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16. ABSTRACT

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The University of Akron Study on Air Pollution and Human Health Effects I. Methodology, Baseline Data, and Aerometrics

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ABSTRACT. This study determined the health effects of ambient air pollutants in two grade school populations in Akron, Ohio. One school is adjacent to industry and has elevated levels of sulfur dioxide (SO_2) and moderate levels of nitrogen dioxide (NO_2), while the other school is 4 km east and unpolluted. This study was designed in this manner for two purposes: (1) to identify and monitor ambient levels of air pollutants in an area proximal to the grade school so that the levels could be accurately assessed, and (2) to determine baseline pulmonary function values and questionnaire responses from the parents indicating any acute and/or chronic respiratory problem in the child. Ninety-five percent of the children enrolled in this study lived within 2 km of the schools and aerometric stations, thus providing for careful control in the study design.

The results of this study indicate that SO_2 and NO_2 levels are *significantly higher in the school adjacent to industry*. Although pulmonary function data were not significantly different between schools, the frequency of questionnaire responses to acute and chronic pulmonary problems was greater in the children at the school adjacent to industry. The data tend to indicate early pulmonary effects of air pollution in children living adjacent to industry and exposed to elevated levels of SO_2 and NO_2. We suggest that additional longitudinal work that carefully monitors total suspended particulates, NO_2, SO_2, and health data should be conducted to confirm these results.

MANY EPIDEMIOLOGICAL STUDIES have been conducted to determine the cause and effect of air pollutants on children. Some of these studies have reported significant air pollutant effects,[1-5] but others have not.[6,7] There are numerous potential problems associated with epidemiological work in air pollution: (1) the inability to accurately monitor air quality in the vicinity of the health study; (2) the inability to determine if the child has a subclinical acute respiratory illness (ARI); and (3) determining if the child has been exposed to some respiratory irritant during the past 4 or 5 days. Obviously, there are other problems inherent in epidemiological research, but it is felt that the previously mentioned are among the most important.

The purpose of this study was to determine the effects of air pollution within a carefully controlled population of children, and also sought to eliminate the three problems cited above.

METHODS AND MATERIALS

Two schools were selected for study: (1) Seiberling elementary school which is located in East Akron and in close proximity to several large industrial plants, and (2) Betty Jane elementary school, located about 4 km east of the Seiberling school. These two schools and the associated air pollution stations are located in a school district where 95% of the students walk to, and live within 2 km of the school. A topographical map outlining the two school districts and indicating point sources of air pollution is provided (Fig. 1).

Historically, the annual mean levels of air pollution in

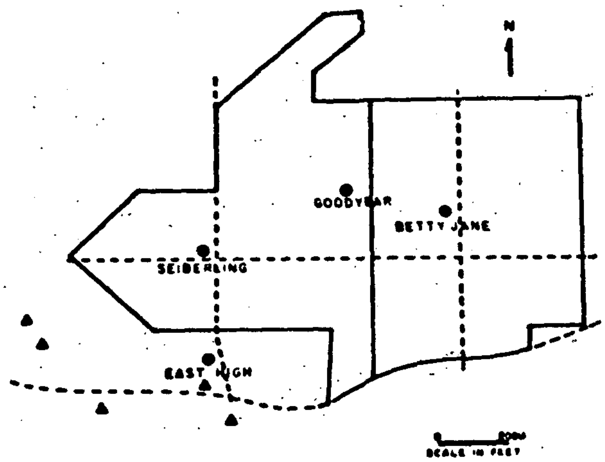

Fig. 1. Geographic locations of aerometric stations in Akron, Ohio (•). Large point sources of air pollution are indicated by (▲).

this area have fluctuated during the past 8 yr. Nitrogen dioxide (NO_2) levels have been constant and have approached 50 $\mu g/m^3$ since 1975. Sulfur dioxide (SO_2) levels have been as high as 104 $\mu g/m^3$ in 1971 and as low as 29 $\mu g/m^3$ in 1974, but during the past 4 yr levels have been about 65 $\mu g/m^3$. Total suspended particulates (TSP) have declined from 133 $\mu g/m^3$ in 1968 to the current level of 55 $\mu g/m^3$.

Air pollution measurements. Air pollution stations were set up in close proximity to each school. The Seiberling station was located across the street and about 100 m from the school building at ground level. The Betty Jane station was set up on the roof of the school, which was at a height of 10 m. A third station, Goodyear, was set up at ground level between the two schools to establish pollution dispersion patterns.

At each of the stations there was a hi-volume filter for TSP and a liquid phase bubbler train for SO_2 and NO_2. The hi-volume flow rates for each site were calibrated using a Sierra orifice calibrated by the United States Environmental Protection Agency Laboratories (Research Triangle Park, NC). The units were operated daily for a 24-hr period beginning and ending at 8:00 a.m. Each unit had a Sierra flow controller which maintained flow at 1.13 m^3/min. The filter papers were supplied and weighed by a Community Health Assessment Monitoring Program (CHAMP) subcontractor (Stewart Laboratories, Knoxville, TN).

The NO_2 and SO_2 absorption solutions were both supplied and analyzed by Stewart Laboratories. The bubblers were operated for the same 24-hr period as the hi-volume sampler. The flow rate through the bubbler train was measured before and immediately after sampling using calibrated rotometers. The flow rate (200 cc/min) was controlled by using a critical flow orifice. Because the stability of the reaction is temperature-dependent, the SO_2 tubes were temperature-controlled during the 24-hr sampling period. After the samples were obtained, the NO_2 bottles were refrigerated, the SO_2 samples were frozen, and both were shipped to Stewart Laboratories in refrigerated boxes.

Health data. At the beginning of the school year an envelope was sent home with each fourth- and fifth-grade child which contained a letter of introduction and a self-completion questionnaire to be completed by the parents. The authors designed the questionnaire, but questions were incorporated from questionnaires used in the Tucson Longitudinal Population Study,[8] which were derived from the NHLI Standard Questionnaire. All questions had been previously validated by the Tucson group. Approximately 85% (74 males and 72 females at Seiberling and 94 males and 59 females at Betty Jane) of the children returned the completed material. Pulmonary function testing (PFT) was initiated using a Warren E. Collins 9-L recording spirometer (Benedict-Roth) located at both schools. Each unit was carefully calibrated with respect to volume by using a 1-L syringe and for paper speed (1920 mm/sec) by using a signal marking device. Both units were similarly calibrated.

There was a medical technologist at each school to conduct tests. Both were thoroughly familiar with the testing apparatus and were trained by one of the authors to explain and administer the forced vital capacity (FVC) maneuver in a standard manner. Intertechnician differences, both for administering the test and for calculating the various volumes and flows from the spirogram, were compared as follows. Each technician administered the test to the same person four times. These "hard-copy" spirograms were then duplicated and the volumes and flows calculated by each technician, repeating each spirogram three times. This entire procedure was repeated for three different subjects. None of the mean values between technicians were significantly different, nor were the repeated measurements and calculations by the same technician. The average difference between two technicians measuring maximal mid-expiratory flow (MMF)—the most difficult to reproduce—was always less than 2% of approximately 2 L. The average difference for forced expiratory volume (FEV_1) and FVC was less than 1%.

Baseline determinations were conducted at the beginning of the school year, concurrent with the completion of the questionnaires by parents. For this initial testing, each child was without any respiratory symptoms; if any were present, baseline testing was delayed until the child was completely asymptomatic. Their height (shoes off) and weight were measured, followed by an explanation of how the spirometer worked, and what was required to successfully perform a FVC maneuver. Children were also questioned concerning smoking habits. The experimenter then demonstrated the FVC maneuver. The child was then given a noseclip and connected to the mouthpiece. Several trial maneuvers were recorded; when the recorded spirogram was satisfactory, the child repeated the maneuver until three acceptable spirograms were obtained. However, if none were satisfactory, the child was asked to return on another day for a re-test. Between 8 and 10 children from each school were eliminated from the study because they were unable to adequately perform the FVC maneuver.

The following values were calculated from each spirogram: FVC, MMF, and forced expiratory volume at 1 sec ($FEV_{1.0}$).

At each testing session a child performed a series of maneuvers which were carefully examined by the technician.

Table 1.—Aerometric Data from Three Stations in Akron, Ohio

	Seiberling ($\mu g/m^3$)	N	Goodyear ($\mu g/m^3$)	N	Betty Jane ($\mu g/m^3$)	N
TSP	55.36 ± 2.85*	106	52.98 ± 2.53	111	51.70 ± 3.14	70
SO_4	11.96 ± 0.50	106	12.19 ± 0.45	111	11.50 ± 0.66	70
NO_3	5.17 ± 0.26	106	4.38 ± 0.14	111	4.21 ± 0.24	70
SO_2	77.48 ± 4.90†	108	23.81 ± 3.01	112	21.39 ± 3.22	62
NO_2	54.36 ± 1.73†	111	27.49 ± 1.65	114	36.90 ± 2.49	64

NOTE: Data collection began October 15, 1977 and ended May 31, 1978.
*Values expressed as mean ± standard error.
†$P < .005$.

When the technician deemed the child had performed three similar spirograms, the session was terminated. After seven unsuccessful maneuvers, however, the session was terminated and the data were not included in the study. The spirograms were returned to the laboratory and all maneuvers were calculated and converted to BTPS. The maneuvers with the largest FVC, and two others which were within 5%, were retained. The $FEV_{1.0}$ and MMF values that accompanied the FVC were kept.

To check the validity of this selection process, we compared $FEV_{1.0}$ and MMF values that accompanied the FVC values with the best individual $FEV_{1.0}$ and MMF that a given child produced. This was possible because many children performed PFT many times during the school year. When the mean values were compared, $FEV_{1.0}$ and MMF were nearly identical for each of the selection processes.

When adjusting the data, PFT data were designated as dependent variables; age, height, and weight were the independent variables. A stepwise linear regression model with forward order of inclusion examined the effects and relative contribution of variation for the three independent variables. We chose the single independent variable or group of independent variables that produced the smallest standard error of the estimate (SEE).

Using these selection criteria, the appropriate coefficients were used to adjust the baseline data according to the following equation:

$$PFT_{adj} = PFT + [\beta_{Ht} (Ht - \overline{Ht}) + \beta_{Wt} (Wt - \overline{Wt}) + \beta_{age} (age - \overline{age})]$$

The coefficients of β were generated using the combined data from both schools.

During the second year of the study the methods and procedures remained the same. Two technicians were placed at each school to share the workload with the two new technicians being carefully trained, again by the same author. They met all of previously described intertechnician tests. The second year questionnaires were slightly different in that we were more interested in acute or chronic events that had developed or had changed during the past year. Baseline testing was conducted at the beginning of the year and adjusted as described.

RESULTS

Air pollution levels. All aerometric data collection began October 15, 1977, and terminated May 31, 1978. This constitutes the school year and for that period the mean values are given in Table 1. From this Table it can be seen that there was substantial data missing from the Betty Jane station. This was a result of the Ohio coal Strike of 1978, that caused the station to shut down for several months. However, the Goodyear station, located approximately 2 km from the Betty Jane station, was operated every day and served as a control or comparative station for Seiberling during this time. The question arises, however, whether the data from the Goodyear station is representative of the Betty Jane station. Therefore, it was decided to examine "same-day" data, i.e., data reported on days when all three stations were operating (Table 2). Although there are some minor differences, the statistical significance between the levels of air pollution remains the same. The SO_4 and NO_3 levels are not reported because they are similar to those in Table 1.

As shown in Figures 2 and 3, NO_2 and SO_2 levels fluctuated from month to month. The suspended sulfates, TSP, and nitrates are not shown because the month to month values are similar.

Because of the differences in the SO_2 and NO_2 levels between these two schools, and their closeness in geographic proximity, we substantiated our data with another source. The Akron Regional Air Pollution Control Agency (ARAPCA) has a ground-level station at East High School (Fig. 1), which is just south of the Seiberling station. This system is part of the national surveillance system and all of the analytical methods are similar to ours. "Same-day" data comparing ARAPCA data with our data are shown in Table 3; there is excellent agreement between the two systems. Because ARAPCA is nearer to the point sources, it is not surprising that the "same-day" ARAPCA mean values are slightly higher than those recorded at the Seiberling station. The sample sizes are small because of the necessity of matching our data with data collected every sixth day.

The mean aerometric values reported at Seiberling school are not excessively high, but the levels do exceed the Ohio standard for SO_2 (60 $\mu g/m^3$), and are close to the national annual average of 80 $\mu g/m^3$. These are annual criteria val-

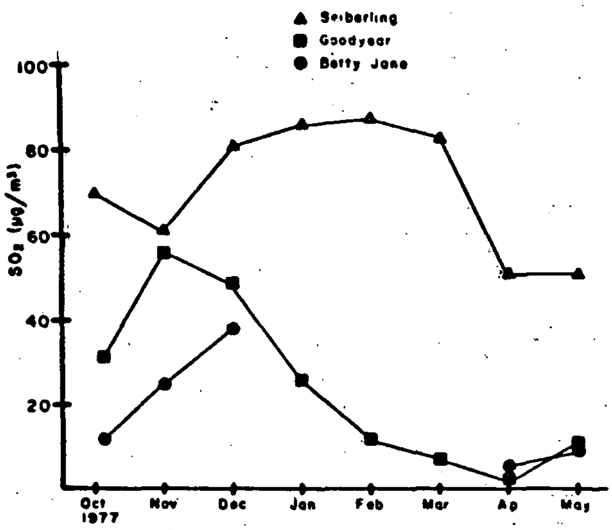

Fig. 2. Monthly means during the school year for sulfur dioxide.

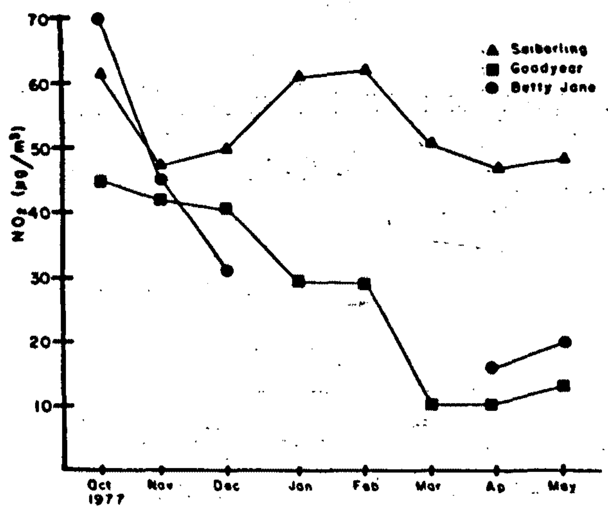

Fig. 3. Monthly means during the school year for nitrogen dioxide.

ues and the data reported only represent 9 months, therefore, some discrepancy in that statement exists.

Of practical importance is that the children were exposed to those levels specifically during the course of the study. Also the difference between the two schools for SO_2 is threefold, which by any standard is significant.

Health data. Socioeconomic characteristics assessed by comparing parental occupation according to the methods of Blishen[9] and Hollingshead,[10] did not differ significantly ($P < .01$) between the two schools. This similarity is important, as numerous studies have demonstrated the effects of socioeconomic factors with respect to epidemiologic studies.

The questionnaire data was assessed using the relative risk ratios (RP.R) technique of Mantel and Haenszel[11] (Table 4). Additionally, some questions were grouped, or their detailed subdivisions were used, to assess syndromes: the cough phlegm syndrome (CPS), which combined cough and phlegm questions; the shortness of breath syndrome (SB), which included the four questions regarding shortness of breath or stop to catch breath while walking or playing; the wheeze syndrome, graded as to when wheezing occurs; wheezing dyspnea, graded according to the frequency of attack per year; and wheezing dyspnea, with doctors' diagnosis of asthma, graded the same as the wheezing dyspnea syndrome. The results of these syndrome tabulations are shown in Table 5, where again the RRR was used as the method of statistical evaluation.

The baseline PFT data for the two study years, which are very similar for both schools, are shown in Tables 6 and 7.

DISCUSSION

Aerometrically, the TSP-SO_2 relationship is not consistent at the three stations. This is supported by the fact that in Akron, the values for TSP are constant and do not depend on point sources within the city because most stack emissions are being well controlled by electrostatic precipitators. All stations to the west of Akron report annual means for TSP in the range of 60-80 $\mu g/m^3$. As the prevailing winds come across the city, little TSP is accumulated, therefore, the constancy of the levels from station to station is not surprising.

Table 2.—Aerometric Data Obtained from Three Stations on the Same Day* in Akron, Ohio

	Seiberling ($\mu g/m^3$)	Goodyear ($\mu g/m^3$)	Betty Jane ($\mu g/m^3$)
TSP	49.90 ± 3.28†	47.80 ± 3.11	48.14 ± 3.11 (N = 31)
SO_2	62.56 ± 7.16‡	32.10 ± 7.47	20.25 ± 4.35 (N = 26)
NO_2	50.18 ± 2.70‡	32.56 ± 3.27	34.72 ± 3.09 (N = 26)

*Data from Table 1 used in calculations.
†Values expressed as mean ± standard error.
‡$P < .005$.

Conversely, SO_2 is not ~~well controlled~~. The Seiberling station is near point sources and is located in an open area near a hilltop. Under these conditions the mixing is good, as are the characteristics of vertical dispersion. Goodyear and Betty Jane, however, are near large stands of trees and are not as open as the Seiberling station, therefore, the mixing is not as good. The foliage could also be a factor in the lower SO_2 levels, as it is known to absorb SO_2.[12,13]

A final possible explanation for the large difference in SO_2 and NO_2 values among the stations could be related to plume direction. Although we have no vector analysis data available, the plume could be funneled from the geographic valley-like location around the Seiberling hill, and not be a factor in the Goodyear and Betty Jane areas.

In summary, these aerometric data were collected in a well-controlled surveillance system. Although there are some missing data at the Betty Jane school and some problems in station location, these data indicate the air pollution levels that these school children were exposed to during the course of the school year. Furthermore, the data have been verified by another independent surveillance system.

In selecting students for study, an effort was made to exclude anyone with any chronic low-level rhinitis or chest congestion, as well as any smokers. Also, the number of black individuals participating in the study was two from each school. Therefore, a very homogenous population was being studied from each school based on the SES index, racial mix, and the similarities in lung function and anthropometric data.

The adjustment criteria used with these data were adopted because although height always contributed the most variance to a given pulmonary function variable, the effects of weight and age frequently contributed enough variability to affect the SEE. Since we are attempting to identify subtle differences in PFT, we felt it important to

Table 3.—Same-Day Samples Collected at Seiberling and East High School Aerometric Stations, October 1977–September 1978

	Seiberling ($\mu g/m^3$)	East High School ($\mu g/m^3$)	N
TSP	74.0 ± 8.3* (ns)†	87.9 ± 6.1	30
SO_2	64.5 ± 9.2 (ns)	67.2 ± 7.4	29
NO_2	46.2 ± 3.9 (ns)	54.6 ± 3.7	31

*Values expressed as mean ± standard error.
†ns = Not significant.

Table 4.—Relative Risk Ratios* and Levels of Probability for Pediatric Questionnaire Responses in Akron, Ohio

	I (#3) Cough without Cold	I (#5) Chest Wheezy and Whistling	I (#6) Shortness of Breath with Wheezing	II (#3) Short of Breath while Playing	II (#4) Catch Breath while Walking	II (#5) Catch Breath while Playing	II (#9) Past 2 yr have seen a Doctor for Shortness of Breath
1976–1977	1.28 (ns)†	1.37 (P = .08)	2.23 (P = .008)	1.53 (ns)	2.26 (P = .09)	1.69 (P = .008)	6.21 (P = .006)
1977–1978	1.06 (ns)	1.70 (P = .04)	1.73 (P = .1)	1.23 (ns)	2.23 (ns)	1.20 (ns)	1.67 (ns)

*Relative risk ratio = RR Seiberling/RR Betty Jane.
†ns = Not significant.

Table 5.—Relative Risk Ratios* and Significance Levels of Syndromes in Akron, Ohio

	Cough Phlegm Syndrome (Grade 1+)	Shortness of Breath (Grade 3+)	Wheeze (Grade 2+)	Wheezing Dyspnea (Grade 1+)	Wheezing Dyspnea and Dx Asthma
1976–1977	1.17 (ns)†	1.29 (P = .103)	2.39 (P = .02)	2.00 (P = .02)	No data
1977–1978	1.16 (ns)	1.40 (P = .2)	1.45 (P = .2)	2.25 (P = .04)	‡

*Relative risk ratios = RR Seiberling/RR Betty Jane, on the assumption that elevated SO_2 and NO_2 levels would have more effect on students residing in the Seiberling school area.
†ns = Not significant.
‡Eight responded at Seiberling; none responded at Betty Jane.

Table 6.—Comparative, Adjusted Baseline PFT Data for Males and Females in Seiberling and Betty Jane Schools, 1976–1977

	Males		Females	
	Seiberling (N = 58)	Betty Jane (N = 77)	Seiberling (N = 65)	Betty Jane (N = 56)
Height (cm)	140.83 ± 0.90*	141.77 ± 0.90	142.25 ± 0.90	142.66 ± 0.90
Weight (kg)	36.06 ± 1.60	36.30 ± 1.10	37.52 ± 1.00	38.20 ± 1.30
Age (mo)	124.63 ± 0.90	127.07 ± 1.07	125.32 ± 0.90	126.42 ± 0.90
FVC (L)	2.11 ± .03	2.13 ± .02	2.01 ± .03	1.98 ± .03
$FEV_{1.0}$ (L)	1.72 ± .03	1.77 ± .02	1.61 ± .02	1.63 ± .03
$FEV_{1.0}$/FVC	0.81 ± .01	0.83 ± .01	0.80 ± .01	0.82 ± .01
MMF (L/sec)	1.06 ± .02	1.06 ± .01	1.01 ± .01	0.99 ± .02

*Values expressed as mean ± standard error.

Table 7.—Comparative, Adjusted Baseline Mean PFT Data for Males and Females in Seiberling and Betty Jane Schools, 1977–1978

	Males		Females	
	Seiberling (N = 74)	Betty Jane (N = 94)	Seiberling (N = 64)	Betty Jane (N = 59)
Height (cm)	144.10 ± 0.90*	145.90 ± 0.90	143.68 ± 0.80	146.60 ± 1.13
Weight (kg)	40.20 ± 1.47	39.60 ± 1.17	39.72 ± 1.10	40.07 ± 1.40
Age (mo)	134.80 ± 1.17	135.20 ± .80	132.50 ± .90	135.20 ± 1.00
FVC (L)	2.61 ± .03	2.49 ± .02	2.37 ± .04	2.33 ± .03
$FEV_{1.0}$ (L)	2.09 ± .03	2.03 ± .02	1.94 ± .04	1.96 ± .03
$FEV_{1.0}$/FVC	0.80 ± .01	0.82 ± .01	0.81 ± .01	0.84 ± .01
MMF (L/sec)	2.26 ± .06	2.22 ± .06	2.50 ± .06	2.40 ± .07

*Values expressed as mean ± standard error.

not only use standing height, but any combination of the three independent variables that would more definitively adjust the data.

A definitive statement cannot be made regarding which pollutation affected children the most. The levels of both SO_2 and NO_2 are not considered to be drastically elevated, and are within the criteria limits. To our knowledge, such low levels have not been associated with pulmonary abnormalities in previous literature.

Other air pollution studies support our finding that no large differences in PFT are apparent.[6,7] This is not surprising, since the levels of air pollution in this study cannot be considered excessive. In a recent study by Sharratt and Cerny,[14] SO_2 and NO_2 levels were similar to data reported in this work. Their sample sizes were smaller than those reported here, but they found significant differences in FVC and $FEV_{1.0}$ in favor of the clean city.

In our data, collected over a 2-yr period, the values for FVC and $FEV_{1.0}$ were very similar between schools or sexes and did not reveal any differences, but the $FEV_{1.0}$/FVC ratio was consistently lower at the Seiberling school. Knudson et al.[15] have shown that this ratio is sensitive to airway obstruction and is as sensitive as instantaneous flow values at 50% and 75% of FVC. This particular lung function variable, when considered alone, might be overlooked as a minor effect, since the differences are small. However, when the questionnaire responses are coupled with the baseline lung function data, there is increased evidence of what we believe is an effect of air pollution. Finally, in Part II of this report, data show pulmonary effects of SO_2 and NO_2, and severity and duration of acute respiratory illness (ARI).

In conclusion, these data seem to indicate that air pollution at levels that are currently deemed acceptable by national criteria standards appear to have an effect on fourth-sixth grade children. The effects are subtle relative to baseline PFT data, but are more convincing when the questionnaire results are examined concurrently.

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