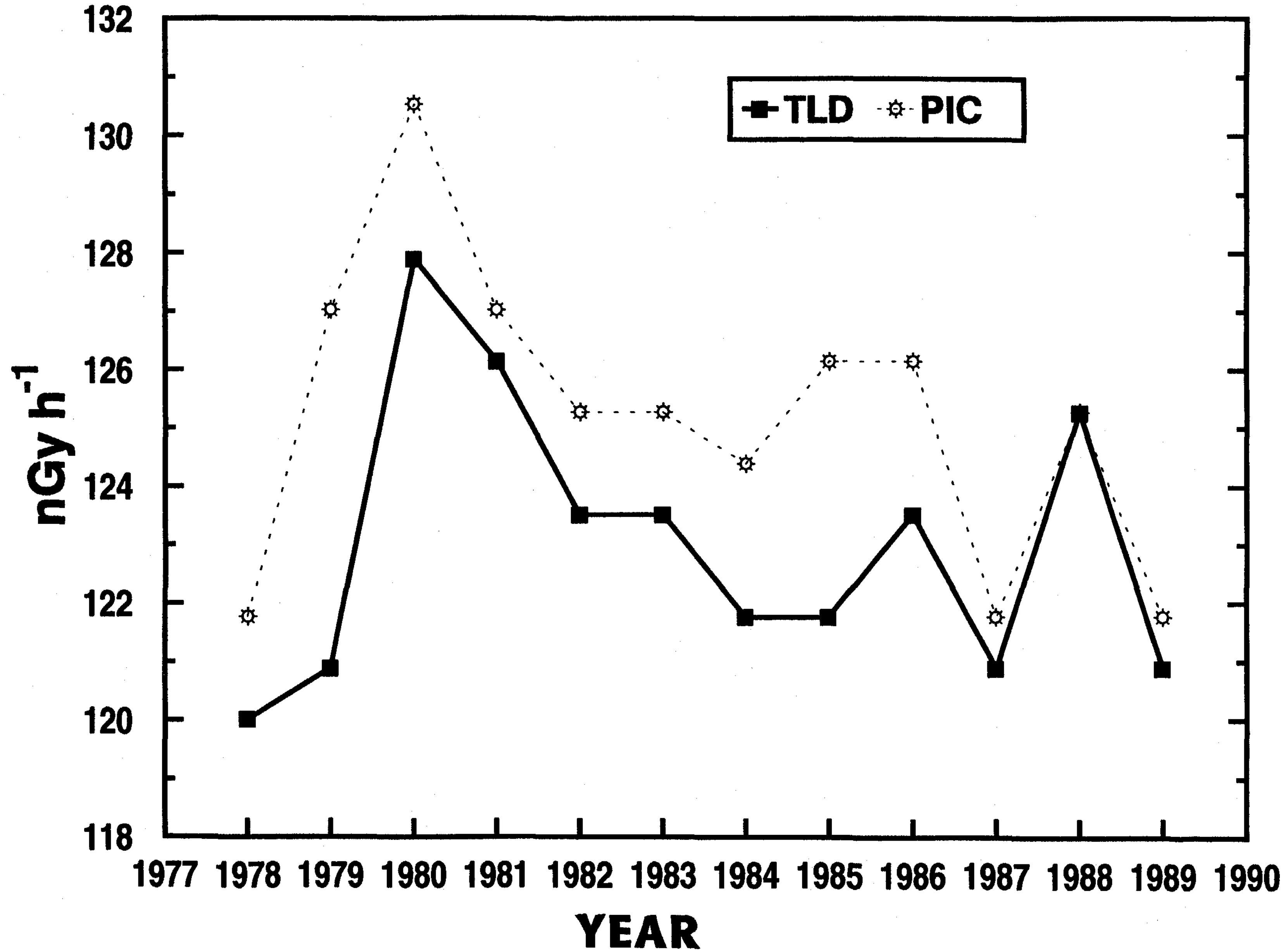

Figure 6. The annual mean dose rates in air at the Chester site measured concurrently with TLDs and a pressurized ion chamber system.

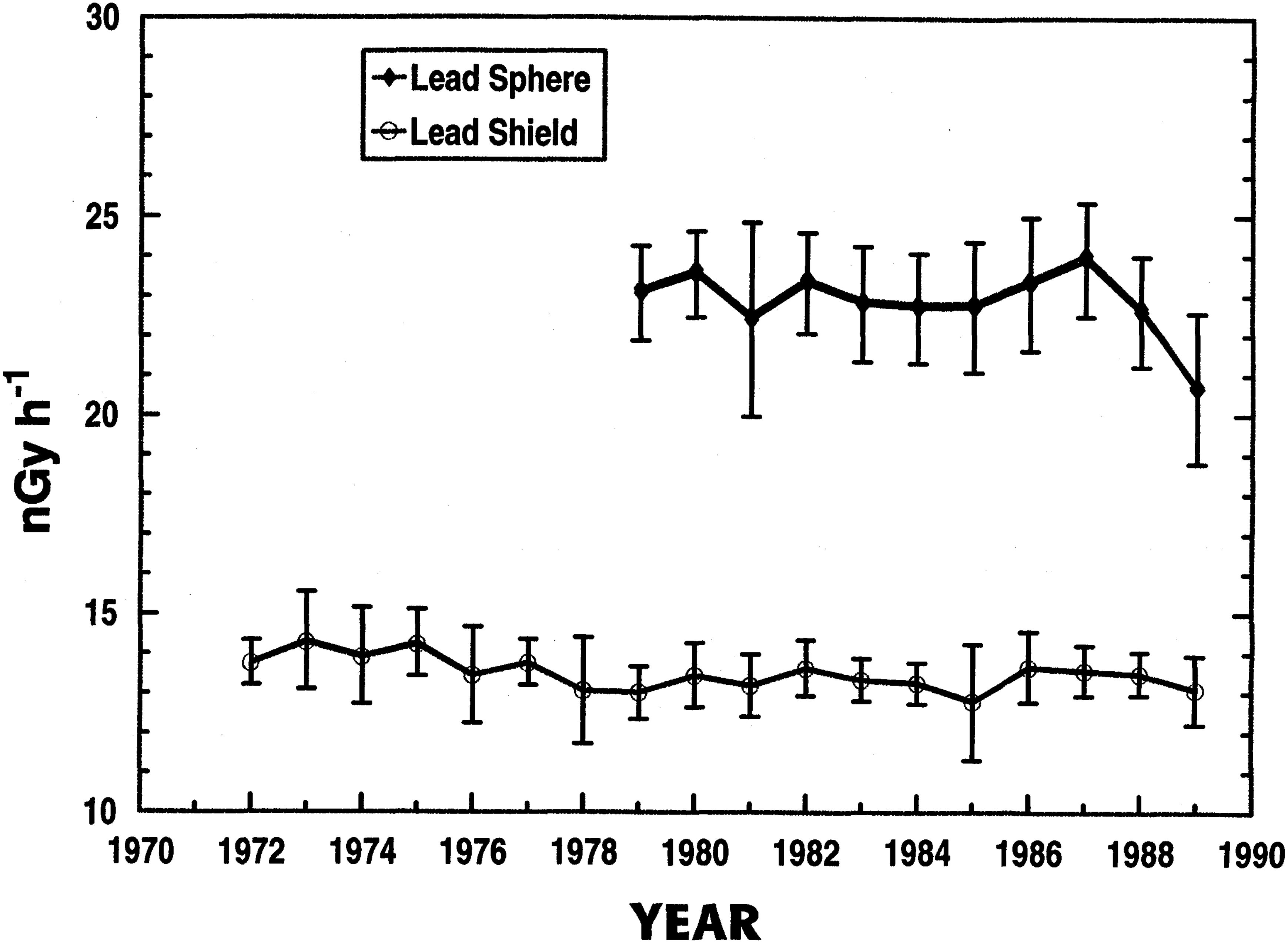

Figure 7. The annual mean dose-rate-in-air equivalents of the ionization due to cosmic-ray interactions ± 1 SD, as measured by TLDs in a lead sphere of 5-cm thickness and placed on the roof of the 12-story EML building (monthly measurements) and that measured on the 5th floor of the EML building inside a 9-cm thick cylindrical lead shield (monthly measurements).