INTERNATIONAL INSTITUTE OF SYNTHETIC RUBBER PRODUCERS, INC.

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Attn: TSCA Section 8(e)
Environmental Protection Agency
1201 Constitution Ave. NW
Washington, D.C. 20460-0001

Attention: Section 8(e) Coordinator

RE: Docket 8(e) HQ-99-14447

Dear Sir or Madam:

The International Institute of Synthetic Rubber Producers, Inc. (IISRP) has been sponsoring a cohort mortality study of nearly 18,000 workers employed between 1943 and 1991 at eight styrene butadiene rubber (SBR) plants in the United States and Canada. IISRP reported to EPA on this study and its findings concerning leukemia and exposure to butadiene on a number of occasions including May 19, 1995 and June 26, 1995and the final report was submitted to this office of October 24, 1995. The cohort was updated and those findings were submitted on 26 January 2000.

Over the past several years, additional collection and refinement of exposure information and reanalysis of the mortality data on SBR worker cohort has been conducted by the investigators of the University of Alabama at Birmingham. The initial preliminary results of this work were provided to this office on May 10, 1999. More recently, efforts have been underway to validate the exposure estimation process used in the 2000 cohort update.

IISRP, on behalf of its member companies and pursuant to TSCA 8 (e) guidelines, is providing the final report of the "Validation of 1,3-Butadiene Exposure Estimates for Workers at A Synthetic Rubber Plant" This study compared the exposure estimation process used in the 2000 Study against actual exposure data maintained at a plant site

This report has also been sent to Dr. Peter Preuss, Dr. William Farland, Dr. Apparna Kopikar and the IRIS docket.

Sincerely,

James L. McGraw
Managing Director and CEO

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VALIDATION OF 1,3-BUTADIENE EXPOSURE ESTIMATES FOR WORKERS AT A SYNTHETIC RUBBER PLANT

Submitted to

The International Institute of Synthetic Rubber Producers

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ABSTRACT

Background. This investigation assessed the validity of estimates of exposure to 1,3-butadiene (BD) developed for a plant included in a study of mortality among synthetic rubber industry workers. The estimates were developed without using historical measurement data and have not been validated previously. **Methods**. Personal BD measurements came from an exposure monitoring program initiated in 1977. For each job, we computed the year-specific difference between the BD estimate and the mean of BD measurements. We also computed rank correlation coefficients and calculated the mean, across all measurements, of the difference between the estimate and the measurement. **Results**. The mean BD concentration was 5.2 parts per million (ppm) for 4,978 measurements and 4.7 ppm for the corresponding estimates. Overall, estimated BD exposure was 10% lower than measured exposure. The mean difference between estimates and measurements was -0.50 ppm (standard deviation, 26.5 ppm) overall and ranged from -227.9 ppm to +27.0 ppm among all 306 job/year combinations. Estimates were correlated with measurements for all 306 combinations (rank correlation coefficient, $r=0.45$, $p<0.0001$), for 82 combinations pertaining to jobs that were well-defined by a specific set of tasks and typically found in styrene-BD rubber (SBR) plants ($r=0.81$, $p<0.0001$), for 70 combinations pertaining to jobs that were well-defined but not typical ($r=0.29$, $p=0.01$) and for 92 combinations pertaining to poorly-defined jobs typically found in SBR plants ($r=0.56$, <0.0001). Estimates were not correlated with measurements for poorly defined jobs not typically found in SBR plants ($r=0.01$, $p=0.93$). For all combinations pertaining to well-defined typical SBR jobs with measurement means that were over 7.0 ppm, estimates were lower than measurements. **Conclusions**. Possible reasons for differences between estimates and measurements included faulty assumptions used in developing BD estimates, unstable or nonrepresentive measurements and errors in linking

measurement data to the job-exposure matrix. Exposure misclassification may have been more severe for subjects from the validation study plant than for subjects from other plants in the mortality study. BD estimates for typical SBR jobs, which comprise most operations at all but one of the plants in the mortality study, appeared to be useful for ranking workers by cumulative exposure. Uncertainty analyses would enhance the utility of the BD exposure estimates for quantitative risk assessment.

INTRODUCTION

Several epidemiologic investigations have evaluated the mortality experience of workers in the North American synthetic rubber industry (Matanoski et al. 1987, Matanoski et al. 1990, Santos-Burgoa et al. 1992, Matanoski et al. 1993, Delzell et al. 1996, Delzell et al. 2001, Delzell et al. 2004, Macaluso et al. 1996, Matanoski et al. 1997, Sathiakumar et al. 1998). One study (Delzell et al. 1996, Macaluso et al. 1996, Sathiakumar et al. 1998, Delzell et al. 2001, Delzell et al. 2004) included over 17,000 men potentially exposed to 1,3-butadiene (BD) and other chemicals at eight synthetic rubber plants. As part of this study, Macaluso et al. (1996, 2004) developed quantitative estimates of exposure to BD and other chemicals for 16,579 workers from six of the eight plants. The other two plants had work histories that were not sufficiently detailed for exposure estimation. Epidemiologic analyses found a positive association between cumulative exposure to BD and leukemia (Macaluso et al. 1996, Delzell et al. 2001, Delzell et al. 2004). The interpretation of this result has been problematic, primarily because of the lack of validation of the BD exposure estimates and because of potential confounding by chemicals other than BD (US EPA, 1998). The present investigation assessed the validity of the BD exposure estimates developed for the largest of the North American synthetic rubber plants included in the previous epidemiologic research.

BACKGROUND

Previous Research

Our study of mortality among men employed at eight North American plants that manufactured styrene-BD rubber (SBR) and related products is the largest study of BD-exposed workers to date (Delzell et al. 1996, Delzell et al. 2001, Macaluso et al. 1996, Sathiakumar et al. 1998, Delzell et al. 2004). Macaluso et al. (1996) initially developed quantitative estimates of

cumulative exposure to BD by: (1) identifying work area/job groups (referred to as "jobs") consisting of reasonably homogenous work activities; (2) identifying the tasks comprising each job; (3) identifying historical changes in exposure potential for each task; (4) computing time-period-specific average exposure concentrations in parts per million (ppm) for tasks and jobs; (5) compiling the job-specific estimates into a job-exposure matrix (JEM) for each plant; and (6) linking the resulting JEMs with subjects' work histories to obtain cumulative exposure estimates.

Epidemiologic analyses of the study indicated that the workers had more than expected leukemia deaths, with excess leukemia risk being prominent in subgroups of workers (laboratory workers, maintenance laborers, polymerization operators) who may have had high exposure to BD and other agents (Delzell et al. 1996, Macaluso et al. 1996). Analyses of leukemia rates by estimated levels of cumulative exposure to BD were consistent with an exposure level-dependent effect of BD.

Concern existed about the validity of the exposure estimates and about the potential impact of exposure misclassification on risk assessment. Sielken et al. (1997) reanalyzed data from the study and found that the observed rates of leukemia were not adequately fit by any of several mathematical models predicting risk as a function of the BD exposure. The latter observation suggested that exposure misclassification might have affected the observed exposure-response relation.

To address the concerns about exposure misclassification, a team of industrial hygiene experts and epidemiologists carried out a comprehensive review of exposure estimation procedures and revised the exposure estimates (Macaluso et al. 2004). This project entailed in-depth review of the exposure estimation approach, visits to each participating plant, collection of supplemental data on exposure and expansion of the documentation of exposure estimates, but

the project included only a very limited validation of the estimates (Macaluso et al. 2004). Uncertainty about the accuracy in the estimation procedures has limited inference about the association between BD and leukemia and has hindered attempts to conduct quantitative risk assessment. At one of the study plants (the Bayer Sarnia plant), we identified a set of historical BD measurements and determined that the data were suitable to carry out a limited validation of the BD exposure estimates for that plant.

The Bayer Sarnia Plant

The Bayer Rubber Division facility in Sarnia is a manufacturing complex that during its history had a variety of processes. These included processing of oil refinery streams, synthesis of monomers such as ethylene, BD and styrene; and manufacturing of synthetic polymers such as butyl and halobutyl rubber, SBR, nitrile rubber, polybutadiene rubber, and acrylonitrile-styrene-BD plastic. The Sarnia plant differs from the other five plants with exposure estimates in the mortality study in that only the Sarnia plant had both typical SBR operations as well as extensive other operations that were not typical of SBR production.

Production of rubber at the Sarnia plant began on September 29, 1943. Initially, Dow Chemicals operated the styrene production units and related laboratories, Canadian Synthetic Rubber Company operated the synthetic rubber manufacturing units and related laboratories, and St. Clair Processing operated the light hydrocarbon processing units that provided feed streams to the styrene and rubber manufacturing units. In 1972, the Canada Development Corporation purchased the complex from the Canadian government and named the site "Polysar." In 1987, BASF Corporation bought the Polysar latex operations. In 1988, the remainder of Polysar was sold to Nova Corporation, which, in 1990 sold the entire operating site except the styrene operations to Bayer Corporation of Germany. The former Polysar complex covered nearly 400

acres and in 1992 had 2,000 employees. Exposure estimation procedures for the mortality study covered all operations.

The Sarnia plant is the only one of the six plants for which we developed exposure estimates that had an industrial hygiene program that, for certain jobs, appears to have monitored "average" exposure levels over a relatively long (16-year) time span. The plants in the United States (US) did exposure monitoring mainly to assess problems and to document conditions after installing new equipment or after scheduled maintenance. In the mid-1980s, the National Institute for Occupational Safety and Health (NIOSH) conducted an investigation of exposures at BD monomer and polymer plants in the US (Fajen et al. 1993). The study was designed to describe average exposure conditions, but it obtained measurement data only for a few jobs and only for approximately a one-week time period at each of five US polymer plants surveyed. Macaluso et al. (2004) described the agreement between job-specific estimates developed for our mortality study, averaged across all six plants, and measurements made by NIOSH, averaged across the five US plants. Comparative data were available for five specific jobs. Estimates were 1.7 to 6.5 times higher than measurements for four of the five jobs and were lower for one job (measurement mean, 0.35 ppm; estimate, 0.00 ppm). The explanation for these differences was not investigated.

OBJECTIVES

The present study assessed the validity of retrospective estimates of exposure to BD developed for the Sarnia plant as part of our research on mortality among synthetic rubber industry workers. The main objective was to measure differences and correlations between calendar year- and job-specific estimates and measurements of BD concentrations (ppm). Other objectives were to determine if the extent of the discrepancy between the estimate and the

measurements for a job/year combination varied according to the type of procedure used to develop the estimate (primary or secondary, defined below) and the type of operation (typical SBR or other operations).

METHODS

Information Sources

Information sources included work histories of Sarnia plant employees, the JEM file containing BD exposure estimates and the Sarnia plant measurement database.

Work histories. Work histories used in the previous mortality study covered the period from an employee's hire through 1991 and consisted of a chronological set of jobs. The data for each job were the start date, the end date, the job title and the payroll classification. Using the work histories, we developed for each plant a list of unique job titles and assigned each to a job group, represented by a three-digit code. Each job group consisted of operations and tasks considered to be similar. We refer to these groups as "jobs" throughout the rest of this paper. Appendix A displays the job classification developed for the Sarnia plant. Of a total of 233 jobs found in work histories during the entire employment period of 1943-1991 considered in the mortality study, 179 (77%) appeared in employees' work histories during 1977-1991, the time period covered by the measurement data.

JEM data. The exposure estimates used for our previous studies were organized into two main data systems: the task-exposure matrix (TEM) file and the JEM file. The TEM file contained plant-specific estimates for each task in each time period during which exposure conditions were assumed to be stable. Each record in the TEM data set contained the plant code, the first and the last year for which the estimate was computed, information on the frequency and duration of exposure and the estimated of exposure concentration (ppm). The JEM file

contained plant-specific estimates of eight-hour time-weighted average exposure concentration for BD and other chemicals for each job and for each year from 1943 through 1991. Each record consisted of the plant code, the job code, the calendar year and the estimated eight-hour time-weighted average concentration of BD in ppm.

Sarnia plant measurement database. In 1977, the plant established a systematic monitoring program to evaluate exposure to BD and other chemicals in jobs in rubber manufacturing, support laboratories and olefin production. On a quarterly basis, all of these areas were monitored. The day for the start of monitoring was chosen randomly from the quarter. For personal monitoring, individual employees were selected randomly to obtain monitoring results representative of average exposure conditions in a specific job. Because the Ontario government required some chemicals including BD to be monitored for time periods exceeding one shift in order to establish average exposure representative of a work week, the sampling time was typically more than eight hours. To accomplish this, a sampling tube was reissued to the same worker during multiple shifts in a week. Task-specific samples (15-minute or grab samples) also were obtained periodically. Results indicating noncompliance with existing exposure limits (>1/2 exposure limit) were followed up with additional monitoring.

Air samples were collected by trained industrial hygiene program staff and were analyzed at the plant's industrial hygiene lab. The typical sampling protocol for BD specified the use of air sampling pumps calibrated at a low flow rate and charcoal tubes with a backup section. Samples were desorbed and analyzed with a gas chromatograph (GC). From 1977 to 1987, sampling at the site involved active collection of BD on coconut charcoal followed by thermal desorption and GC analysis. In 1987-1991, the ATD 50/400 passive tube with a synthetic absorbent was used as the main sampling technique, followed by thermal desorption and GC

analysis. There also were brief periods in which the 3M 3500 badge or 3M 3520 badge passive dosimeters were used to collect samples, followed by GC analysis.

The plant carried out validation studies throughout the period 1977-1998 to address desorption coefficient, breakthrough and sampling rate for BD. The air monitoring and analytical procedures used before 1987 were reviewed and validated for BD monitoring in 1985. We were unable to locate the results of any of the validation studies.

We obtained the electronic Sarnia measurement database, a computer file containing information on personal measurements taken from 1977 through 1992. The data included for each sample, the employee number, sample number, sample date, chemical being monitored, duration of monitoring, monitoring method, a code for the job title and process unit (referred to as "job code") and the measured concentration in ppm. The original database had 9,148 measurements for BD.

We resolved problems with missing and invalid data in the measurement database by reviewing original hard-copy data sheets. To assess the accuracy of the electronic data, we selected a sample of 410 records and compared these with the original hard-copy data. We were able to retrieve hard-copy data for 402 of the 410 records. On comparing information on the measurements in the database with information found in the hard-copy records, we found errors in 67 measurement database records (17% of 402 records) (Appendix B). Consequently, we reviewed all of the available hard-copy records (N~25,000), identified those pertaining to BD and edited the database to correct erroneous data. This effort resulted in the addition of 1,137 records to the original 9,148 records pertaining to BD, bringing the total to 10,285 records.

We subsequently excluded 5,307 records for various reasons, including: BD not measured because of pump failure, N=1,141; measurement pertained to chemicals other than

BD, N=1,676; sample year >1991, N=99; job not recorded, N=387; record pertained to employees not included in the mortality study, N=118; sample duration <360 minutes, N=477; measurement pertained to turnaround jobs, N=1,282; record pertained to jobs with less than 10 measurements overall, N=42; implausible BD values, N=2; and record pertained to jobs that never appeared in administrative work histories, N=83.

A priori, we excluded the measurements with sample duration <360 minutes because they pertained to tasks, not jobs, and we excluded turnaround job measurements because they pertained to atypical conditions. Comparison of short-term measurements with long-term measurements in the same jobs indicated mean BD concentrations of 19.7 ppm (N, 477; standard deviation (SD), 84.6 ppm) for the former and 5.7 ppm (N, 2,870; SD, 28.5 ppm) for the latter. BD concentrations also were higher for turnaround measurements (N, 1,282; mean, 12.8 ppm; SD, 64.2 ppm) than for other measurements in the same jobs (N, 2,700; mean, 4.1 ppm; SD, 32.4 ppm).

We excluded records with missing job codes and job descriptions because they could not be linked to the JEM. The two records excluded as implausible included BD measurements of 20,071 ppm (job 813 - rubber production polymerization, tank farm, transfer pumphouse) and of 2,872 ppm (job 832 - finishing). Acute health effects of BD in humans, known to occur at levels of 2,000 ppm, include extreme irritation of the eyes and respiratory tract and neurological effects such as blurred vision, fatigue, headache and vertigo (Carpenter et al. 1944). These effects are severe enough to make full-shift average exposure above 2,000 ppm improbable. The records excluded because they belonged to jobs not found in administrative work histories pertained to latex lab technicians.

We assigned to each of the 4,978 BD measurement records that remained after exclusions the best matching job from the JEM used in the epidemiologic studies. Two of the investigators (JL, BS) independently assigned job codes and resolved discrepancies among code assignments collaboratively, through verbal analysis of the assumptions each investigator used to assign a code to the job in the measurement database. Appendix C lists, for each of the JEM jobs, the corresponding job codes and job titles in the measurement database.

Job categories. We classified each JEM file job and each measurement file job according to two exposure estimation procedures used in our previous studies. "Primary" jobs had exposure estimates that were derived from a specific set of tasks. Examples included tank farm operators (job 813), reactor operators (job 815) and recovery operators (job 817), all of which are jobs in the polymerization area of the plant. "Secondary" jobs had exposure estimates that were derived as a weighted average or arbitrary percentage of the estimates for several primary jobs. For example, exposure in secondary job 812, "polymerization operator unspecified," was the average of estimates developed for primary jobs 813, 815 and 817, weighted by the proportion of polymerization area workers in each of the three primary jobs. We also classified jobs according to type of operation. “Typical SBR” jobs were found at all of the synthetic rubber industry plants included in the mortality study; “other operations” jobs were not typically found in synthetic rubber plants other than the Sarnia plant. The latter included jobs related to latex operations, petrochemicals production, BD production and support jobs (maintenance, labor, laboratories) for these manufacturing operations.

For two reasons, we anticipated that agreement between estimates and measurements would be better for typical SBR jobs than for other operations jobs, better for primary than for secondary jobs and best for primary typical SBR jobs. First, all of the plants for which we

developed exposure estimates in our mortality study had typical SBR operations, and development of plant-specific estimates for typical SBR operations benefited from information accumulated from all six plants. In contrast, most of the other operations at the Sarnia plant were limited to that single facility and did not occur at the US plants.

Second, linkage of jobs in the measurement database with jobs in the JEM database was relatively straightforward for primary jobs, but it was not possible to identify an appropriate mix of jobs in the measurement database that would correspond to each secondary JEM job, mainly because measurements were not available for all primary jobs comprising a secondary job. For example, the exposure estimate for secondary job 832 (finishing operator unspecified) was the weighted average of exposures estimated for primary jobs 820 (coagulation operator, weight=25%), 833 (dryer operator, 25%) and 835 (baler operator, 50%). Measurements available for job 832 (N=39) pertained to finishing operators unspecified (Appendix C). We did not know if the actual jobs of the measured finishing operators unspecified were distributed in the same manner as that assumed for developing estimates. Because of such limitations, the measurements available for secondary jobs may not constitute a "gold standard" for evaluating estimates.

Analysis

Descriptive analyses determined the number of measurements available for each job and examined the distribution of measurements for each job over all years combined and within each year. These analyses determined that both job and calendar year were related to BD concentration. Thus, most analyses compared estimates with measurements within particular job/year combinations and within subgroups of combinations specified on the basis of estimation procedure (primary or secondary) and the type of operation (typical SBR or other operations).

We computed two different weighted averages of job/year combination-specific differences between the estimate and the measurement mean. The first used as weights the number of BD measurements for each combination. The resulting weighted average difference is a measure of bias and is equivalent to the mean, across all measurements, of the difference between the estimate and each measurement (Hornung, 1991). The closer the value of bias is to zero, the better the concordance between the estimates and the measurements. The second weighted average of differences used as weights the number of person-years in the mortality study for a particular job/year combination divided by the total number of person-years accrued in all jobs for that year. This weight reflected the importance of the combination in contributing to mortality subjects' cumulative BD exposure. All means cited in the text were weighted by the number of measurements, unless otherwise indicated. We also computed nonparametric (Spearman's) interclass rank correlation coefficients to assess the relationship between the estimated BD ppm for each job/year combination and the mean of the BD measurements for the combination.

In presenting and discussing the results, we place more emphasis on primary than on secondary jobs because the BD measurements constitute a convincing gold standard only for the former. Also, we place more emphasis on typical SBR jobs than on other operations jobs, because of the greater relevance of the typical SBR jobs to the issue of exposure misclassification in the mortality study.

We further examined all primary job/year combinations that appeared in subjects' work histories and had severe underestimation or overestimation. We considered the difference between the estimate and the measurement mean to be severe when the absolute difference was greater than 5.0 ppm or when the relative difference was greater than 100%. For

underestimation, the relative difference was calculated for job/year combinations where the estimates was greater than zero as the absolute difference between the estimate and mean of measurements divided by the estimate and multiplied by 100. For overestimation, the relative difference was computed as the estimate minus the mean of measurements divided by the mean of measurements and multiplied by 100. We evaluated the job/year combination with severe underestimation or overestimation using two criteria: the number of measurements in a year (<10, 10+) and whether or not the measurement mean fell within the credibility range of estimates developed for the combination. A small number of measurements in a year (<10) suggested that measurements might not have been representative of average exposure conditions. A measurement mean not within the credibility range of the estimate for the particular year suggested that the estimate was affected by erroneous assumptions about emissions, about the timing of changes leading to increases or decreases in exposure or about other determinants of BD exposure, such as the frequency and/or duration of tasks comprising a job.

RESULTS

The monitoring method was not recorded for 3,978 (80%) of the 4,978 BD measurements, was by ATD/charcoal tube for 551 (11%) measurements and was by 3M passive dosimeter for 449 (9%) measurements. The median sampling time was 735 minutes (25^{th} and 75^{th} percentiles, 709 and 922 minutes) for the 4,978 BD measurements and was similar for the 2,047 measurements pertaining to the primary jobs (median, 731 minutes; 25^{th} and 75^{th} percentiles, 707 and 917 minutes) and for the 2,931 measurements pertaining to secondary jobs (median, 737 minutes; 25^{th} and 75^{th} percentiles, 710 and 925 minutes) and for typical SBR and other jobs.

The 4,978 BD measurements pertained to 33 jobs and 754 employees (table 1). With the exception of the years 1977, 1983 and 1991, there were at least 200 measurements in each year. The annual number of measurements peaked in 1978 and again in 1984. The number of jobs annually monitored increased gradually during the late 1970s and early 1980s, varying from three to 21 during 1977 to 1983 and from 25 to 30 during 1984 to 1991.

Of the 33 jobs with monitoring data, 29 appeared in mortality study subjects' work histories during 1977-1991 (table 2); four did not appear in work histories because the job recorded in a specific employee's work history was nonspecific (e.g., "finishing operator"), whereas the job recorded for the same employee in the measurement database was specific ("dryer operator"). The 29 jobs with measurements accounted for 16% of the total of 179 jobs recorded in work histories in 1977-1991. BD measurements were available for 306 job/year combinations. Of these, 235 appeared in the work histories of subjects included in the mortality study and accounted for 11% of the total job/year combinations found in work histories during 1977-1991. Of combinations appearing in subjects' work histories, the proportion having BD measurements was higher for typical SBR jobs (14-15%) than for other operations jobs (8-9%).

The mean value over all years of measured BD concentrations varied by job, from 0.08 ppm for job 731 (petrochemicals, production, minimal exposure) to 46.7 ppm for job 813 (SBR tank farm operator) (table 3). The mean of estimates over all years varied from 0.00 ppm for job 731 and several other jobs to 27.2 ppm for job 704 (BD production, BD extraction, compressor house).

Among all 33 jobs combined, the mean value both of measurements and of estimates decreased over time (table 4). The mean of measurements was 24.8 ppm (SD, 69.9 ppm) in 1977 and 0.34 ppm (SD, 0.61 ppm) in 1991, and for the same jobs the mean of estimates was 15.5

ppm in 1977 and 2.4 ppm in 1991. Estimates tended to be lower than measurements before 1984 and higher than measurements in or after 1984. Plots of year-specific measurement means and estimates for each of 15 individual jobs with a total of at least 100 BD measurements also indicated that exposure declined over the 1977-1991 time period (Appendix D).

Figure 1 confirms the pattern of declining exposure over time for the 29 jobs appearing in mortality study subjects' work histories and confirms that estimates tended to be lower than measurements in earlier years and higher than measurement means in more recent years. The latter pattern was present for primary typical SBR jobs (figure 2), for secondary typical SBR jobs (figure 4) and for secondary other operations jobs (figure 5). Estimates tended to be higher than measurement means in all years for primary other operations jobs (figure 3).

For 150 jobs that appeared in subjects' work histories during the period 1977-1991 but that did not have any BD measurements, estimated BD concentrations were low relative to measured jobs until 1986 (figure 1). After 1986, unmeasured jobs had estimates that were slightly lower than measurements for measured jobs and slightly higher than estimates for measured jobs. For primary typical SBR jobs, unmeasured jobs had BD estimates lower than measurements or estimates for measured jobs, for all years (figure 2).

The mean value of the 4,978 BD measurements for all 306 job/year combinations and of the corresponding estimates were, respectively, 5.2 ppm (SD, 57.9 ppm) and 4.7 ppm (SD, 30.2 ppm) (table 5). The median values of the BD measurements and estimates were, respectively, 1.2 ppm (range, 0.00-914.0 ppm; 25^{th} and 75^{th} percentiles, 0.55 and 3.3 ppm) and 0.27 ppm (range, 0.00-27.2 ppm; 25^{th} and 75^{th} percentiles, 0.23 and 5.8 ppm). The measurement means and estimates were, respectively, 11.3 ppm and 6.0 ppm for primary typical SBR job/year combinations (1,388 measurements), 2.4 ppm and 10.7 ppm for primary other job/year

combinations (N=643), 4.8 ppm and 6.2 ppm for secondary typical SBR job/year combinations (N=957) and 2.0 ppm and 1.1 ppm for secondary other job/year combinations (N=1,990).

Figure 6 displays the distribution of the difference between the estimated BD concentration and the mean of BD measurements for all 306 job/year combinations. The size of the difference varied considerably across the combinations, from -227.9 ppm (job 523/1979 - maintenance BD, maintenance field, pipefitter/oiler/mechanic/blacksmith/boilermaker/ outside machinist) to +27.0 ppm (job 704/1990, 1991 - BD production, BD extraction, compressor house) (Appendix E). Of the 306 differences, 156 were negative (estimates < measurements), and 150 were positive (estimates > measurements). The absolute value of the difference was <1.0 ppm for 35% of the combinations, 1.0-<5.0 ppm for 35% and ≥ 5.0 ppm for 30%. Among the 198 combinations for which the absolute value of the difference was ≥ 1.0 ppm, 126 had estimates higher than the mean of measurements, and 62 had estimates lower than the mean of measurements.

The mean difference between the estimates and the measurements (bias) was -0.50 ppm for all 306 combinations and was -5.3 ppm for combinations pertaining to primary typical SBR jobs, 8.3 ppm for primary other operations combinations, 1.4 ppm for secondary typical SBR combinations and -0.92 ppm for secondary other operations combinations (table 6). The median difference between the estimate and the measurement mean was -0.04 ppm for all 306 job/year combinations. The pattern of median differences by job category was similar to that seen for the mean difference, but all median differences were smaller than mean differences. Person-year-weighted mean differences between estimated and measured BD ppm were somewhat larger than those described above, but patterns by job category were similar.

We plotted the difference between the estimate and the mean of BD measurements for each of the 306 job/year combinations against the mean BD concentration of the measurements for the combination. For primary typical SBR job/year combinations, estimates were less than measurement means when the latter were ≥ 7.1 ppm (figure 7). For combinations with measurement means <7.1 ppm, there was no distinct pattern of higher or lower estimates. For primary other operations, the estimates were greater than measurement means for most combinations (figure 8).

Estimates were correlated with mean values of measurements for all 306 combinations ($r=0.45$, $p<0.0001$), for 82 combinations pertaining to primary typical SBR jobs ($r=0.81$, $p<0.0001$), for 70 combinations pertaining to primary other operations jobs ($r=0.29$, $p=0.01$) and for 92 combinations pertaining to secondary typical SBR jobs ($r=0.56$, $p<0.0001$) (table 6). Estimates were not correlated with mean values of measurements for 62 combinations pertaining to secondary other operations jobs ($r=0.01$, $p=0.93$). Results of analyses of the correlation between estimates and median values of measurements were similar to those for correlations between estimates and mean values of measurements.

Primary typical SBR jobs with severe underestimation in some years were job 813 (tank farm operator) in 1977-1986, job 815 (reactor operator) in 1981-1984 and job 817 (recovery operator) in 1980 (table 7, figures 9-11). Job 813 had 10+ measurements in each of seven of the 10 years with underestimation. The credibility range of the estimates contained the measurement mean only in one year, 1977. Estimated BD exposure in this job was 26.0 ppm in 1977-1979 and declined to 7.5 ppm in 1980 and to 5.1 ppm in 1989. We assumed that the decrease in exposure was due primarily to the installation of centrifugal pumps with double mechanical seals in the tank farm transfer pumphouse. Measurement means, in contrast to estimates, increased

from 39.0 ppm in 1977 to 75.3 ppm in 1978, were 67.7-110.2 ppm in 1979 and 1980, declined to 16.0 ppm in 1986 and to 5.7 ppm in 1988, the last year with 10+ measurements. Our assumptions about the timing and impact on exposure of the introduction of new equipment appears to partly, but not completely, explain the underestimation of exposure for this job.

Job 815 had 10+ measurements in three of the four years (1981-1984) with severe underestimation, and none of the measurement means in these years was in the credibility range of the estimates. The estimates were 0.23 ppm in each of the four years. Measurement means in these years ranged from 7.6-11.4 ppm during 1981-1983, declining to 2.9 ppm in 1984 and to less than 1.0 ppm after 1986. BD estimates for job 815 mainly reflected the background BD concentration estimated for the reactor area. These estimates declined in the early 1980s because we assumed that centrifugal pumps with mechanical seals were introduced beginning in 1980, with complete replacement of old pumps by 1981. The measurements indicated that these changes occurred later than assumed (1984 v. 1981).

For job 817, severe underestimation of exposure was limited to only one year, 1980. The measurement mean for 1980 (29.1 ppm) was based on 33 measurements. It was not consistent with measurement means recorded for all other years, which ranged from 0.20 to 13.4 ppm and, in particular, it was inconsistent with the measurement mean in the two years adjacent to 1980 (1979, 5.2 ppm; 1981, 7.1 ppm), both of which were much closer to the estimate for 1980 of 8.0 ppm. A review of the 33 measurements for this job in 1980 indicates a wide range of values. Ten measurements ranged from 13.0 to 543.0 ppm, and the remaining 23 measurements ranged from 0.30 to 6.7 ppm. Our documentation for job 817 does not record any reason for particularly high BD emissions in 1980.

Primary typical job/year combinations with severe overestimation included job 813 in 1990 and 1991, job 815 in 1978-1980 and job 817 in 1985 and 1990. For job 813, overestimation was limited to two years, 1990 and 1991. Measurement data in both of these years were based on <10 observations (1990, N=5; 1991, N=2); neither measurement mean was in the credibility range of the corresponding estimate.

Measurement means for job 815 were based on 10+ observations in all three years with overestimation, and the means were not in the credibility range of the corresponding estimates. Measurement means ranged from 3.5 to 5.2 ppm during 1978-1980, whereas estimates were 21.3 ppm in 1978 and 1979 and 13.3 ppm in 1980. Our assumptions about the main determinant of exposure in this job, the amount of emissions from leaking pumps, may have been erroneous for this time period.

Overestimation occurred in job 817 in two years, 1985 (13 observations) and 1990 (5 observations), and the measurement mean was not within the credibility range of the estimates for either year. In 1985, the high estimate of BD concentration was due primarily to background exposure in the recovery area. Our assumptions about the amount of emissions from multiple sources (leaking compressors, recycle monomer pumps and valves, cleaning of flash tanks and stripping columns) that contributed to background exposure may have been incorrect.

For primary other operations job/year combinations, underestimation occurred in two job/year combinations, 330 (stereo technician) in 1989 and job 740 (feed prep supervisors) in 1986. Measurement data for both of these job/year combinations were based on <10 observations (330, N=4; 740, N=5); neither measurement mean was in the credibility range of the corresponding estimate.

Severe overestimation for primary other operations job/year combinations occurred in multiple years in jobs 330, 704 (BD extraction operator) and 852 (latex plant operator) and in one year (1982) in job 762 (feed prep K1 production operator). For job 330, measurement means were based on 10+ observations only in two years (1979 and 1981) with severe overestimation, and both of these means were within the credibility range of the estimates. The credibility range of the estimates for this job were quite wide in all years. The task in the TEM responsible for most of the BD exposure in job 330 in 1979 was collecting the rubber-solvent mixture beginning in 1972. Estimates were 18.5 ppm in 1979 and 4.5 ppm from 1980-1992. The estimates declined in 1980 because of our assumption that the container used to collect samples changed from a pail to a plastic bag. The year when this change occurred and the corresponding sharp decline in exposure levels may have been earlier than assumed for the estimates.

For job 704, the estimates and the measurements may differ because the job for which the estimates were developed is not the same as the job to which the measurements pertain. Job 704 in the JEM pertains to a BD extraction compressor house operator in BD production (Appendix A). The job titles in the Sarnia database that were assigned to job 704, in contrast, were a mix of operator and maintenance jobs in BD production (Appendix C). We classified BD production maintenance jobs into a separate job group, 523. Our estimates were high for job 704 (27.2 ppm from 1982-1991), whereas they were lower for job 523 (2.8 ppm from 1982-1991).

For job 762, measurement data were based on only two observations. The measurement mean was not in the credibility range of the corresponding estimate.

Job 852 had 10+ measurements in five (1984-1988) of six years (1982, 1984-1988) with severe overestimation, and none of the measurement means in these years was in the credibility range of the estimates. Measurement means were <1.0 ppm in all six years, whereas estimates

were 14.4 ppm during the same time period. The overestimation of exposure for this job appeared to be due to faulty assumptions that failed to take into account a downsizing of operations in the 1980s and a reduction in exposure due to the introduction of control measures, similar to those changes taking place in the SBR reactor area and impacting the estimates for jobs 813, 815 and 817.

DISCUSSION

This study found that the difference between estimated and measured BD concentrations was small (-0.50 ppm) overall, but varied considerably by job category. For primary typical SBR combinations, the mean of estimates was 47% lower than the mean of measurements (6.0 ppm v. 11.3 ppm), whereas for primary other operations combinations the mean of estimates was four times higher than the mean of the measurements (10.7 ppm v. 2.4 ppm). As expected, the correlation between estimated and measured BD ppm was highest for primary typical SBR job/year combinations.

There are several possible reasons for differences between estimates and measurements. First, it is likely that assumptions used in estimating BD ppm were faulty for some jobs in some years. Erroneous information on the timing of process changes and on the timing of the introduction of exposure controls may have contributed to discrepancies between BD exposure estimates and measurements. This type of error appears to explain some of the discrepancies between estimates and measurements for primary typical SBR jobs. Also, our assumptions about the amount of emissions during certain this time periods appears to have been erroneous for several primary jobs in SBR polymerization. Such errors are difficult to correct because they involve assumptions based on employees' recall of events influencing exposure. Any alternative

approach to exposure estimation, such as back-extrapolation from current or recent measurement data, would be prone to error for the same reason.

Second, the Sarnia plant was different from the other synthetic rubber plants included in the mortality study. In addition to being more complex, the plant also had a more intensive monitoring program. This program may have resulted in a decrease in BD exposures over time that was larger or earlier than at the other plants, and we may not have accounted for this difference accurately in developing exposure estimates. In general, we found that overestimation for primary jobs was most severe in later years.

Third, measurements for some job/year combinations may not have constituted a gold standard for evaluating estimates. Measurements for many job/year combinations were highly variable, and we do not know if the mean value accurately reflected average exposure conditions in the combination. Also, we do not know which measurements were made as part of the routine monitoring program and which were made to follow up on results from routine monitoring that indicated noncompliance with exposure limits. The latter type of measurement would lead to a measurement mean higher than the value representing average exposure. Problems with linking jobs in the Sarnia monitoring database with jobs in the JEM also may have produced spurious differences between estimates and measurements.

Finally, our estimation procedures may have not been good at distinguishing "high" exposure from "very high" exposure for some jobs. The pattern of differences that we observed for primary typical SBR combinations in particular was consistent with this problem, with the most severe underestimation occurring in job/year combinations with relatively high concentrations of BD. This phenomenon is consistent with findings of studies of workers

exposed to a number of different agents in various industries (Stayner et al. 2003; Steenland et al. 2004).

The large differences between estimated and measured BD concentrations found in this investigation for some job/year combinations are not necessarily present for the other plants in our mortality study of synthetic rubber industry workers. Although the general procedures for estimating exposure were the same for all six plants, data on determinants of exposure were plant-specific. For example, the large error in exposure estimation for latex operations (job 852) at the Sarnia plant, discussed earlier, may not have occurred at the one other plant in our mortality study that had small latex operations. Review of the BD estimates for job 852 at this plant indicated that the estimated BD ppm was quite low (0.39 ppm) for all time periods. This suggests that our overestimation of BD ppm for 852 was limited to the Sarnia plant.

Data from the NIOSH study (Fajen et al. 1993) also suggest that generalizing our validation results for the Sarnia plant to the US plants may be inappropriate. We compared the Sarnia measurement data for 1984-1987 with NIOSH data on BD measurement means available for three primary typical SBR jobs (813 - tank farm operator, 815 - reactor operator and 835 - finishing operator). The measurement mean for the Sarnia plant was similar to the measurement mean for the US plants for jobs 815 (Sarnia plant, 1.8 ppm; NIOSH data, 1.8 ppm) and 835 (Sarnia plant, 0.32 ppm; NIOSH data, 0.35 ppm), but the Sarnia measurement mean for job 813 was 10 times higher than the mean reported for the US plants (Sarnia plant, 20.4; NIOSH data, 2.0 ppm).

The better rank correlation noted between estimated and measured BD concentrations in Sarnia jobs that pertained to typical SBR operations is not surprising. Most of the other five plants for which we developed exposure estimates in our mortality study had typical SBR

operations, only; a few had other operations that were very limited in terms of the time period during which they were active and the number of workers employed. The Sarnia plant is the only study plant that had major other operations. Understanding of operations and exposure determinants was better for typical SBR than for other operations because information on exposure determinants obtained from one plant often guided the acquisition and interpretation of such information from other plants. The information collected for exposure estimation indicated that the basic architecture, engineering and production procedures were similar for SBR operations at all plants, at least in early decades of operation.

Most studies have not validated their estimates because they used the available measurements to develop estimates and thus, did not have any independent data for use in validation (Dunham et al., 2001; Glass et al. 2001). Thus, relatively few studies have carried out extensive comparisons of exposure measurements with independently developed exposure estimates. Post et al. (1991) found correlations of 0.67 to 0.73 between exposure estimates and measurements for methylene chloride and correlations of 0.12 to 0.29 for styrene estimates and measurements. Oestenstad et al. (2002) reported a correlation of 0.55 when comparing estimated respirable dust concentrations to available historical measurements among talc workers. Stewart et al. (1996), in their evaluation of exposure assessment for a retrospective follow-up study of acrylonitrile workers, reported correlations of 0.80, 0.47 and 0.31 for fiber, monomer and resin operations, respectively. Overall, our results are comparable with those of other studies.

The main strength of the study stems from the fact that the Sarnia BD exposure measurements comprise a large database of monitoring data, some of which were collected in a systematic effort to assess average exposure conditions in a variety of plant jobs. The Sarnia measurement database and our investigation have several limitations. The monitoring data were

limited to a relatively recent time period (1977-1991), whereas the time period covered by the mortality study of synthetic rubber workers began in 1943. BD measurements were available only for 11% of the job/year combinations found in subjects' work histories during 1977-1991. BD estimates for the residual 89% (N=1,879) of job/year combinations without corresponding measurement data had a distribution that was skewed towards low values, with a mean of 3.0 ppm (SD, 9.0 ppm) and a median of 0.03 ppm. Comparison of BD estimates that were below 2.0 ppm with their corresponding measurement means (when these were available) indicated that the estimates tended to be slightly lower than the measurements (median difference, -0.26 ppm; mean difference, -1.0 ppm).

The present study did not evaluate the impact on the exposure-response results of our mortality study of errors in exposure estimation suggested by differences between estimated and measured BD concentrations at the Sarnia plant. Twenty-two (27%) of the total of 81 employees who had leukemia and were included in exposure-response analyses came from the Sarnia plant. Of the 22 leukemias from the Sarnia plant, all began work before 1977, and only seven were working during the period 1977 through 1991. Although data for the Sarnia plant could have an important impact on the results for all six plants combined, quantitative evaluation of exposure misclassification for the Sarnia plant is not straight-forward because the measurement data are temporally restricted and cover only a small proportion of jobs.

Ideally, a thorough investigation of the reasons for discrepancies between estimates and measurements would lead to reformulating the assumptions used in the exposure estimation and to a revised JEM for the Sarnia plant and, possibly, for the US plants. Because of the limitations discussed above, this approach may not be feasible for the entire exposure estimation system,

and it may be time-consuming and expensive even on a limited basis. Several alternative strategies may be more feasible, although methodologically weaker.

A simple assessment of the impact of the discrepancies that we observed for the Sarnia plant could be done as follows: 1) develop a revised BD JEM by replacing the exposure estimates with measurement means when available; 2) recalculate cumulative exposure indices using the new JEM; 3) repeat the exposure-response analysis using the revised information; 4) compare the results of the revised analysis with the results reported by Delzell et al. (2004). This approach could be supplemented with a comparison of measurement-based revised cumulative exposure estimates with original estimates for the subgroup of employees and leukemia decedents who were at work in 1977 or later.

A complementary strategy would be to compute partial cumulative exposure among Sarnia employees who were at work in 1977 or later, using exposure measurements instead of estimates as outlined in steps 1-2 above and ignoring BD exposure for years prior to 1977, and then to compare the revised with the original cumulative exposure values. These analyses would clarify the amount of change in cumulative exposure indices attributable to discrepancies between estimates and measurements. Correction factors could then be developed and applied to the overall distribution of cases and person-years for other plants and time periods, and this procedure could yield an alternative data set for the analysis of mortality rates.

Another strategy would be to determine the percentile of estimates that corresponds most closely to the measurement mean for each job/year combination and to use this information to develop correction factors. We also could determine if any of the 1,000 alternative JEMs used in previous uncertainty analyses contained estimates for 1977-1991 closer to measurement means for jobs with large differences between estimates and measurements in the present study.

None of the strategies outlined above would be adequate to replace the primary analysis of the follow-up study. However, they may give an indication of whether the variability in the exposure-response relation documented in our previous uncertainty analyses (Delzell et al. 2004) is insufficient to describe the level of uncertainty associated with our exposure estimation procedures.

CONCLUSIONS

BD estimates for typical SBR jobs, which comprise most operations at all but one of the plants in the mortality study, appeared to be useful for ranking workers by cumulative exposure. Variability among measurements within a particular job/year combination was large for most combinations. Also, variability in the size of differences between estimates and measurements was high across combinations. The correlation between estimated and measured BD ppm was moderate overall and was highest for jobs that pertained to typical SBR operations. Correlation was poorer for primary jobs, and absent for secondary jobs that did not pertain to typical SBR operations. On average, estimates were about 10% lower than measurements. Possible reasons for discrepancies between estimates and measurements include faulty assumptions used in estimating BD concentrations and errors in assigning JEM job codes to the Sarnia measurement data. The impact on the mortality study of exposure misclassification due to faulty estimation of BD concentrations is difficult to assess because the time period and number of jobs for which measurements were available were limited. Exposure estimates could be improved for several Sarnia jobs by correcting faulty assumptions used in estimation. Uncertainty analyses would enhance the utility of the BD exposure estimates for quantitative risk assessment.

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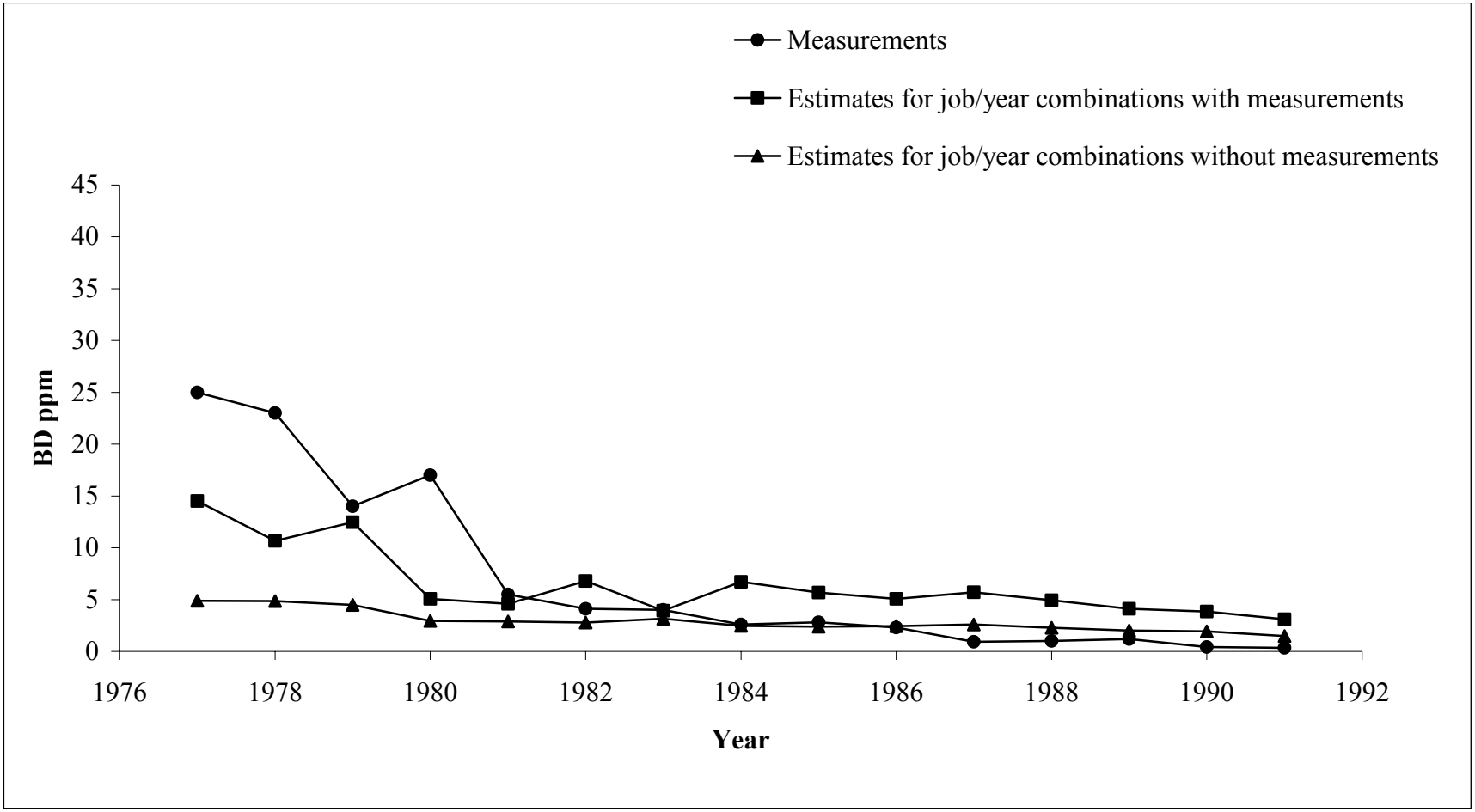

Figure 1. Year-specific mean of measurements and year-specific estimates for 235 job/year combinations appearing in subjects' work histories; year-specific estimates for 1,879 job/year combinations that appeared in subjects' work histories but that did not have any BD measurements

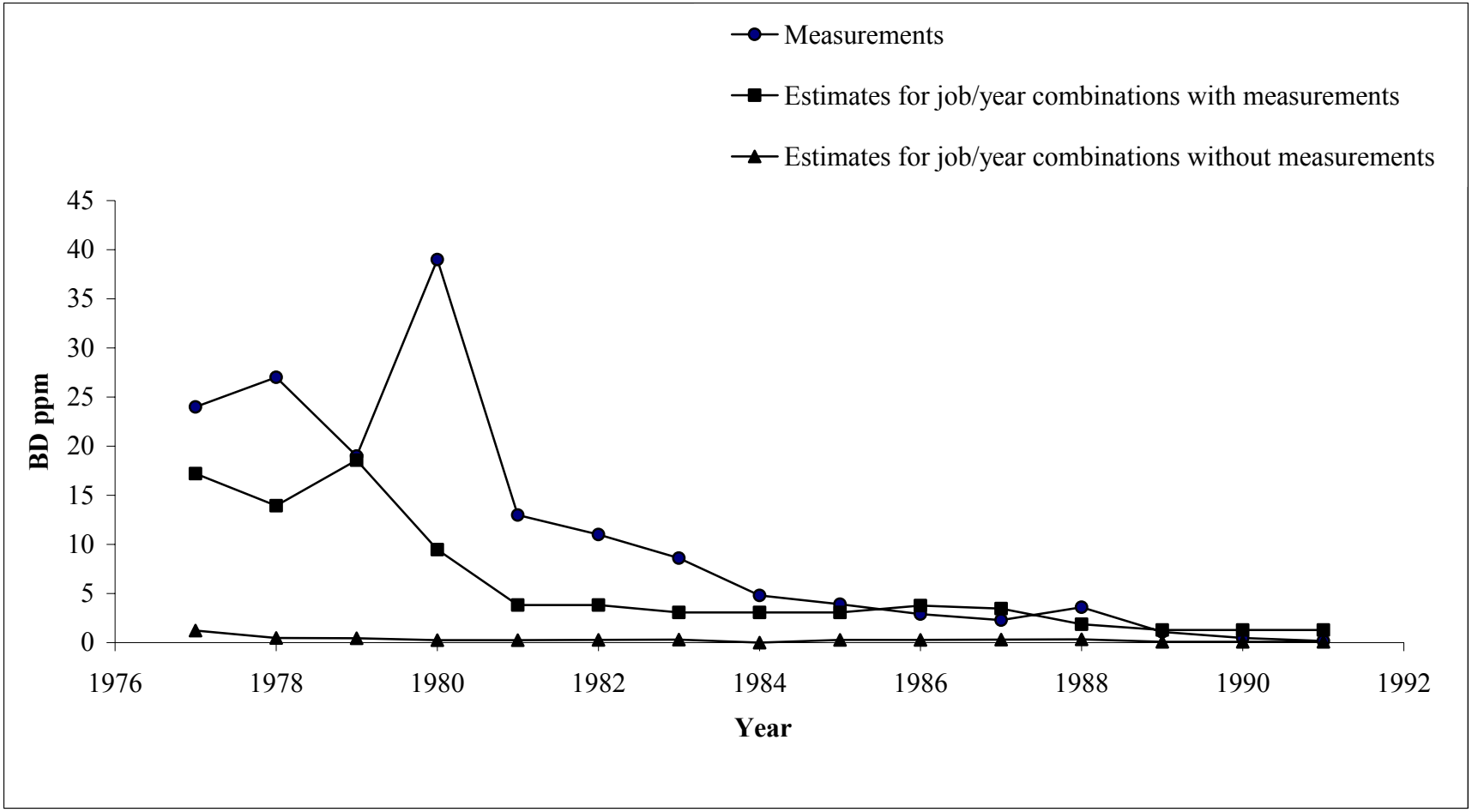

Figure 2. Year-specific mean of measurements and year-specific estimates for 59 primary typical SBR job/year combinations appearing in subjects' work histories; year-specific estimates for 350 job/year combinations that appeared in subjects' work histories but that did not have any BD measurements

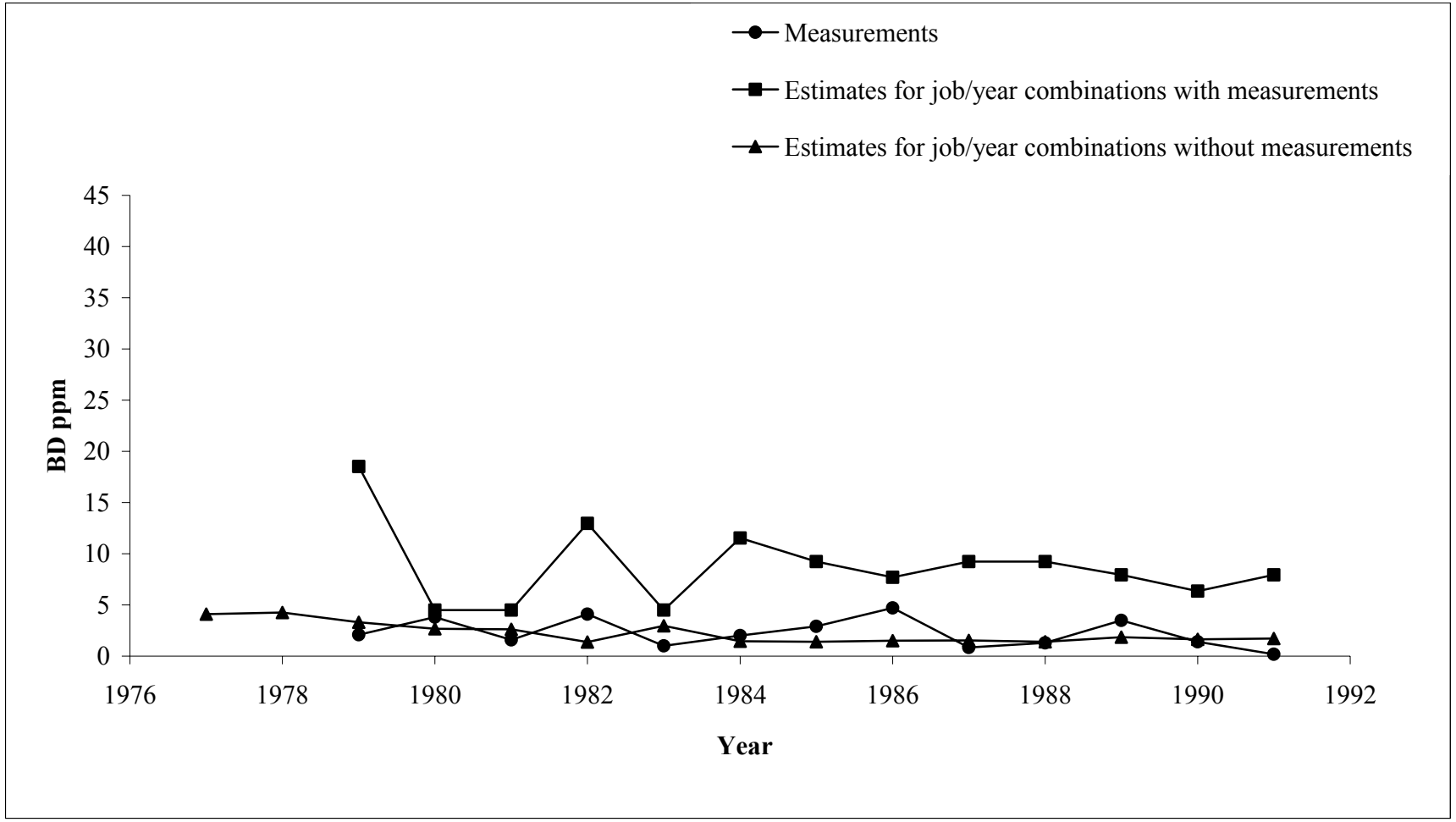

Figure 3. Year-specific mean of measurements and year-specific estimates for 47 primary other operations job/year combinations appearing in subjects' work histories; year-specific estimates for 520 job/year combinations that appeared in subjects' work histories but that did not have any BD measurements

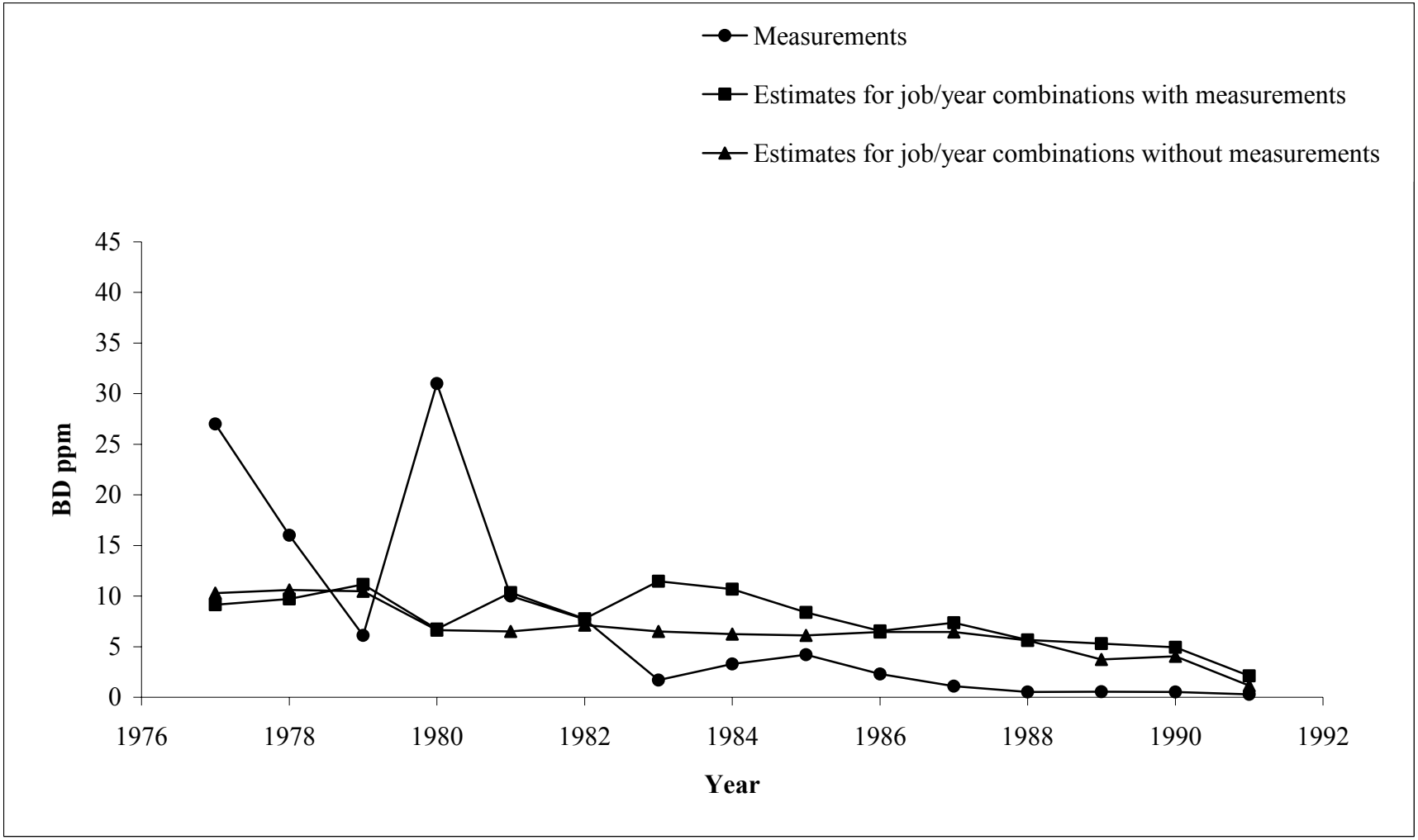

Figure 4. Year-specific mean of measurements and year-specific estimates for 68 secondary typical SBR job/year combinations appearing in subjects' work histories; year-specific estimates for 377 job/year combinations that appeared in subjects' work histories but that did not have any BD measurements

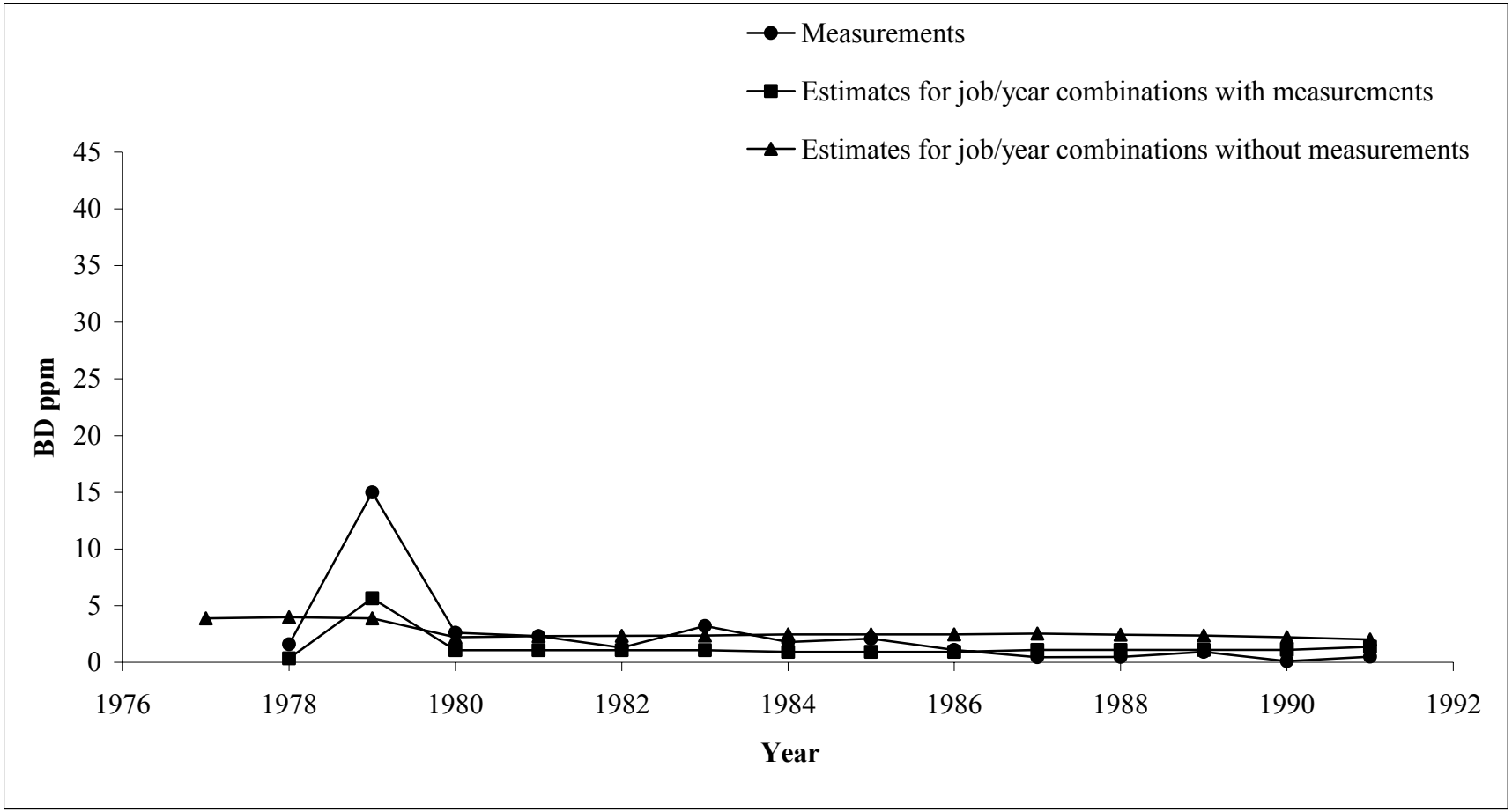

Figure 5. Year-specific mean of measurements and year-specific estimates for 61 secondary other operations job/year combinations appearing in subjects' work histories; year-specific estimates for 632 job/year combinations that appeared in subjects' work histories but that did not have any BD measurements

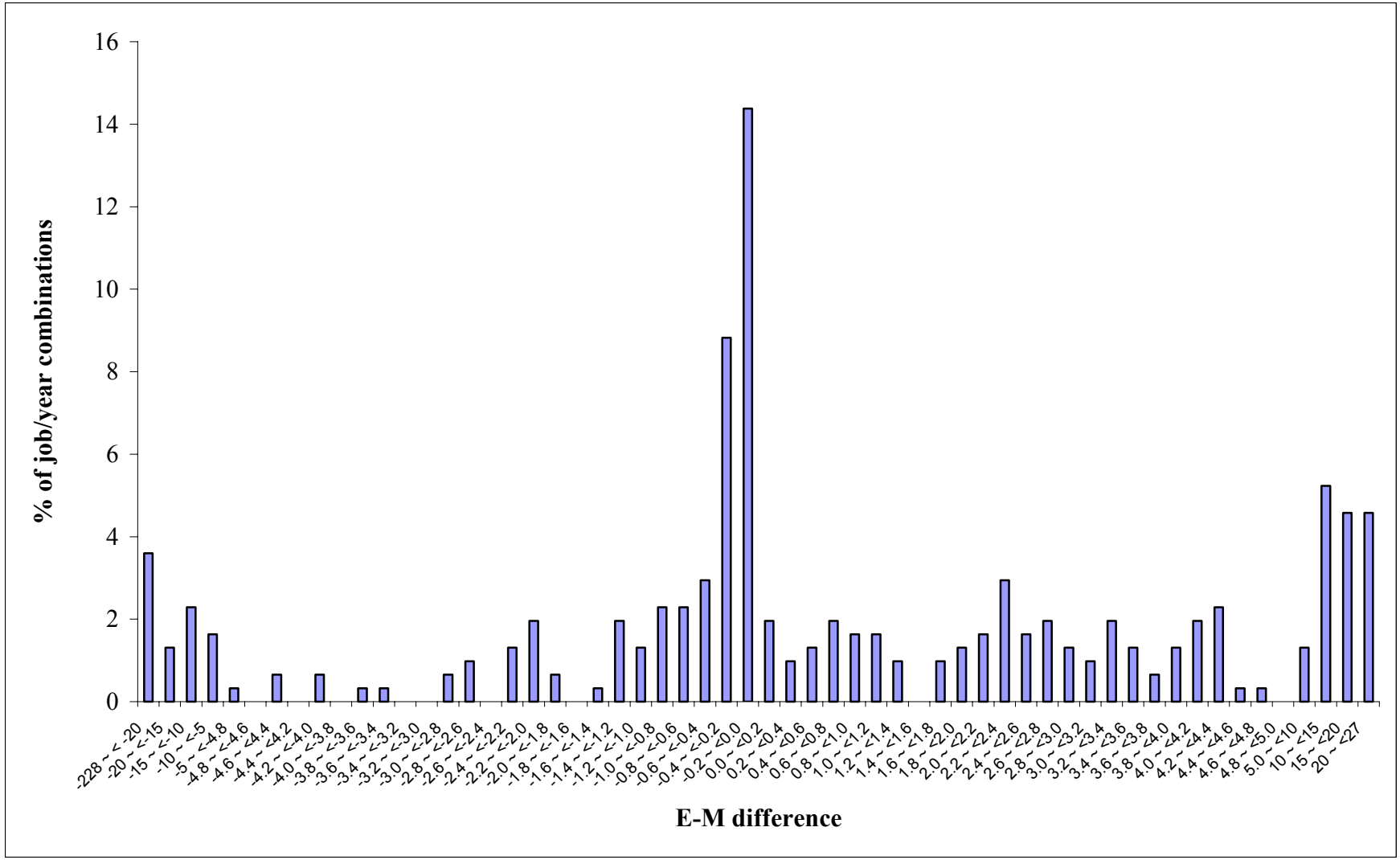

Figure 6. Distribution of the difference between the estimated BD concentration and the mean of measured BD concentration (e-m) for 306 job/year combinations

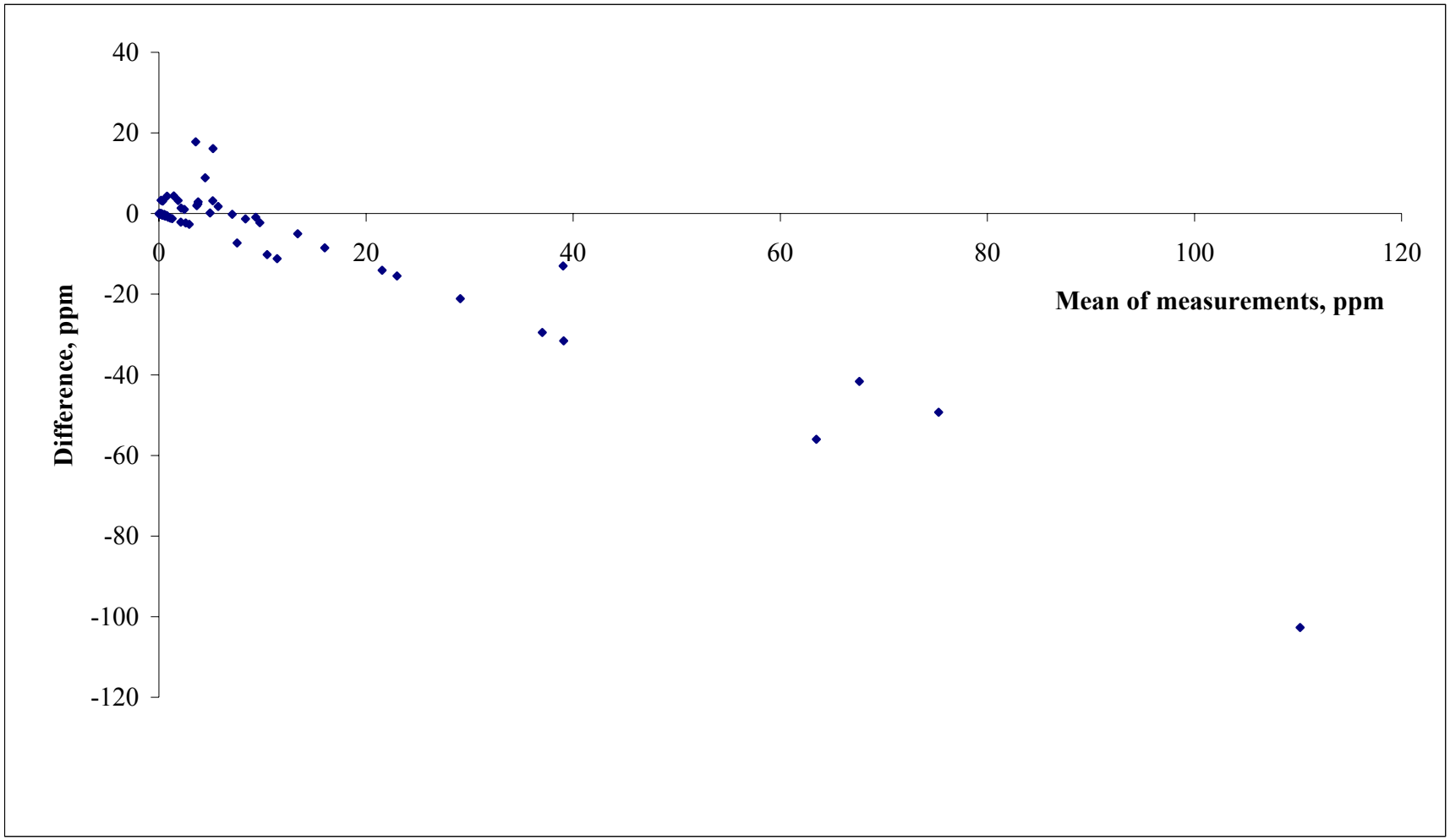

Figure 7. Difference between estimated and mean of measured BD ppm, by mean measured value, 82 primary typical SBR job/year combinations

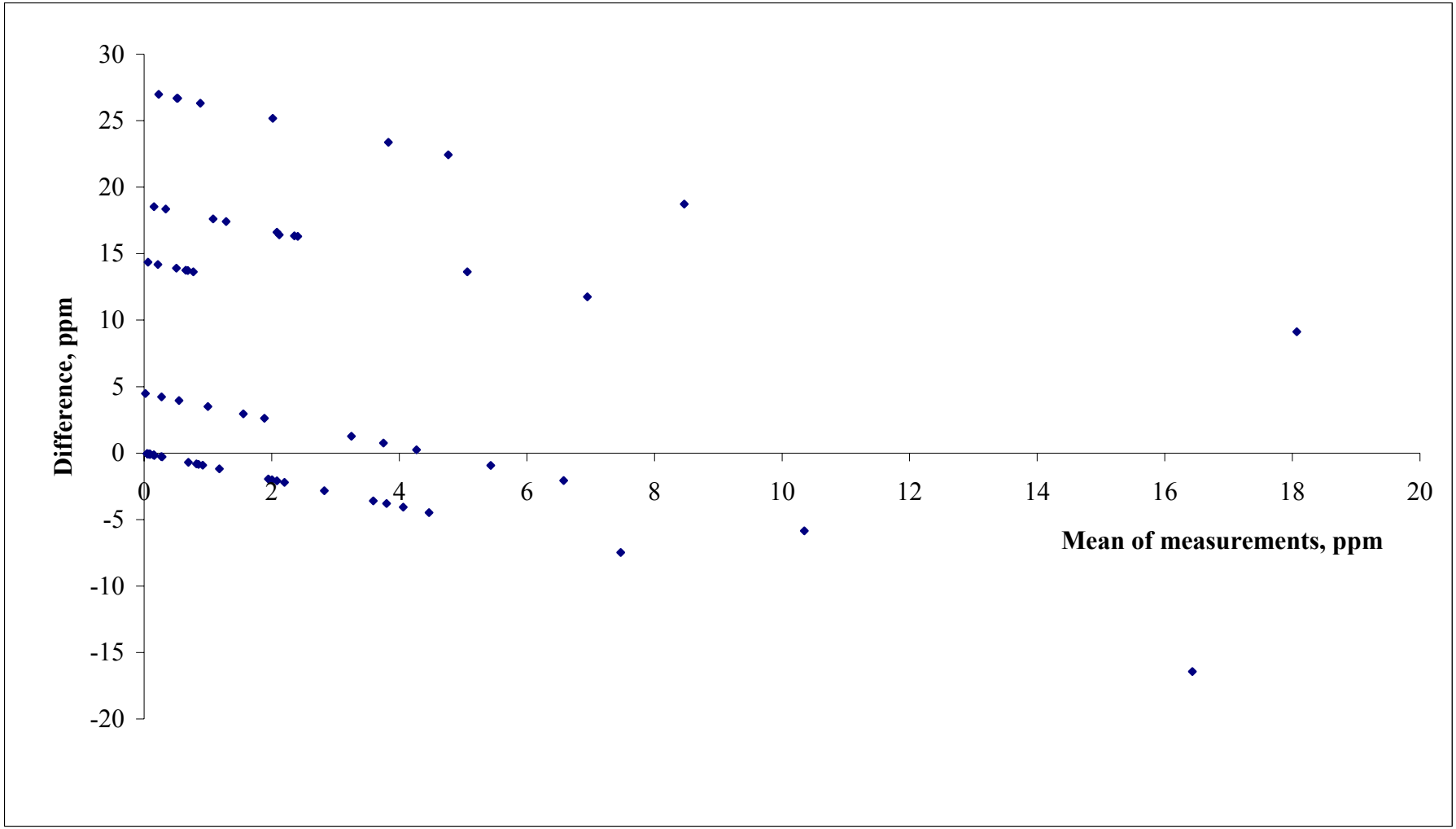

Figure 8. Difference between estimated and mean of measured BD ppm, by mean measured value, 70 primary other operations job/year combinations

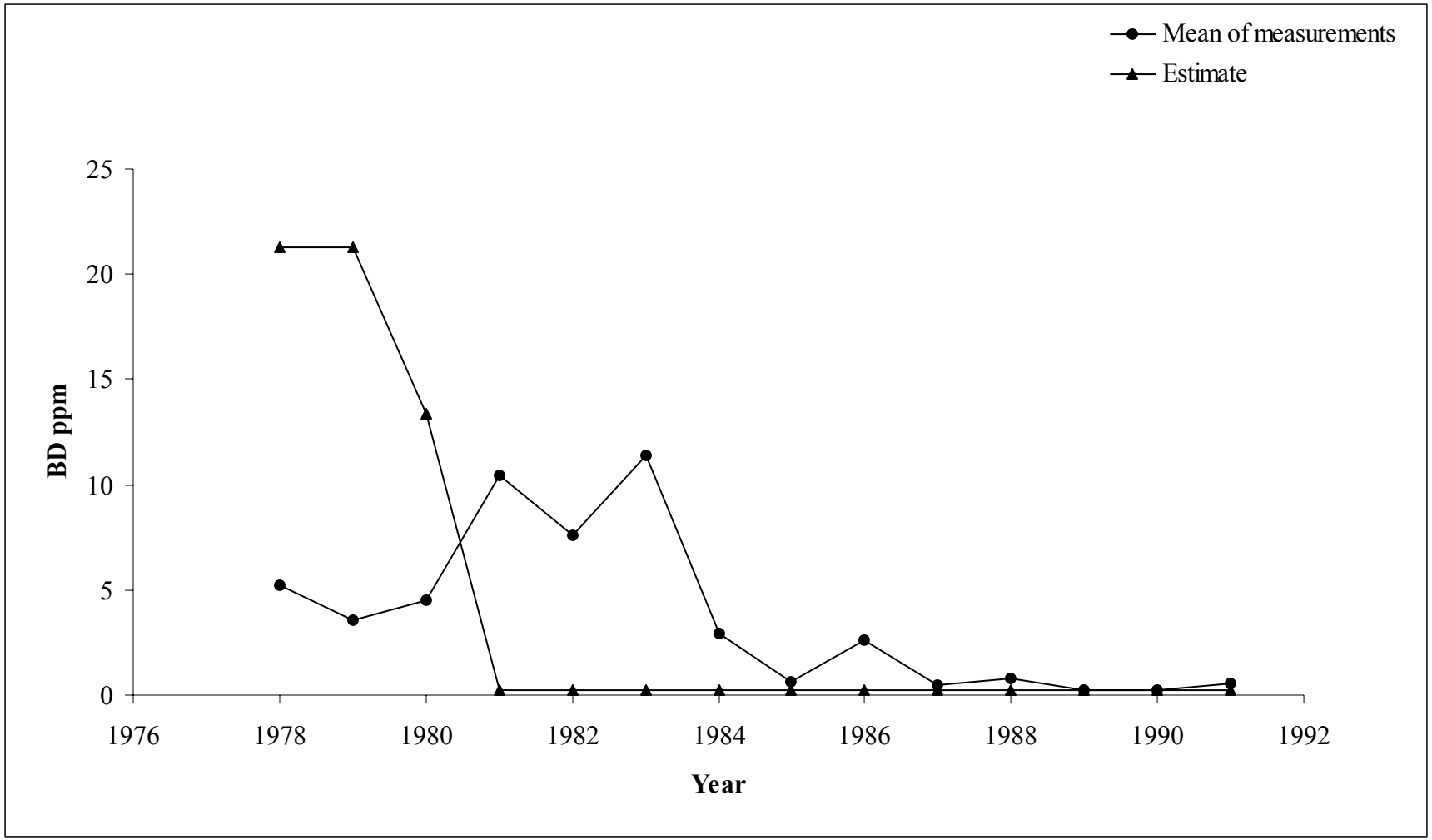

Figure 9. Year-specific measured and estimated BD concentrations for primary typical job 815 (rubber production, polymerization (SBR), reactor, blowdown, panel board) with 261 measurements

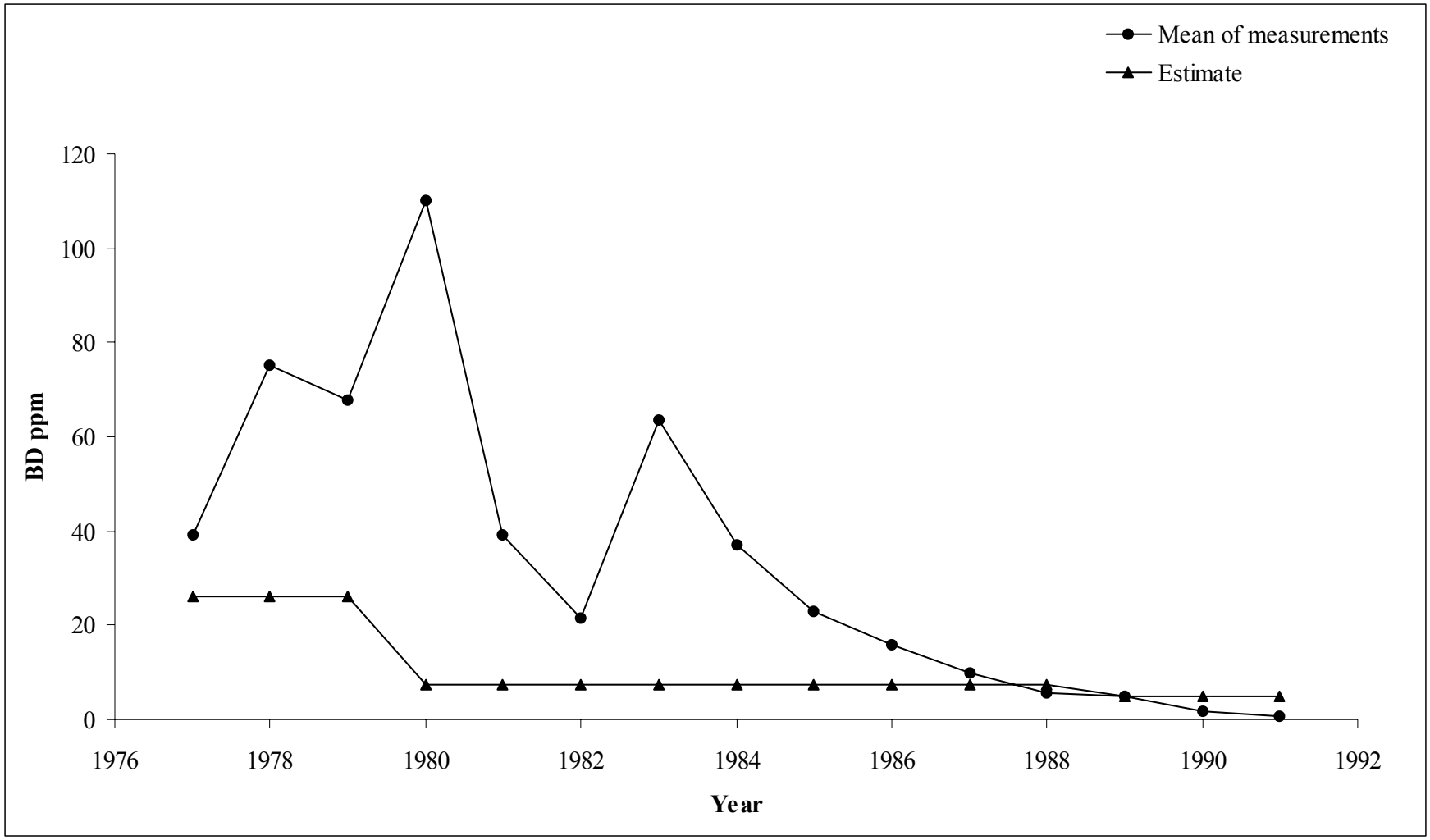

Figure 10. Year-specific measured and estimated BD concentrations for job 813 (rubber production, polymerization (SBR), tank farm, transfer pumphouse) with 231 measurements

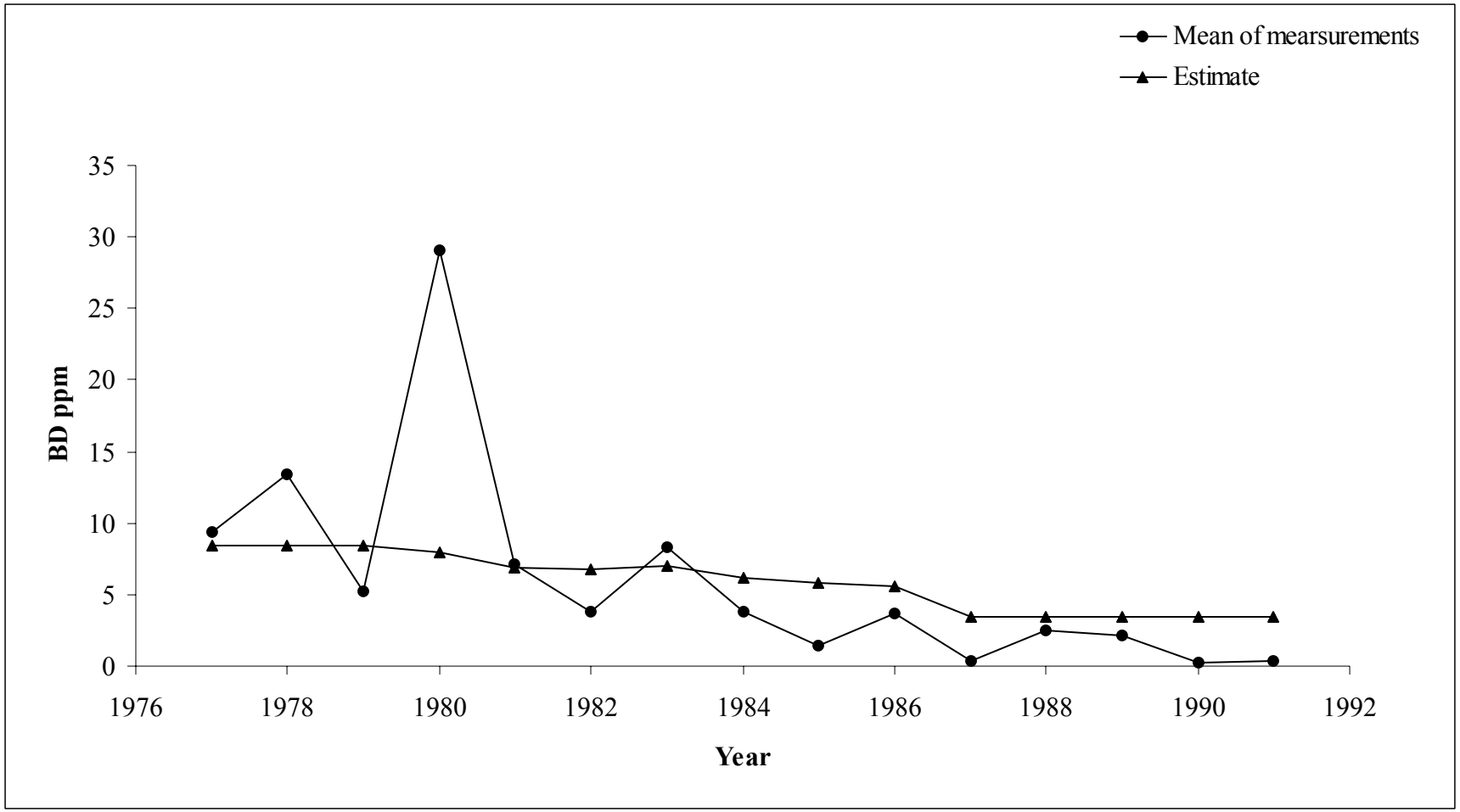

Figure 11. Year-specific measured and estimated BD concentrations for primary typical job 817 (rubber production, polymerization (SBR), recovery, compressor house, high solids recovery) with 333 measurements

Table 1. Number of butadiene measurements, individual employees monitored, job/year combinations monitored and jobs monitored, by year of monitoring

Year	Measurements	Employees	Jobs
1977	56	22	3
1978	527	116	11
1979	274	117	13
1980	301	176	13
1981	307	174	15
1982	406	210	21
1983	113	79	13
1984	658	285	27
1985	482	257	27
1986	504	256	30
1987	310	181	26
1988	417	175	28
1989	238	146	27
1990	223	147	27
1991	162	117	25
Total	4,978	754	33

Table 2. Number of job/year combinations and jobs in the Sarnia measurement database and in Sarnia employees' work histories, according to job category

	Job/year combinations				Jobs			
Job category	Total with measure-ments	Total in work histories	With measure-ments & in work histories	With measure-ments, not in work histories	Total with measure-ments	Total in work histories	With measure-ments, in work histories	With measure-ments, not in work histories
Total	306	2,114	235	1,879	33	179	29	150
Primary	152	976	106	870	16	86	14	72
Typical SBR	82	409	59	350	7	37	6	31
Other	70	567	47	520	9	49	8	41
Secondary	154	1,138	129	1,009	17	93	15	78
Typical SBR	92	445	68	377	10	37	8	29
Other	62	693	61	632	7	56	7	49

Table 3. Summary data on measured and estimated BD ppm, according to job category

Job Code	Job title	Person-years	Number of measurements: Total	Year range	Avg/ year	No of Yrs	Butadiene ppm measurements: Range	Mean (SD)	Median†	Butadiene ppm estimates: Range	Mean (SD)	Median†
Primary typical SBR operations												
300*	Shipping/distribution, labor, utilityman, serviceman	171	24	1988-1991	6.0	4	0.00-0.30	0.09 (0.06)	0.07	0.00-0.00	0.00 (0.00)	0.00
600	Utilities, operative, unspecified/misc.	146	114	1983-1991	12.7	9	0.00-1.9	0.19 (0.31)	0.10	0.00-0.00	0.00 (0.00)	0.00
813	Rubber production, polymerization (SBR), tank farm, transfer pumphouse	106	231	1977-1991	15.4	15	0.06-672.0	46.7 (69.1)	15.0	5.1-26.0	15.5 (9.3)	7.5
815	Rubber production, polymerization (SBR), reactor, blowdown, panel board	10	261	1978-1991	18.6	14	0.02-66.2	4.5 (8.9)	1.0	0.23-21.3	8.7 (9.8)	0.23
817	Rubber Production, polymerization (SBR), recovery, compressor house, high solids recovery	206	333	1977-1991	22.2	15	0.02-543.3	10.2 (33.3)	1.6	3.5-10.9	7.4 (1.7)	8.4
820	Rubber production, coagulation/blending/ solutions prep carbon black (SBR)	-	314	1978-1991	24.2	13	0.02-19.0	0.93 (1.8)	0.20	0.00-0.00	0.00 (0.00)	0.00
835*	Rubber production, finishing (SBR), baler, packager, reclaim	207	111	1978-1991	9.3	12	0.03-1.9	0.29 (0.35)	0.15	0.00-0.00	0.00 (0.00)	0.00
Primary other operations												
330*	Stereo technical, technician	80	84	1979-1991	6.5	13	0.02-30.8	3.3 (5.4)	1.3	4.5-18.5	6.2 (4.6)	4.5
471	Feed prep, other, maintenance, operative	15	112	1984-1991	14.0	8	0.00-25.8	1.2 (3.8)	0.10	0.00-0.00	0.00 (0.00)	0.00
593*	Polysar general/rubber unspecified/maint/ equip/vehicle operator, garage mechanic	211	24	1982-1990	4.8	5	0.05-0.30	0.09 (0.07)	0.05	0.00-0.00	0.00 (0.00)	0.00
704	Butadiene production, butadiene extraction, compressor house	124	136	1982-1991	15.1	9	0.00-199.0	4.6 (18.8)	0.40	27.2-27.2	27.2 (0.00)	27.2
731*	Petrochemicals, production, min. exp.	1	11	1988-1991	2.3	4	0.03-0.22	0.08 (0.06)	0.08	0.00-0.00	0.00 (0.00)	0.00
732	Petrochemicals, production, operative (petrochem general)	-	84	1982-1991	10.6	9	0.02-39.6	2.5 (7.0)	0.10	0.00-0.00	0.00 (0.00)	0.00
740*	Feed prep, other production, min. exp.	2	29	1985-1991	4.1	7	0.02-36.8	2.5 (7.0)	0.17	0.00-0.00	0.00 (0.00)	0.00
762*	Feed prep, K1 production, operative	1	71	1982-1991	7.9	9	0.02-24.0	2.2 (4.4)	0.37	18.7-18.7	18.7 (0.00)	18.7
852	Rubber production, latex plant operative, unspec	203	92	1982-1988	15.3	6	0.03-5.2	0.49 (0.82)	0.20	14.4-14.4	14.4 (0.00)	14.4
Secondary typical SBR operations												
511*	Maintenance, production, maint. field, min. exp.: foreman, engineer	6	15	1986-1991	3.0	5	0.02-0.70	0.20 (0.22)	0.18	1.2-1.2	1.2 (0.01)	1.2
512*	Maintenance, production, maint. field, instrument man/meterman/ electrician/maint. inspect.	7	56	1984-1991	7.0	8	0.02-48.7	2.2 (8.4)	0.19	2.5-2.6	2.5 (0.04)	2.6

Table 3. Summary data on measured and estimated BD ppm, according to job category

Job Code	Job title	Person-years	Number of measurements: Total	Number of measurements: Year range	Number of measurements: Avg/ year	Number of measurements: No of Yrs	Butadiene ppm measurements: Range	Butadiene ppm measurements: Mean (SD)	Butadiene ppm measurements: Median†	Butadiene ppm estimates: Range	Butadiene ppm estimates: Mean (SD)	Butadiene ppm estimates: Median†
513	Maintenance, production, maint. field, pipefitter/oiler/mechanic/blacksmith/ boilermaker/outside machinist	245	250	1978-1991	20.8	12	0.02-106.0	4.4 (12.2)	0.80	4.4-14.2	4.7 (1.5)	4.5
519*	Maintenance production, maint. field, cleanup crew, laborer, work pool, utilityman	-	74	1978-1986	9.3	8	0.05-18.1	1.4 (2.6)	0.50	4.4-5.8	4.7 (0.59)	4.4
605*	Utilities, copolymer effluent operative	89	103	1978-1991	7.9	13	0.00-7.9	0.59 (0.91)	0.40	4.2-5.8	5.1 (0.75)	4.4
812*	Rubber production, polymerization (SBR), operative, unspec.	60	35	1984-1991	4.4	8	0.00-15.5	1.1 (2.6)	0.41	2.8-3.6	3.2 (0.34)	3.2
832*	Rubber production, finishing (SBR), operative, unspec.	111	39	1982-1991	7.8	5	0.02-0.70	0.13 (0.17)	0.07	0.00-0.00	0.00 (0.00)	0.00
834	Rubber production, finishing (SBR), dryer, baler dryer	-	134	1978-1987	14.9	9	0.05-122.6	1.3 (10.6)	0.20	0.00-0.00	0.00 (0.00)	0.00
910	Technical/lab, rubber control, technician	300	210	1977-1991	15.0	14	0.00-522.0	13.6 (55.4)	0.95	0.34-24.0	15.8 (8.1)	9.4
920*	Technical/lab, BD control/hydrocarbon control, technician	247	41	1979-1991	4.1	10	0.00-30.5	2.2 (7.0)	0.07	2.3-18.5	6.3 (7.0)	2.3
Secondary other operations												
482	Stereo maintenance, operative	165	337	1979-1991	25.9	13	0.00-85.7	1.4 (6.3)	0.30	1.1 (4.7)	1.1 (0.20)	1.1
489*	Stereo Maintenance, laborer	6	29	1980-1986	4.1	7	0.05-5.2	0.81 (1.1)	0.50	0.22-0.22	0.22 (0.00)	0.22
521*	Maintenance butadiene, maint. field, min. exp.: foreman, engineer	8	18	1984-1990	2.6	7	0.03-1.0	0.18 (0.24)	0.10	0.27-0.27	0.27 (0.00)	0.27
523	Maintenance butadiene, maint. field, pipefitter/oiler/mechanic/blacksmith/ boilermaker/outside machinist	89	136	1979-1991	10.5	13	0.00-914.0	13.2 (79.5)	0.70	2.8-11.9	3.0 (1.5)	2.8
585*	Maintenance, latex, maint. field, operative	32	63	1984-1988	12.6	5	0.05-7.3	0.54 (1.0)	0.10	13.9-13.9	13.9 (0.00)	13.9
586*	Maintenance latex, maint. field, laborer	1	15	1984-1986	5.0	3	0.05-2.2	0.33 (0.53)	0.30	13.9-13.9	13.9 (0.00)	13.9
772	Stereo production, operative	1007	1392	1978-1991	99.4	14	0.00-51.3	1.2 (3.2)	0.30	0.23-0.36	0.24 (0.03)	0.23

SD=standard deviation.

* <10 average measurements per year.

† Median of year-specific medians of a group.

Table 4. Number of jobs monitored, measurement mean (standard deviation, SD), BD estimates and difference, by year of monitoring

Year	Jobs	No. of measurements	Mean* (SD)		Mean difference† (SD)
			Measurement	Estimate	
1977	3	56	24.8 (69.9)	15.5 (44.7)	-9.2 (36.5)
1978	11	527	16.0 (166.6)	9.5 (65.5)	-6.6 (128.3)
1979	13	274	10.6 (153.2)	6.1 (38.9)	-4.5 (141.6)
1980	13	301	14.5 (137.8)	3.8 (22.9)	-10.7 (130.0)
1981	15	307	4.8 (38.4)	2.2 (19.3)	-2.6 (36.1)
1982	21	406	3.8 (28.2)	2.9 (24.7)	-0.88 (26.4)
1983	13	113	3.9 (19.4)	2.5 (9.3)	-1.4 (20.5)
1984	27	658	2.5 (20.3)	3.6 (30.3)	1.2 (35.6)
1985	27	482	2.6 (18.4)	4.4 (31.4)	1.8 (32.2)
1986	30	504	2.3 (16.2)	3.7 (27.6)	1.4 (23.1)
1987	26	310	0.85 (6.3)	4.8 (28.6)	4.0 (28.4)
1988	28	417	1.0 (5.2)	5.8 (36.6)	4.7 (35.3)
1989	27	238	1.5 (5.5)	4.1 (24.0)	2.6 (22.3)
1990	27	223	0.63 (3.3)	3.9 (23.0)	3.3 (22.6)
1991	25	162	0.34 (0.61)	2.4 (14.1)	2.0 (14.1)

* Weighted by the number of measurements for job/year combinations in a year.
† Estimate minus mean of measurements.

Table 5. Mean (standard deviation, SD) and medians of measurements and estimates, by job category

Job category	No. of combin-ations	No. of measurements	Mean* (SD)		Median * (25^{th}, 75^{th} percentile)	
			Measurement	Estimate	Measurement	Estimate
Total	306	4,978	5.2 (57.9)	4.7 (30.2)	1.2 (0.55, 3.3)	0.27 (0.23, 5.8)
Primary	152	2,031	8.5 (66.8)	7.5 (34.0)	2.0 (0.48, 6.6)	4.5 (0, 13.3)
Typical SBR	82	1,388	11.3 (88.3)	6.0 (33.1)	2.9 (0.41, 10.4)	0.23 (0, 8.4)
Other	70	643	2.4 (10.4)	10.7 (33.2)	1.2 (0.51, 2.8)	4.5 (0, 18.7)
Secondary	154	2,947	2.9 (45.2)	2.7 (22.3)	1.2 (0.55, 2.1)	0.23 (0.23, 3.1)
Typical SBR	92	957	4.8 (27.8)	6.2 (22.1)	1.2 (0.40, 3.8)	4.5 (2.5, 5.8)
Other	62	1,990	2.0 (62.3)	1.1 (15.5)	1.2 (0.58, 1.4)	0.23 (0.23, 1.1)

*Weighted by the number of measurements for the job category.

Table 6. Mean (standard deviation, SD) and median of differences between estimates and measurement means and correlations between job/year–specific estimates and measurements, by job category

Job category	No. of combin-ations	Mean difference* (SD)	Mean difference† (SD)	Median difference‡ (25^{th}, 75^{th} percentiles)	Spearman's correlation: Estimate with measurement mean (r, p-value)	Spearman's correlation: Estimate with measurement median (r, p-value)
Total	306	-0.50 (26.5)	1.0 (1.1)	-0.04 (-0.56, 3.3)	0.45 (<0.0001)	0.41 (<0.0001)
Primary	152	-0.99 (61.8)	1.9 (1.0)	-0.10 (-0.92, 3.1)	0.55 (<0.0001)	0.48 (<0.0001)
Typical SBR	82	-5.3 (34.5)	-3.7 (1.1)	-0.21 (-1.3, -0.05)	0.81 (<0.0001)	0.78 (<0.0001)
Other	70	8.3 (13.9)	9.3 (0.69)	-0.05 (-0.82, 14.2)	0.29 (0.01)	0.27 (0.02)
Secondary	154	-0.17 (45.8)	0.45 (1.1)	1.1 (-0.36, 3.4)	0.30 (0.0001)	0.28 (0.0003)
Typical SBR	92	1.4 (27.8)	2.4 (1.0)	2.3 (0.21, 4.0)	0.56 (<0.0001)	0.46 (<0.0001)
Other	62	-0.92 (21.2)	-1.1 (1.2)	-0.10 (-1.1, 0.98)	0.01 (0.93)	0.01 (0.92)

* Weighted average of the combination-specific difference between the estimate and the mean of BD measurements for the combination, with the weight equal to the number of measurements for the combination.

† Weighted average of the combination-specific difference between the estimate and the mean of BD measurements for the combination, with the weight equal to the fraction of person-years in the combination.

‡ Median of the combination-specific difference between the estimate and the mean of BD measurements for the combination.

Table 7. Evaluation of primary job/year combinations with severe† overestimation or underestimation of BD concentrations

Job/year	No. of measurements	Mean of measurements (SD)*, ppm	Estimate, ppm (credibility range)	> 10 measurements (+/-)	Measurement means within the credibility range (+/-)
Primary typical SBR					
Underestimation					
813/1977	22	39.0 (40.0)	26.0 (15.7-40.4)	+	+
813/1978	62	75.3 (79.0)	26.0 (15.1-40.2)	+	-
813/1979	17	67.7 (30.0)	26.0 (15.7-40.4)	+	-
813/1980	19	110.2 (145.0)	7.5 (4.0-15.0)	+	-
813/1981	11	39.1 (45.0)	7.5 (4.0-14.6)	+	-
813/1982	27	21.5 (26.0)	7.5 (4.0-15.0)	+	-
813/1983	1	63.5	7.5 (4.0-14.6)	-	-
813/1984	8	37.0 (22.0)	7.5 (4.0-15.0)	+	-
813/1985	9	23.0 (22.0)	7.5 (4.0-14.6)	-	-
813/1986	11	16.0 (17.0)	7.5 (4.0-15.0)	+	-
815/1981	21	10.4 (14.0)	0.23 (0.12-0.41)	+	-
815/1982	25	7.6 (9.1)	0.23 (0.12-0.41)	+	-
815/1983	7	11.4 (24.0)	0.23 (0.12-0.41)	-	-
815/1984	20	2.9 (4.9)	0.23 (0.12-0.41)	+	-
817/1980	33	29.1 (94.0)	8.0 (3.5-19.1)	+	-
Overestimation					
813/1990	5	1.9 (2.5)	5.1 (2.2-12.4)	-	-
813/1991	2	0.78 (0.16)	5.1 (2.2-12.0)	-	-
815/1978	71	5.2 (9.4)	21.3 (14.3-29.8)	+	-
815/1979	15	3.5 (2.3)	21.3 (14.3-29.8)	+	-
815/1980	30	4.5 (7.9)	13.3 (8.7-18.5)	+	-
817/1985	13	1.4 (1.4)	5.8 (3.5-20.0)	+	-
817/1990	5	0.20 (0.29)	3.5 (3.4-14.9)	-	-
Primary Other					
Underestimation					
330/1989	4	10.3 (13.0)	4.5 (0.57-20.6)	-	-
740/1986	5	7.5 (16.0)	0.0 (0.0-0.0)	-	-
Overestimation					
330/1979	10	2.1 (2.0)	18.5 (1.0-98.7)	+	+
330/1981	11	1.6 (0.72)	4.5 (0.57-20.6)	+	+
330/1983	1	1.0	4.5 (0.57-20.6)	-	+

Table 7. Evaluation of primary job/year combinations with severe† overestimation or underestimation of BD concentrations

Job/year	No. of measurements	Mean of measurements (SD)*, ppm	Estimate, ppm (credibility range)	> 10 measurements (+/-)	Measurement means within the credibility range (+/-)
330/1985	7	1.9 (1.8)	4.5 (0.57-20.6)	-	+
330/1988	8	0.55 (0.66)	4.5 (0.57-20.6)	-	-
330/1990	4	0.28 (0.33)	4.5 (0.57-20.6)	-	-
330/1991	1	0.02	4.5 (0.57-20.6)	-	-
704/1982	3	4.8 (6.9)	27.2 (1.9-248.4)	-	+
704/1984	13	0.52 (0.41)	27.2 (2.0-248.4)	+	-
704/1985	20	8.5 (16.0)	27.2 (2.0-248.4)	+	+
704/1986	16	18.1 (49.0)	27.2 (2.0-248.4)	+	+
704/1987	18	0.88 (1.5)	27.2 (2.0-248.4)	+	-
704/1988	43	2.0 (5.4)	27.2 (1.9-248.4)	+	+
704/1989	11	3.8 (9.0)	27.2 (2.0-248.4)	+	+
704/1990	7	0.23 (0.26)	27.2 (2.0-248.4)	-	-
704/1991	5	0.53 (0.99)	27.2 (2.0-248.4)	-	-
762/1982	2	7.0 (7.4)	18.7 (0.62-82.3)	-	+
852/1982	7	0.69 (0.57)	14.4 (8.6-20.0)	-	-
852/1984	15	0.65 (0.61)	14.4 (8.6-20.0)	+	-
852/1985	28	0.51 (0.59)	14.4 (8.6-20.0)	+	-
852/1986	16	0.77 (1.5)	14.4 (8.6-20.0)	+	-
852/1987	11	0.06 (0.04)	14.4 (8.6-20.0)	+	-
852/1988	15	0.22 (0.63)	14.4 (8.6-24.0)	+	-

*SD=standard deviation.

† Absolute difference between estimate (E) and measurement mean (M) > 5.0 ppm or the relative difference [underestimation: (E-M)/E where E >0; overestimation: (E-M)/M] > 100% and person-year weight >0.

APPENDIX A

List of Sarnia Plant Jobs Developed for the Job-Exposure Matrix Used in the Mortality Study of Synthetic Rubber Industry Workers

Table A. Sarnia jobs with their corresponding text translations

Job	Text translation
100	Administration general/unspecified, account /executive/employee relation/finance/human resource/industrial relations/marketing/personnel /sales
109	Administration, labor, utilityman, serviceman
210	Service, safety, SBR/SP/latex: fireman, inspector
211	Service, safety, SBR/SP/latex: guard, marshal, engineer, chief, first aid man
212	Service, safety, SBR/SP/latex: coordinator, director, manager, supervisor.
300	Shipping/distribution, labor, utilityman, serviceman
310	ABS area, technical, technician
311	ABS area, technical, no exposure/chemist
320	Butyl rubber area, butyl rubber, technical technician
321	Butyl rubber area, butyl rubber technical
330	Stereo technical, technician
331	Stereo technical, minimal exposure/chemist
332	Stereo technical, no exposure/supervisor
340	Styrene technical, technician
341	Styrene technical, minimal exposure/chemist
342	Styrene technical, no exposure/supervisor
350	Polysar general/rubber unspecified PS general technical, technician
351	Polysar general/rubber unspecified PS general technical, minimal exposure/chemist
352	Polysar general/rubber unspecified PS general technical, no exposure/supervisor
353	Polysar general/rubber unspecified PS general technical, sampler
354	Polysar general/rubber unspecified PS general technical, field lab/mooney
359	Polysar general/rubber unspecified PS general technical, laborer
399	Polysar general/rubber unspecified maintenance, laborer, exposed
400	Engineering, SBR/SP/latex
401	Engineering general, BD
402	Engineering general, styrene
403	Engineering general, petrochemicals
404	Engineering general, utility/butyl/ABS/FP
405	Engineering general, field unspecified
406	Engineering general, miscellaneous/unspecified
410	Engineering, design engineering
420	Engineering, process engineering, SBR/SP

Table A. Sarnia jobs with their corresponding text translations

Job	Text translation
421	Engineering, process engineering, ABS
422	Engineering, process engineering, BD
423	Engineering, process engineering, butyl/feed prep
424	Engineering, process engineering, petrochemicals
425	Engineering, process engineering, latex
426	Engineering, process engineering, stereo
427	Engineering, process engineering, styrene
428	Engineering, process engineering, utilities
429	Engineering, process engineering, general/unspecified
430	Engineering, process control, SBR/SP
431	Engineering, process control, BD
432	Engineering, process control, butyl/feed prep
433	Engineering, process control, ABS
434	Engineering, process control, petrochemicals
435	Engineering, process control, stereo
436	Engineering, process control, styrene
437	Engineering, process control, utilities
438	Engineering, process control, general/unspecified
440	Abs maintenance, no/minimal exposure
441	Abs maintenance, operative
450	Butyl rubber area, maintenance, no/minimal exposure
451	Butyl rubber area, maintenance, operative
459	Butyl rubber area, maintenance, laborer
460	Petrochemicals, maintenance, no exposure
461	Petrochemicals, maintenance, minimal exposure
462	Petrochemicals, maintenance, operative
469	Petrochemicals, maintenance, laborer
470	Feed prep, other, maintenance, no/minimal exposure
471	Feed prep, other, maintenance, operative
472	Feed prep, light ends recovery maintenance, operative
473	Feed pre, K1, maintenance, operative/mechanic
479	Feed prep, other, maintenance, laborer
480	Stereo maintenance, no exposure

Table A. Sarnia jobs with their corresponding text translations

Job	Text translation
481	Stereo maintenance, minimal exposure
482	Stereo maintenance, operative
489	Stereo maintenance, laborer
490	Stereo maintenance, minimal exposure
491	Stereo maintenance, operative
499	Stereo maintenance, laborer
500	Maintenance, mint. unspecified/shop, no exposure: supervisor, manager, coordinator, planner, superintendent., clerk
501	Maintenance, maintenance unspecified /shop, minimal exposure: foreman, engineer
502	Maintenance, maintenance unspecified /shop, operative unspecified
503	Maintenance, maintenance unspecified /shop, plumber, painter, carpenter, steamfitter, insulator
504	Maintenance, maintenance unspecified /shop, ironworker, sheetmetal, welder
505	Maintenance, maintenance unspecified /shop, machinist
509	Maintenance, maintenance unspecified /shop, labor, utility, serviceman
511	Maintenance, production, maintenance field, minimal exposure: foreman, engineer
512	Maintenance, production, maintenance field, instrument man/meterman/electrician/maintenance inspector
513	Maintenance, production, maintenance field, pipefitter/oiler/mechanic/blacksmith/boilermaker/outside machinist
514	Maintenance, production, maintenance field, not specified: driver
519	Maintenance, production, maintenance field, cleanup crew, laborer, work pool, utilityman
520	Maintenance butadiene maintenance field, no exposure: supervisor/manager/coordinator/planner/superintendent/clerk
521	Maintenance butadiene, maintenance field, minimal exposure: foreman, engineer
522	Maintenance butadiene, maintenance field, instrument man/meter man/electrician/ maintenance inspection
523	Maintenance butadiene, maintenance field, pipefitter/oiler/mechanic/blacksmith/biolermaker/outside machinist
524	Maintenance butadiene, maintenance field, not specified: driver
529	Maintenance, butadiene, maintenance field, cleanup crew, laborer, work pool, utilityman
551	Maintenance, finishing, maintenance field, minimal exposure: foreman, engineer
560	Maintenance, pilot plant, maintenance field, no exposure: supervisor/manager/coordinator/planner/ superintendent/clerk
561	Maintenance, pilot plant, maintenance field, minimal exposure: foreman, engineer
562	Maintenance, pilot plant, maintenance field, instrument man/meterman/electrician/maintenance inspector
563	Maintenance, pilot plant, maintenance field, pipefitter/oiler/mechanic/blacksmith/boilermaker/ outside machinist

Table A. Sarnia jobs with their corresponding text translations

Job	Text translation
570	Maintenance, buildings yard/labor unspecified, operator
571	Maintenance, buildings yard/labor unspecified, foreman, supervisor
579	Maintenance, buildings yard/labor unspecified, laborer
580	Maintenance, utilities, maintenance field, no exposure
581	Maintenance, utilities, maintenance field, minimal exposure
582	Maintenance, utilities, maintenance field, operative
583	Maintenance, latex, maintenance field, no exposure
584	Maintenance, latex, maintenance field, minimal exposure
585	Maintenance, latex, maintenance field, operative
586	Maintenance, latex, maintenance field laborer
589	Maintenance, utilities, maintenance field, laborer
590	Polysar general/rubber unspecified maintenance, no exposure
591	Polysar general/rubber unspecified maintenance, minimal exposure shop/BG/construction/unspecified
592	Polysar general/rubber unspecified maintenance, minimal exposure, field
593	Polysar general/rubber unspecified maintenance, equipment/vehicle operator, garage mech.
594	Polysar general/rubber unspecified maintenance, construction operator/rigger/yard scaffoldman/ painter/
595	Polysar general/rubber unspecified maintenance, metal worker, welder, lead burner, machinist, millwright
596	Polysar general/rubber unspecified maintenance, pipefitter/mechanic/boilermaker/oiler/ blacksmith
597	Polysar general/rubber unspecified maintenance, electrician, instrumentman
598	Polysar general/rubber unspecified maintenance, operative, miscellaneous/unspecified
599	Polysar general/rubber unspecified maintenance, laborer, no exposure
600	Utilities, operative, unspecified/miscellaneous
605	Utilities, copolymer effluent operative
609	Utilities, labor, utilityman, serviceman
610	Utilities, utilities powerhouse
630	Utilities, utilities pump house
640	Utilities, utilities refrigeration
641	Copolymer utilities, Polysar refrigeration/compressor unspecified
650	Laboratory, emulsion polymers research and development, technician
651	Laboratory, emulsion polymers research and development, minimal exposure/chemist
652	Laboratory, emulsion polymers research and development, supervisor
660	Laboratory, poly BD, EPDM, solutions N.S., technician
661	Laboratory, poly BD, EPDM, solutions N.S., minimal exposure/chemist

Table A. Sarnia jobs with their corresponding text translations

Job	Text translation
662	Laboratory, poly BD, EPDM, solutions N.S., supervisor
669	Laboratory, poly BD, EPDM, solutions N.S., labor
670	Laboratory, bottle polymerization/batch reactors, technician
672	Laboratory, bottle polymerization/batch reactors, supervisor
679	Laboratory, bottle polymerization/batch reactors, labor
680	Laboratory, hydrocarbon research and development, technician
681	Laboratory, hydrocarbon research and development, minimal exposure/chemist
682	Laboratory, hydrocarbon research and development, supervisor
689	Laboratory, hydrocarbon research and development, labor
690	Laboratory, low exposure polymer research and development (plastics, butyl), minimal exposure/chemist
692	Laboratory, low exposure polymer research and development (plastics, butyl), supervisor
700	Butadiene production, operative unspecified
701	Butadiene production, minimal exposure
703	Butadiene production, butadiene dehydro
704	Butadiene production, butadiene extraction, compressor house
707	Butadiene production, refrigeration, compressor Polysar
709	Butadiene production, labor, utilityman, serviceman
710	ABS area, production, no exposure
711	ABS area, production, minimal exposure
712	ABS area, production, operative
719	ABS area, production, laborer
720	Butyl rubber area, production, no/minimal exposure
721	Butyl rubber area, production, operative
729	Butyl rubber area, production, laborer
730	Petrochemicals, production, no exposure
731	Petrochemicals, production, minimal exposure
732	Petrochemicals, production, operative (petrochemical general)
739	Petrochemicals, production, laborer
740	Feed prep, other, production, no/minimal exposure
741	Feed prep, other, production, operative
749	Feed prep, other, production, laborer
750	Feed prep, light ends recovery, production, minimal exposure
751	Feed prep, light ends recovery, production, operative

Table A. Sarnia jobs with their corresponding text translations

Job	Text translation
759	Feed prep, light ends recovery, production, laborer
760	Feed prep, K1, production, no exposure
761	Feed prep, K1, production, minimal exposure
762	Feed prep, K1, production, operative
769	Feed prep, K1, production, laborer
770	Stereo production, no exposure
771	Stereo production, minimal exposure
772	Stereo production, operative
773	Stereo production, refrigeration/compression operation
780	Styrene production, no exposure
781	Styrene production, minimal exposure
782	Styrene production, operative, tank farm
783	Styrene production, operative, ethylbenzene
784	Styrene production, operative, cracking
785	Styrene production, operative, finishing
786	Styrene production, operative, miscellaneous/unspecified
789	Styrene production, laborer
790	Polysar general/rubber unspecified, production, no exposure
791	Polysar general/rubber unspecified, production, minimal exposure
792	Polysar general/rubber unspecified, production, operative, finishing
793	Polysar general/rubber unspecified, production, operative, other/unspecified
794	Polysar general/rubber unspecified, production, safety
799	Polysar general/rubber unspecified, production, laborer
800	Rubber production (SBR), unspecified, no exposure: supervisor/manager/coordinator/planner/superintendent/clerk
801	Rubber production (SBR), unspecified, minimal exposure: foreman, engineer
802	Rubber production (SBR), unspecified, operative, unspecified
809	Rubber production (SBR), unspecified, labor, utilityman, serviceman
810	Rubber production, polymerization (SBR), no exposure
811	Rubber Production, polymerization (SBR), minimal exposure
812	Rubber Production, polymerization (SBR), operative, unspecified
813	Rubber production, polymerization (SBR), tank farm, transfer
814	Rubber production, polymerization (SBR), pigment preparation
815	Rubber production, polymerization (SBR), reactor, blowdown, panel board

Table A. Sarnia jobs with their corresponding text translations

Job	Text translation
816	Rubber production, polymerization (SBR), reactor recovery
817	Rubber production, polymerization (SBR), recovery, compressor house, high solids recovery
819	Rubber production, polymerization (SBR), labor, utilityman, serviceman
820	Rubber production, coagulation/blending/solutions prep carbon black (SBR)
830	Rubber production, finishing (SBR), no exposure
831	Rubber production, finishing (SBR), minimal exposure
832	Rubber production, finishing (SBR), operative, unspecified
833	Rubber production, finishing (SBR), filter, filter dryer, dryer filter, fluid bed
834	Rubber production, finishing (SBR), dryer, dryer baler, baler dryer
835	Rubber production, finishing (SBR), baler, packager, reclaim
839	Rubber production, finishing (SBR), cleanup, labor, utilityman, serviceman
850	Rubber production, latex plant, no exposure: supervisor, manager, coordinator, planner, superintendent
851	Rubber production, latex plant, minimal exposure: foreman, engineer
852	Rubber production, latex plant, operative, unspecified
859	Rubber production, latex plant, labor
900	Technical/laboratory technician
901	Technical/ laboratory minimal exposure/chemist
902	Technical/ laboratory supervisor
910	Technical/ laboratory rubber control, technician
911	Technical/ laboratory rubber control, minimal exposure/chemist
912	Technical/ laboratory rubber control, supervisor
915	Technical/ laboratory rubber control, physical tester
919	Technical/ laboratory rubber control, labor
920	Technical/ laboratory BD control/hydrocarbon control, technician
921	Technical/ laboratory BD control/hydrocarbon control, minimal exposure/chemist
922	Technical/ laboratory BD control/hydrocarbon control, supervisor
929	Technical/ laboratory BD control/hydrocarbon control, labor
930	Technical/ laboratory applications research/production quality service, technician
931	Technical/ laboratory applications research/production quality service, minimal exposure/chemist
932	Technical/ laboratory applications research/production quality service, supervisor
940	Technical/ laboratory research/research and development, technician
941	Technical/ laboratory research/research and development, minimal exposure/chemist
942	Technical/ laboratory research/research and development, supervisor

Table A. Sarnia jobs with their corresponding text translations

Job	Text translation
949	Technical/ laboratory research/research and development, labor
950	Technical/ laboratory pilot plant/development, process/development, technician
951	Technical/ laboratory pilot plant/development, process/development, minimal exposure/chemist
952	Technical/ laboratory pilot plant/development, process/development, supervisor
980	Technical/ laboratory SBR/process control, technician
981	Technical/ laboratory SBR/process control, chemist
982	Technical/ laboratory SBR/process control, coordinator/foreman/ supervisor

Jobs that appear in employees' work histories during 1977 – 1991.

APPENDIX B

Comparison of a Sample Sarnia Plant Measurement Database Records with the Original Sample Sheet Data

Table B1. Discrepancies in the Sarnia plant measurement database in comparison with the original sample sheets

		Discrepancy category*		
		Any	Major	Minor
1,3-butadiene monitoring result incorrect	N	67	7	60
	Discrepancy rate†	17%	2%	15%
Sample date incorrect	N	13	3	10
	Discrepancy rate	3%	1%	2%
Sample duration incorrect	N	7	2	5
	Discrepancy rate	2%	0.5%	1%
Work area/job title incorrect	N	4	2	2
	Discrepancy rate	1%	0.5%	0.5%
Sample type and method incorrect	N	5	2	3
	Discrepancy rate	1%	0.5%	1%
Shift incorrect	N	24	-	-
	Discrepancy rate	6%		

* **Any:** disagreement between the original sample sheet data and the Sarnia plant measurement database record. **Major:** for 1,3-butadiene results, discrepancy of ≥1 ppm; for date of sample, ≥1 year; for sample duration, ≥60 minutes; for work area/job code disagreement in work area or job code; for sample type and retrieval, disagreement in the work area.

† Discrepancy rate: proportion of the total of 402 sets of records.

Table B2. Discrepancies between the original sample sheet and the Sarnia measurement database for 1,3-butadiene monitoring results

Year Sampled	Clock number	Sample number	Result recorded in sample sheet (ppm)	Result recorded in measurement database (ppm)
		Minor discrepancy (< 1.0 ppm difference)		
Underestimated in IH database				
1980	15744	0004380	<0.10	0.00
1981	16563	0005500	<0.10	0.00
1978	11137	0001100	<0.10	0.05
1980	16058	003776	<0.10	0.05
1981	15382	0004969	<0.10	0.05
1983	12764	0007974	<0.10	0.05
1984	16236	0008700	<0.10	0.05
1985	15377	0011792	<0.10	0.05
1985	17230	0011597	<0.10	0.05
1986	17240	0012959	<0.10	0.05
1986	17276	0012268	<0.10	0.05
1986	17449	0012313	<0.10	0.05
1986	17414	0012312	<0.10	0.05
1986	13326	0013089	<0.10	0.05
1986	11408	0012699	<0.10	0.05
1986	12686	0012343	<0.10	0.05
1986	15744	0013079	<0.10	0.05
1986	15677	001300	<0.10	0.05
1987	15007	0014052	<0.10	0.05
1987	10946	0013937	<0.10	0.05
1987	16826	0013915	<0.10	0.05
1987	17550	0013467	<0.10	0.05
1987	16826	0013916	<0.10	0.05
1988	10946	0014147	<0.10	0.05
1988	10946	0015045	<0.10	0.05
1988	13605	0014773	<0.10	0.05
1988	13854	0015397	<0.10	0.05
1988	15744	0014653	<0.10	0.05
1988	16422	0015166	<0.10	0.05
1988	16605	0014876	<0.10	0.05
1988	16619	0014294	<0.10	0.05
1988	16943	0014384	<0.10	0.05
1988	17686	0014701	<0.10	0.05
1988	17751	0014896	<0.10	0.05
1988	13324	0014821	<0.20	0.05
1981	17275	0005390	0.50	0.00
1980	13548	0004083	0.60	0.00
1977	16566	0000885	18.3	18.0
1977	16164	0000904	20.4	20.0

Table B2. Discrepancies between the original sample sheet and the Sarnia measurement database for 1,3-butadiene monitoring results

Year Sampled	Clock number	Sample number	Result recorded in sample sheet (ppm)	Result recorded in measurement database (ppm)
1978	14637	0002166	106.1	106.0
1981	17072	0004777	779.3	779.0
Over estimated in IH database				
1990	16133	0021356	<0.03	0.03
1991	16644	0024772	<0.04	0.04
1991	12235	0024730	<0.05	0.05
1991	14871	0024797	<0.05	0.05
1991	11550	0024038	<0.09	0.09
1990	17431	0022674	<0.12	0.12
1990	17370	0022676	<0.12	0.12
1990	14393	0022535	<0.12	0.12
1990	16050	0021848	<0.12	0.12
1990	16999	0022360	<0.13	0.13
1990	17180	0022762	<0.13	0.13
1990	17737	0022638	<0.14	0.14
1990	17700	0022358	<0.15	0.15
1991	15744	0023395	<0.25	0.25
1989	16561	0015491	<0.30	0.30
1981	13587	0004931	<0.10	0.70
1981	15930	0005935	12.5	12.8
1981	17072	0004776	104.9	105.0
1981	17072	0005922	297.7	298.0
Major discrepancy (≥ 1.0 ppm difference)				
Underestimated in IH database				
1981	16694	0005332	1.60	0.00
1979	11759	0003439	5.00	0.00
1989	16567	0015508	5.26	0.20
1980	15393	0003824	5.70	0.00
1980	16495	0003641	11.7	0.00
1980	11759	0003830	15.8	0.00
1977	14845	0000922	86.0	8.60

Table B3. Discrepancies between the original sample sheet and Sarnia plant measurement database for selected results

Year sampled	Clock Number	Sample number	Recording in sample sheet	Recording in measurement database
		Sample date (mm/dd/yy)		
Minor discrepancy (< 1 year)				
1979	11759	0003439	12/31/79	12/03/79
1986	12220	0013057	11/21/86	12/15/86
1978	12843	0001069	02/08/78	02/09/78
1980	13548	0004083	05/29/80	05/28/80
1991	15018	0024918	05/27/91	05/23/91
1990	15744	0021857	03/09/90	05/09/90
1989	16050	0015859	03/21/89	03/29/89
1979	16417	0003045	06/19/79	05/19/79
1988	16943	0014384	03/07/88	03/17/88
1988	17686	0014701	04/05/88	07/05/88
Major discrepancy (≥ 1 year)				
1980	15742	0021360	01/30/80	01/30/90
1979	15904	0000627	07/28/79	07/28/77
1987	16420	0005927	09/05/87	09/05/81
		Sample duration (minutes)		
Minor discrepancy (<60 minutes)				
1988	10946	0014147	350	300
1978	12843	0001069	712	720
1980	13548	0004083	749	746
1986	16128	0012475	1005	1040
1985	17276	0011344	959	939
Major discrepancy (≥60 minutes)				
1986	12220	0013057	721	945
1981	13587	0004931	246	346
		Work area/job group code*		
Minor discrepancy (no change in the job descriptions)				
1986	15506	0012215	7J11	7U11
1990	15742	0021360	1O01	1H07
Major discrepancy (change in the work area or job title)				
1988	15339	0014685	7T20	7T99
1991	15801	0025109	8T99	6Z04

Table B3. Discrepancies between the original sample sheet and Sarnia plant measurement database for selected results

Year sampled	Clock Number	Sample number	Recording in sample sheet	Recording in measurement database
		Sample type and retrieval†		
Minor discrepancy (no change in the work area)				
1988	13605	0015289	RNUT	RNNT
1985	15541	0011646	ENUT	FNUT
1991	17871	0025101	MDKT	MOKT
Major discrepancy (change in the work area)				
1988	10946	0014147	MNCT	ROUT
1986	12220	0013057	MNUT	QNUT
		Shift		
1988	10946	0015045	12 hour days	8 hour days
1988	12326	0014834	12 hour days	8 hour days
1983	12369	0008464	12 hour days	8 hour days
1988	13324	0014821	12 hour days	8 hour days
1988	13854	0015397	12 hour days	8 hour days
1988	14883	0014873	12 hour days	8 hour days
1988	15699	0015063	12 hour days	8 hour days
1990	15742	0021360	12 hour days	8 hour days
1988	15744	0014667	12 hour days	8 hour days
1989	16096	0015527	12 hour days	8 hour days
1990	16133	0021356	12 hour days	8 hour days
1988	16164	0014899	12 hour days	8 hour days
1988	16422	0015166	12 hour days	8 hour days
1988	16603	0015254	12 hour days	8 hour days
1988	16605	0014876	12 hour days	8 hour days
1988	16619	0015188	12 hour days	8 hour days
1988	17268	0014878	12 hour days	8 hour days
1988	17751	0014896	12 hour days	8 hour days
1991	17136	0024656	12 hour days	8 hour nights
1984	15744	0008709	8 hour days	12 hour days
1984	15744	0009308	8 hour days	12 hour days
1984	15744	0009687	8 hour days	12 hour days
1984	16339	0009332	8 hour days	12 hour days
1984	16544	0009502	8 hour days	12 hour days

* Work area/job code translations:
7J11=invalid code } job description in sample sheet and IH database 7U11=BE
#2/Maintenance turnaround/boilermaker } match
1O01=invalid code } job description in sample sheet and IH data base
1H07=Biox Unit/maint oil separator/operator } match
7T20=Stereo NR Unit/maintenance turnaround/pipefitter
7T99=Stereo NR Unit/maintenance turnaround
8T99=Stereo NR Unit/maintenance resident
6Z04=Distribution process assistant

†Sample type and retrieval codes:

MNCT= Routine OVM (organic vapor monitoring) sampling for maintenance personnel, no protection worn by subject, sample obtained by 3M dosimeter

ROUT= Routine sampling for process personnel, unknown if respirator was worn, sample obtained by Century Charcoal tubing

MNUT= Routine sampling for maintenance personnel, no protection worn, sample obtained by Century Charcoal tubing

QNUT= Follow-up OVM sampling for process personnel, no protection worn, sample obtained by Century Charcoal tubing

RNUT= Routine OVM/Noise sampling for process personnel, no protection worn, sample obtained by Century Charcoal tubing

RNNT= Routine OVM/Noise sampling for process personnel, no protection worn, sample obtained by atd50 tube packed with porapak N sorbent

ENUT= Turnaround OVM sampling of maintenance personnel during pre- turnaround conditions as of 4/15/85, no protection worn, sample obtained by Century Charcoal tubing

FNUT= Turnaround OVM sampling of maintenance personnel during the 1st 3 days of turnaround as of 4/15/85, no protection worn, sample obtained by Century Charcoal tubing

MDKT= Routine OVM sampling for maintenance personnel, respirator worn, sample obtained by atd50 tube packed with tenax

MOKT= Routine OVM sampling for maintenance personnel, unknown if respirator was worn, sample obtained by atd50 tube packed with tenax

APPENDIX C

List of Sarnia Job Codes Assigned to a Corresponding Job in the Job-Exposure Matrix Used in the Mortality Study

Table C. List of Sarnia job codes assigned to a corresponding job in the job-exposure matrix (JEM) used in the mortality study

JEM job	Sarnia job code	Sarnia job code text translation
300	4Z01	Distribution / Material Receiver / Material Controller
	6Z01	Distribution / Polytainers / Process Assistant
330	3T06	Stereo BR Unit / Laboratory Technician
471	8K01	Feed Prep / Maintenance Resident / Group Leader
	8K17	Feed Prep / Maintenance Resident / Mechanic
	8K20	Feed Prep / Maintenance Resident / Pipefitter
482	8T01	Stereo BR Unit / Maintenance Resident / Group Leader Disc
	8T14	Stereo BR Unit / Maintenance Resident / Electrician
	8T17	Stereo BR Unit / Maintenance Resident / Millwright Mechanic
	8T20	Stereo BR Unit / Maintenance Resident / Pipefitter
	8T29	Stereo BR Unit / Maintenance Resident / Instrument Mechanic
489	8T05	Stereo BR Unit / Maintenance Resident / Utility Laborer Disc
	8T06	Stereo BR Unit / Maintenance Resident / Laborer
511	8C01	Copolymer NBR / Maintenance Resident / Group Leader
	8C99	Copolymer NBR / Maintenance Resident / Janitress
	8T99	Stereo BR Unit / Maintenance Resident / Janitress
512	8C14	Copolymer NBR / Maintenance Resident / Electrician
	8C29	Copolymer NBR / Maintenance Resident / Instrument Mechanic
513	8C11	Copolymer NBR / Maintenance Resident / Boilermaker Disc
	8C17	Copolymer NBR / Maintenance Resident / Mechanic
	8C20	Copolymer NBR / Maintenance Resident / Pipefitter
519	8C05	Copolymer NBR / Maintenance Resident / Utility Laborer Disc
	8C06	Copolymer NBR / Maintenance Resident / Laborer Disc
521	8J01	BE #1 / #2 / Maintenance Resident / Group Leader
523	8J17	BE #1 / #2 / Maintenance Resident / Mechanic
	8J20	BE #1 / #2 / Maintenance Resident / Pipefitter
	8J21	BE #1 / #2 / Maintenance Resident / Mach Disc
585	8A15	Maintenance Resident / Latex / Insulator
	8A17	Maintenance Resident / Latex / Mechanic
	8A20	Maintenance Resident / Latex / Pipefitter
	8A29	Maintenance Resident / Latex / Instrument Mechanic
586	8A05	Maintenance Resident / Latex / Utility Laborer
593	8W04	Waste Disposal / Maintenance Resident / Backhoe Operator
600	1H01	Biox Unit / Unit Control In Out / Operator
	1H07	Biox Unit / Main Oil Separator / Operator
	3H02	Biox Unit / Shift In Out / Operator Assistant
	3H06	Biox Unit / Days Disc / Operator Assistant
	3H08	Biox Unit / Main Oil Separator / Outside Man Operator Assistant
605	1C14	Copolymer NBR / Gravor Effluent Disc / Operator
	1H02	Biox Unit / Gravor Effluent / Operator
	3C15	Copolymer NBR / Gravor Effluent Disc / Operator Assistant
	3W04	Lab Tech, Operator Assistant – Waste Disposal
704	1K01	IB #2 Resident And BE #3 Maintenance Resident / Operator
	1U01	BE #2 Day / Operator
	3K02	Biox Unit / IB #2 And BE #3 Maintenance Resident Houseman / Operator Assistant
	3K03	BE #3 Maintenance Resident / Operator Assistant
731	9K10	Petrochem / Salaried Personnel / Shift Foreman

Table C. List of Sarnia job codes assigned to a corresponding job in the job-exposure matrix (JEM) used in the mortality study

JEM job	Sarnia job code	Sarnia job code text translation
732	3K04	IB #2 Resident / Reactors / Operator Assistant
	3K05	IB #2 Resident / Towers / Operator Assistant
	3K06	IB #2 Resident And BE #3 Maintenance Resident / Spareman Operator Assistant
740	9K09	Feed Prep 1 Plant / Salaried Personnel / Day Foreman
762	1K07	K1 Pumphouse / Operator
	3K08	K1 Pumphouse / Loading Rack / Operator
772	1T01	Stereo BR Unit / Control Room / Operator
	1T09	Stereo BR Unit / Finishing Bldg / Operator
	1T22	Stereo BR Unit / Energy Conservation / Operator
	1T24	Stereo BR Unit / Days Permit Issue Disc / Operator
	1T26	Stereo, BR Unit / Operator
	2T23	Stereo BR Unit / Reblend Disc / Operator Assistant
	3T03	Stereo BR Unit / Tank Farm / Operator Assistant
	3T04	Stereo BR Unit / Reactor Area / Operator Assistant
	3T05	Stereo BR Unit / Utility Reactor / Operator Assistant
	3T07	Stereo BR Unit / Process Control Disc / Operator Assistant
	3T08	Stereo BR Unit / Coagulation Recovery / Operator Assistant
	3T10	Stereo BR Unit / Ext Deck Lines 1 And 2 / Operator Assistant
	3T11	Stereo BR Unit / Ext Deck Line 3 / Operator Assistant
	3T12	Stereo BR Unit / Ext Deck Lines Relief / Operator Assistant
	3T21	Stereo BR Unit / Disc / Operator Assistant
	3T30	Stereo BR Unit / Tank Farm / Operator Assistant
	3T31	Stereo BR Unit / Reactor Area / Operator Assistant
	3T32	Stereo BR Unit / Coagulation Recovery / Operator Assistant
	3T33	Stereo BR Unit / Utility Reactor / Operator Assistant
	3T36	Stereo BR Unit / Control Room / Operator Assistant
	6T13	Stereo BR Unit / Inspector Disc / Process Assistant
	6T14	Stereo BR Unit / Crate Make Up Disc / Process Assistant
	6T15	Stereo BR Unit / A Stacker Disc / Process Assistant
	6T16	Stereo BR Unit / C Stacker Disc / Process Assistant
	6T17	Stereo BR Unit / Baler Relief Disc / Process Assistant
	6T19	Stereo BR Unit / Material Receiver Days Disc / Process Assistant
	6T20	Stereo BR Unit / Trucker Disc / Process Assistant
	6T21	Stereo BR Unit / Clean Up / Process Assistant
	6T22	Stereo BR Unit / Packaging / Process Assistant
812	1C37	Copolymer NBR / Energy Conservation North End / Operator
	1C38	Copolymer NBR / Energy Conservation South End Disc / Operator
813	1C01	Copolymer NBR / Tank Farm / Operator
	3C02	Copolymer NBR / Tank Farm / Operator Assistant
815	1C03	Copolymer NBR / # 1 Reactor Building / Operator
	1C05	Copolymer NBR / #2 Reactor Building / Operator
	3C04	Copolymer NBR / #1 Reactor Bldg / Operator Assistant
	3C06	Copolymer NBR / #2 Reactor Bldg / Operator Assistant
817	1C10	Copolymer NBR / Recovery / Operator
	1C36	Copolymer NBR / Recovery Days / Operator
	3C11	Copolymer NBR / Recovery / Operator Assistant
	3C12	Copolymer NBR / #1 Compressor House Disc / Operator Assistant
	3C13	Copolymer NBR / #2 Compressor House / Operator Assistant
820	1C40	Copolymer NBR / Finishing and Holding Tank / Operator
	3C16	Copolymer NBR / Blend Tanks / Operator Assistant

Table C. List of Sarnia job codes assigned to a corresponding job in the job-exposure matrix (JEM) used in the mortality study

JEM job	Sarnia job code	Sarnia job code text translation
	3C17	Copolymer NBR / Coag Deck Lines 2 To 4 Disc / Operator Assistant
	3C18	Copolymer NBR / Coag Deck Lines 5 To 7 Disc / Operator Assistant
	3C19	Copolymer NBR / Coag Deck Relief Disc / Operator Assistant
	3C25	Copolymer NBR / Coag Deck Line 9 Disc / Operator Assistant
	3C39	Copolymer NBR / Coag Deck Lines 2 to 7 Disc / Operator Assistant
	3C42	Copolymer NBR / Coag Deck Lines 5 and 6 Disc / Operator Assistant
	3C44	Copolymer NBR / Coag Deck Lines 1 and 2 Disc / Operator Assistant
832	3C41	Copolymer NBR / Finishing / Operator Assistant
	3C43	Copolymer NBR / Finishing Relief / Operator Assistant
	5C30	Copolymer NBR / Line 9 Days Disc / Material Receiver
834	1C24	Copolymer NBR / Line 9 Disc / Operator
	3C26	Copolymer NBR / Driers Line 9 Disc / Operator Assistant
	3C29	Copolymer NBR / Driers Line 2 To 7 Disc / Operator Assistant
835	1C39	Copolymer NBR / Polytainers Disc / Operator
	1Z01	Distribution / Polytainers / Operator
	3C38	Copolymer NBR / Refeed Disc / Operator Assistant
	6C27	Copolymer NBR / Reclaim Disc / Process Assistant
	6C32	Copolymer NBR / Balers 2 To 7 / Process Assistant
	6C33	Copolymer NBR / Loader Stackers / Process Assistant
	6C34	Copolymer NBR / Polytainers Disc / Process Assistant
852	1A01	Operator – Latex
	1A11	Operator – Latex
	4A04	Latex Handler, Material Controller – Latex
	4A15	Latex Handler, Material Controller - Latex
910	3C08	Copolymer NBR / Chains / Laboratory Technician
	3C09	Copolymer NBR / D Group / Laboratory Technician
	3C28	Copolymer NBR / Control Lab Disc / Lab Technician
	3C37	Copolymer NBR / Field Lab Days Disc / Lab Technician
	3C40	Copolymer NBR / Finished Product / Laboratory Technician
920	1H05	Biox Unit / Environmental Control Lab / Operator
	3L01	Petrochem / Lab Unit Sampler / Lab Technician
	3L02	Petrochem Main Lab / Mass Spec / Cylinder Cleaner / Lab Technician

BE=Butadiene extraction; BR=Butadiene rubber; IB=Isobutylene plant; NBR=Nitrobutyl rubber.

APPENDIX D

Year-Specific Measured and Estimated BD ppm for Fifteen Jobs/Year Combinations with 100+ Measurements

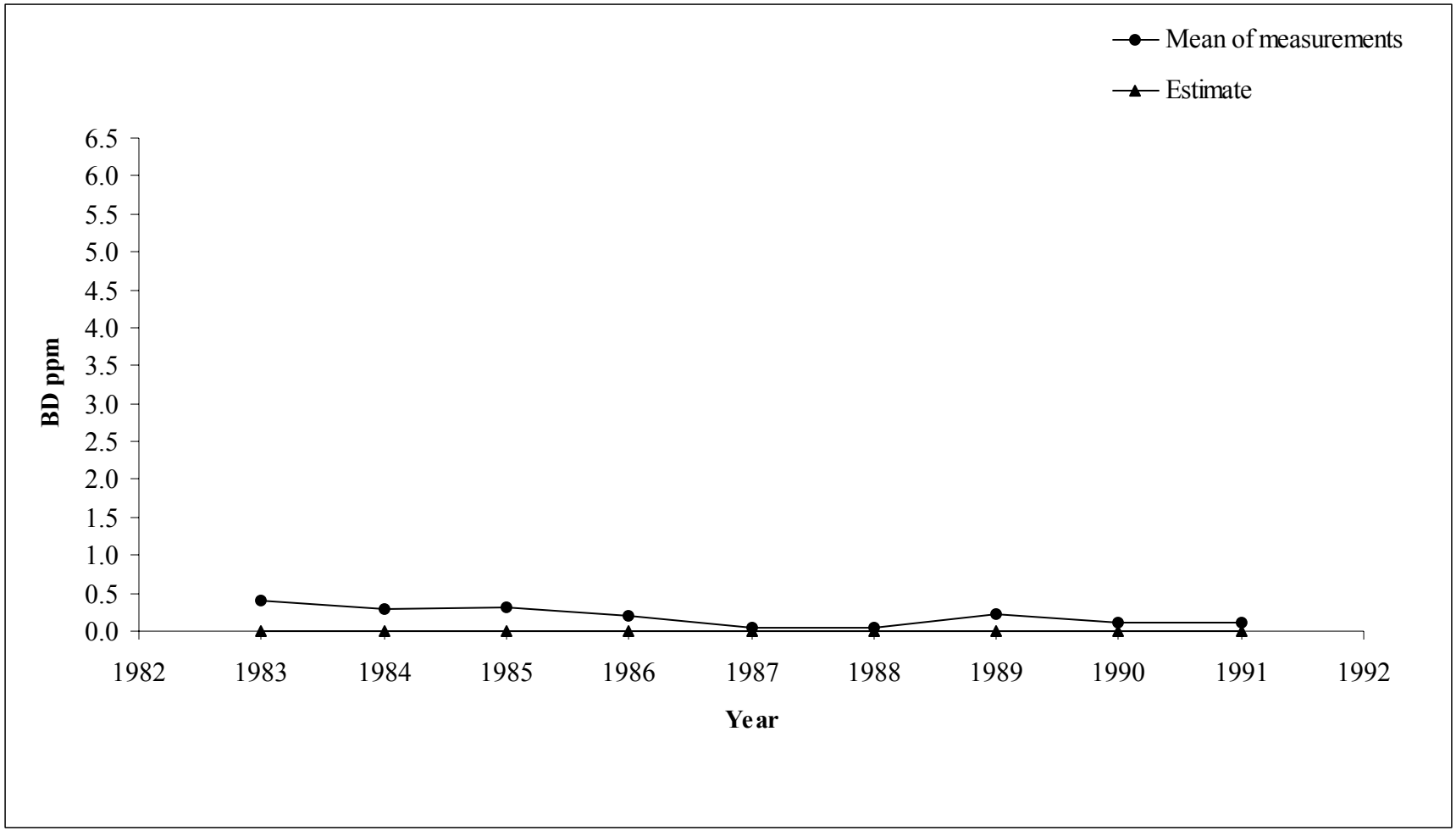

Figure D1. Year-specific measured and estimated BD concentrations for primary typical job 600 (utilities, operative, unspecified/ miscellaneous) with 114 measurements

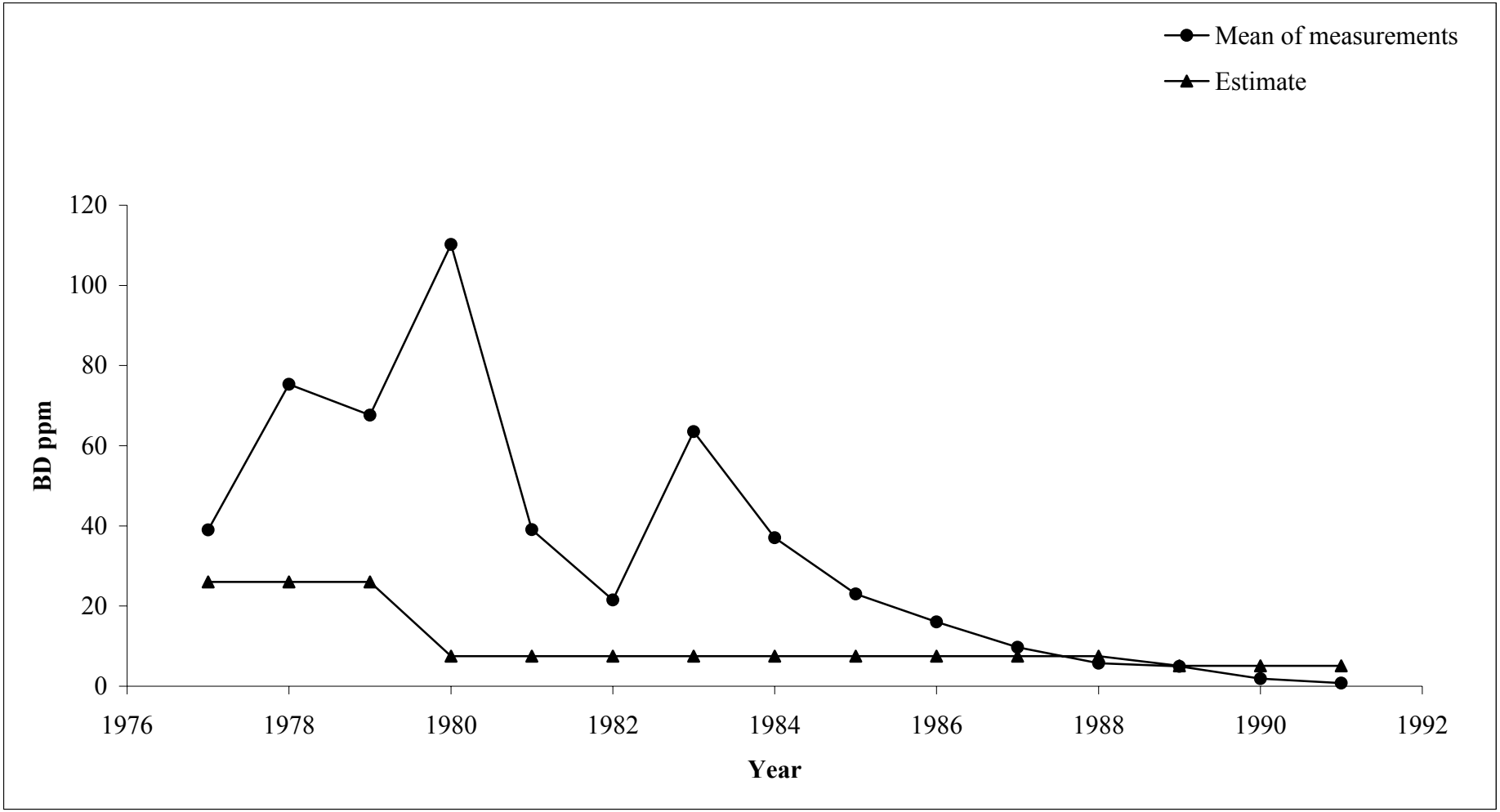

Figure D2. Year-specific measured and estimated bd concentrations for primary typical job 813 (rubber production, polymerization (sbr), tank farm, transfer) with 231 measurements

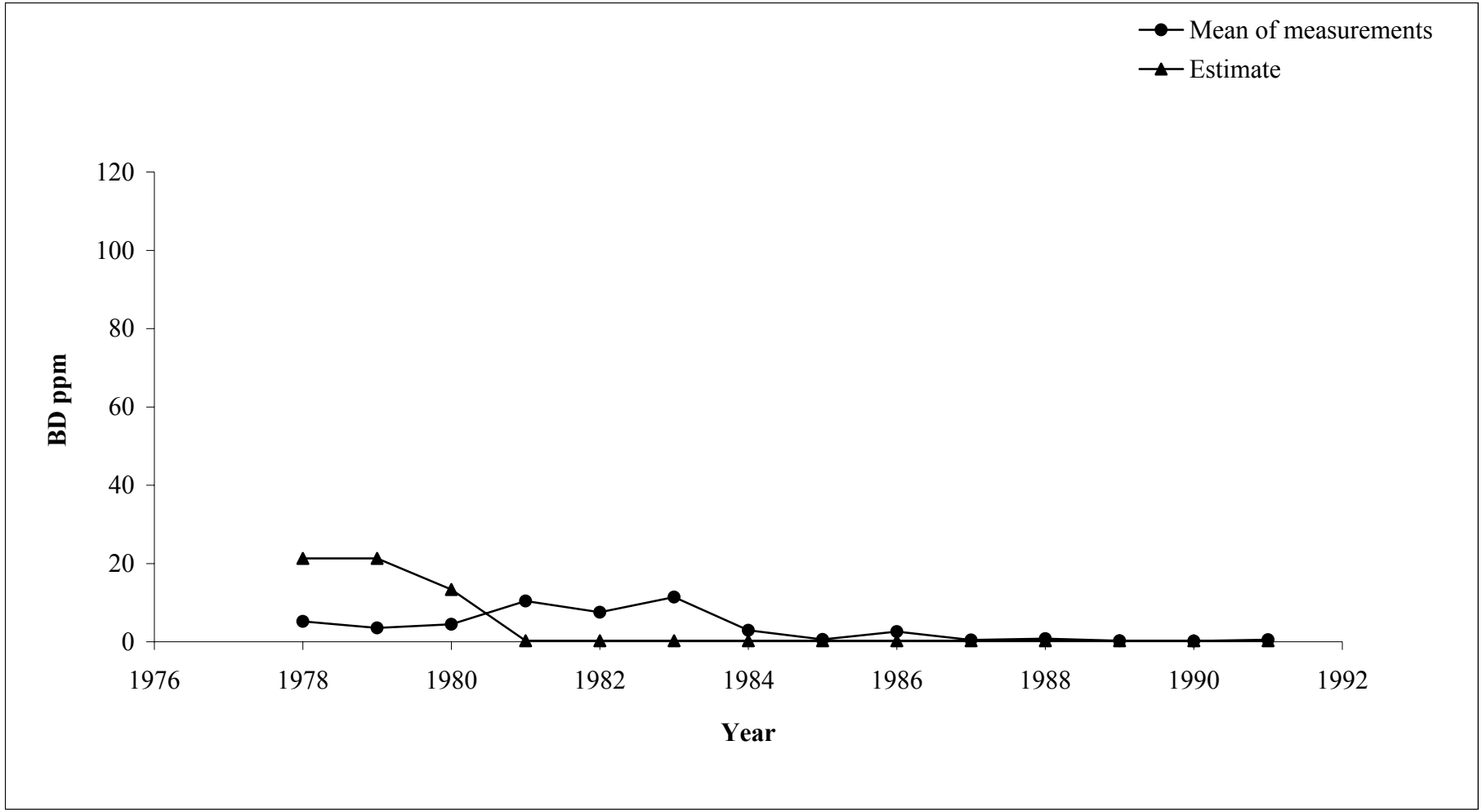

Figure D3. Year-specific measured and estimated BD concentrations for primary typical job 815 (rubber production, polymerization (SBR), reactor, blowdown, panel board) with 261 measurements

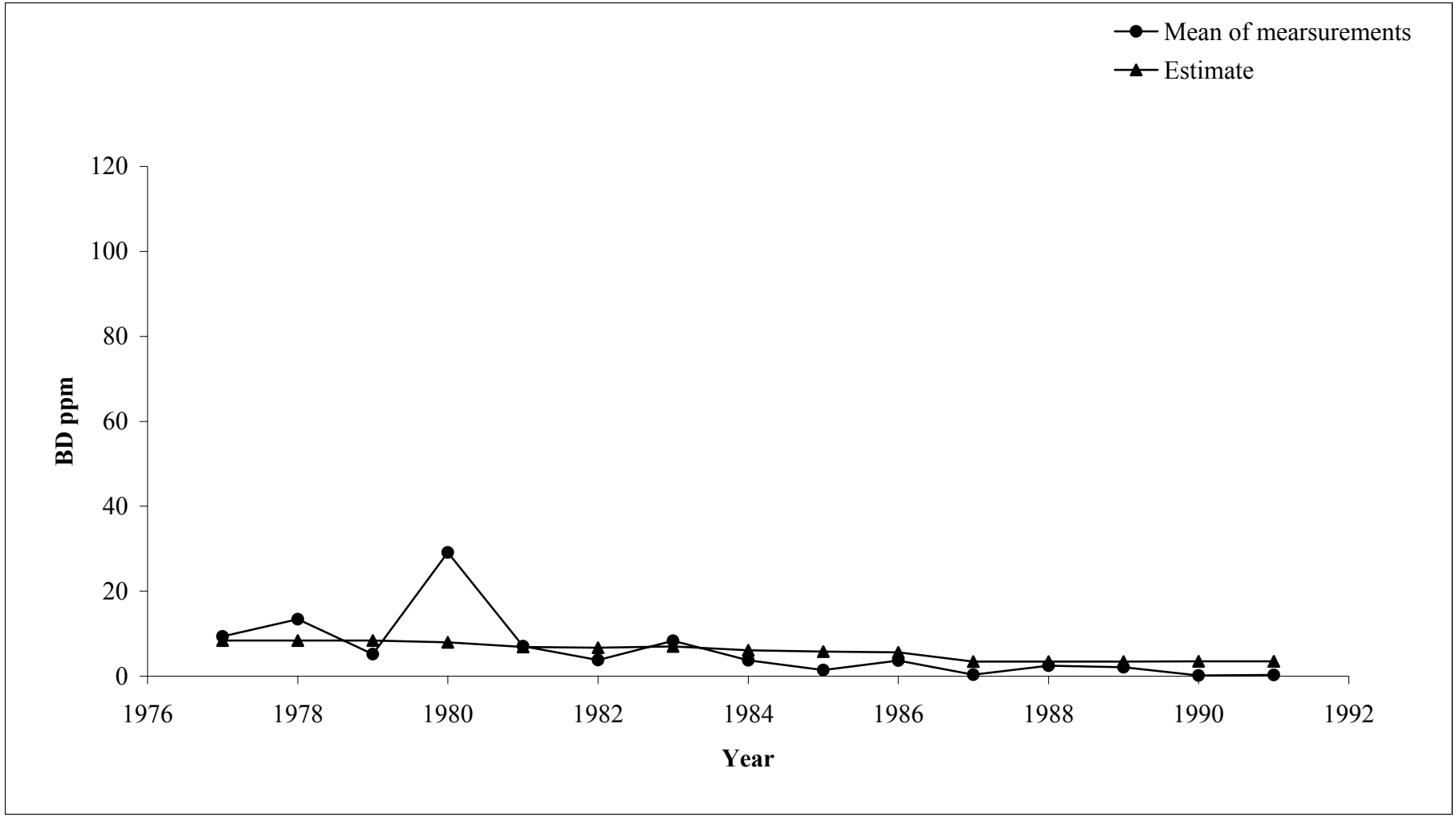

Figure D4. Year-specific measured and estimated BD concentrations for primary typical job 817 (rubber production, polymerization (SBR), recovery, compressor house, high solids recovery) with 333 measurements

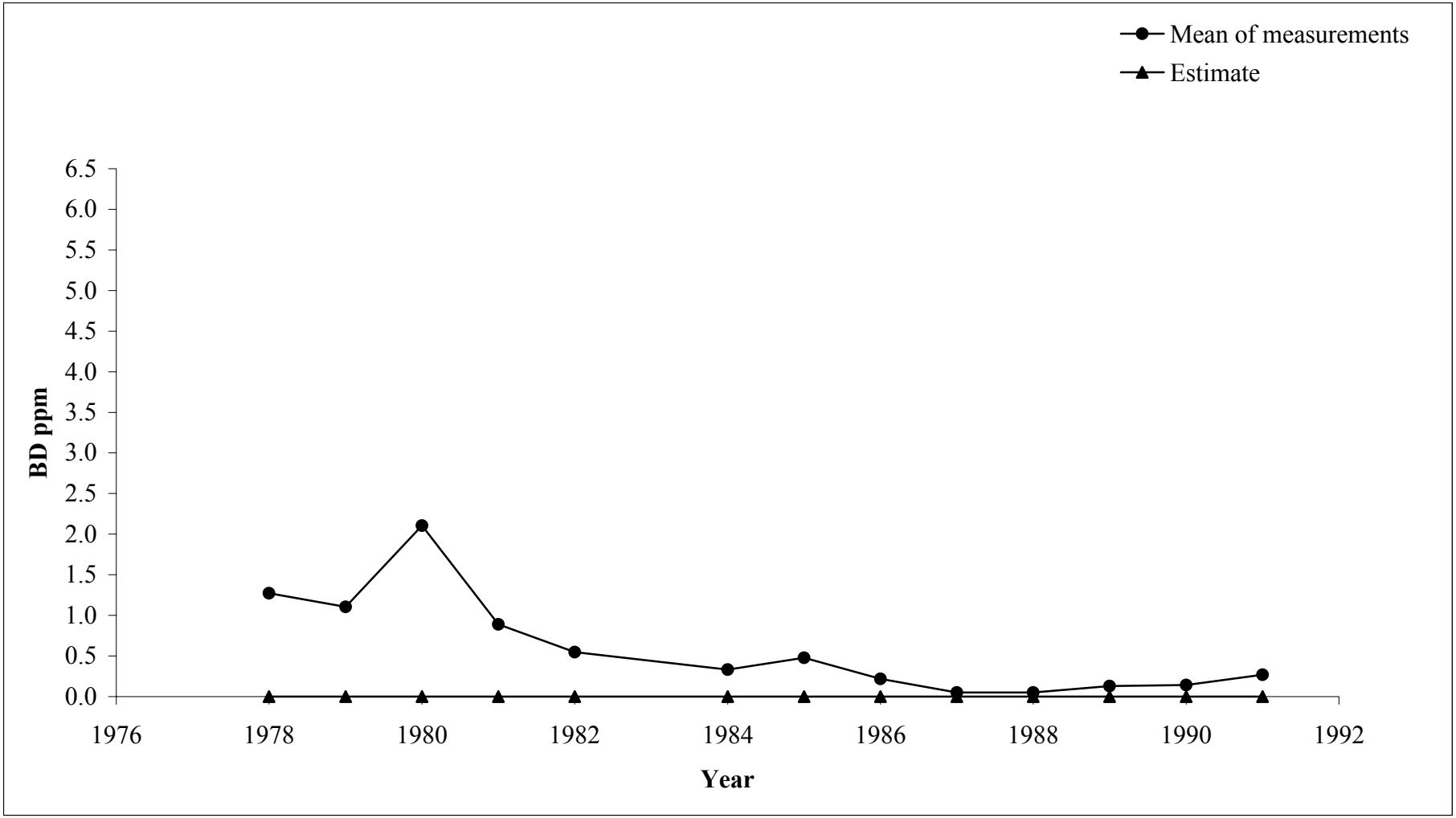

Figure D5. Year-specific measured and estimated BD concentrations for primary typical job 820 (rubber production, coagulation/ blending/solutions prep carbon black (SBR)) with 314 measurements

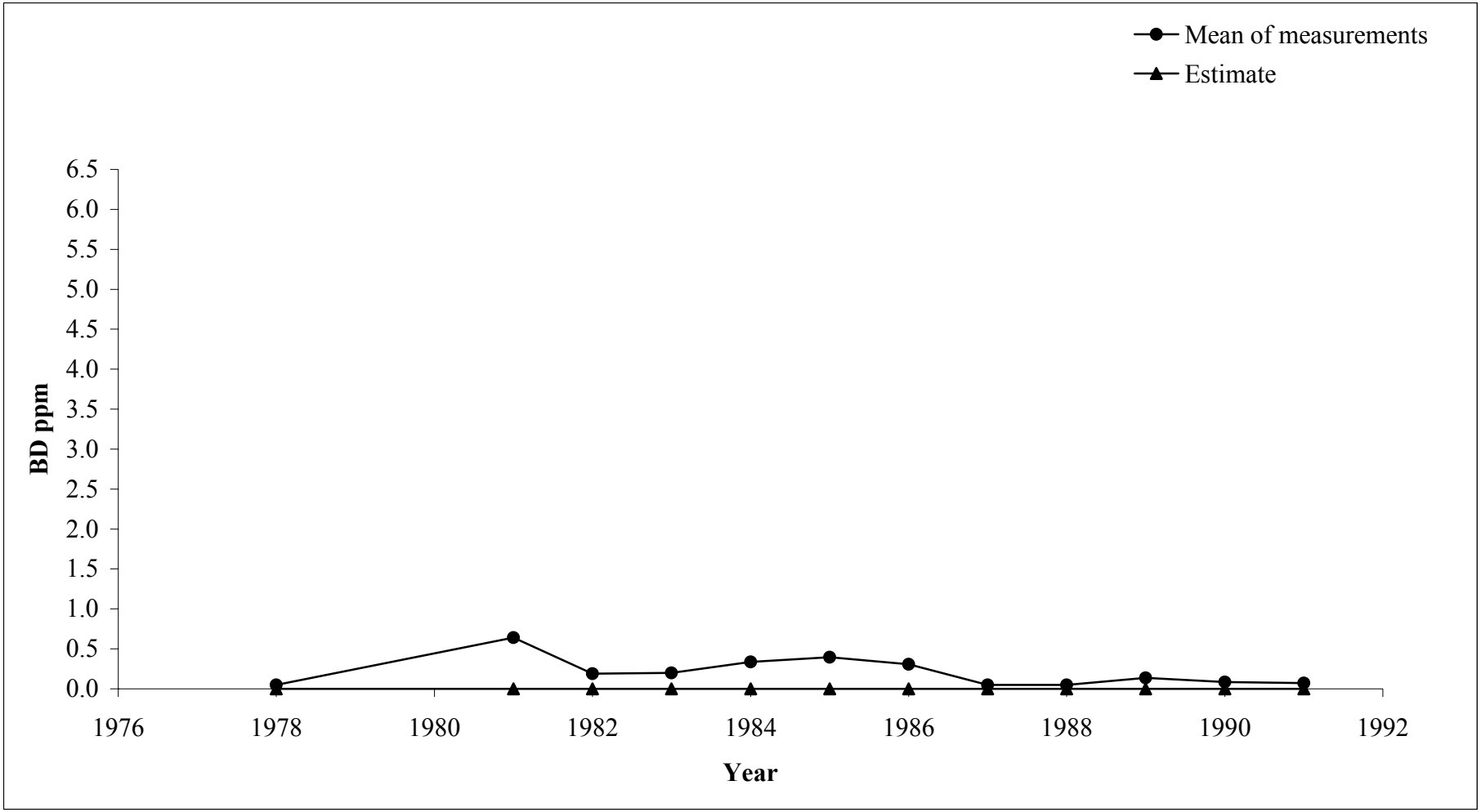

Figure D6. Year-specific measured and estimated BD concentrations for primary typical job 835 (rubber production, finishing (SBR), baler, packager, reclaim) with 111 measurements

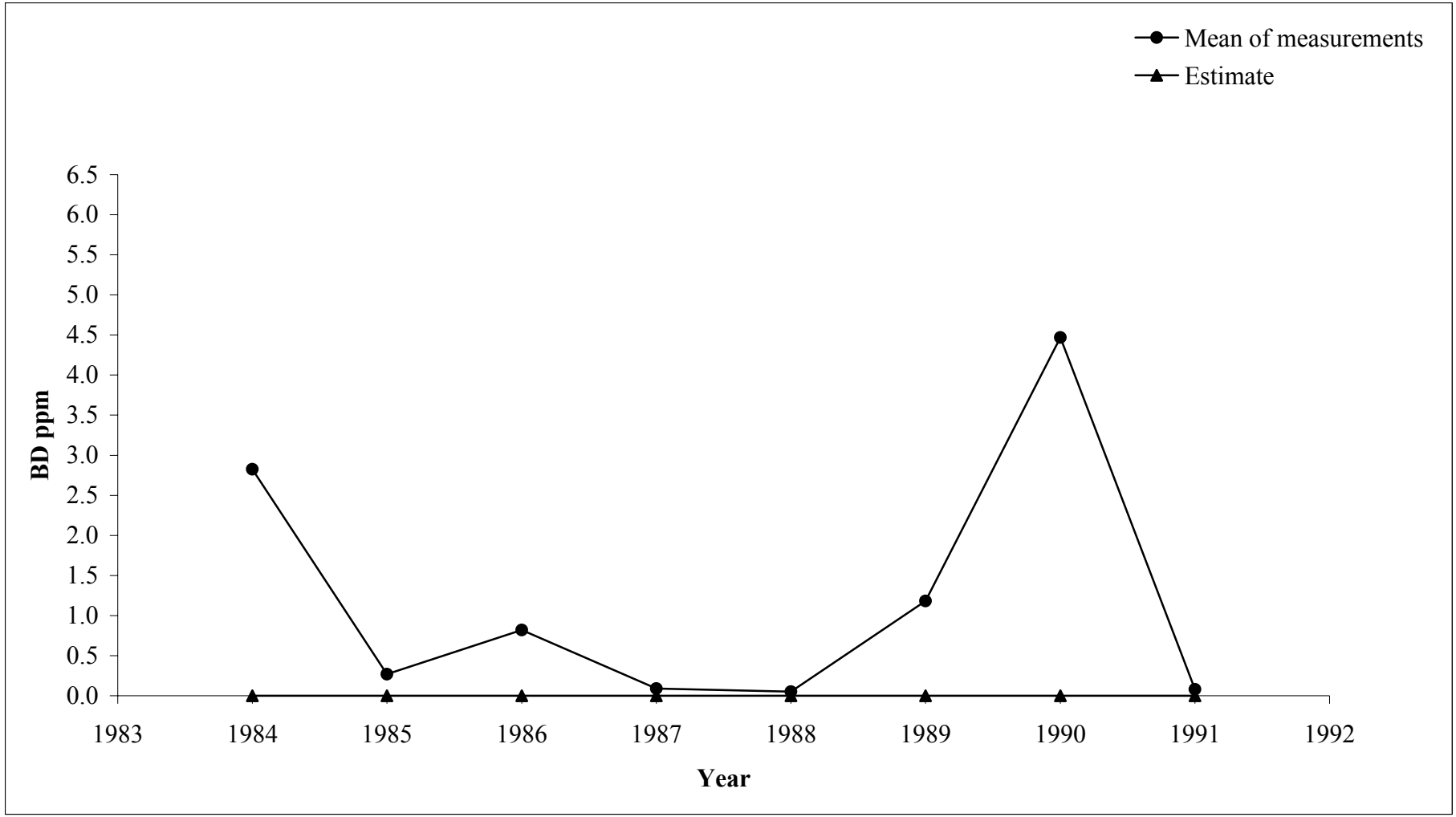

Figure D7. Year-specific measured and estimated BD concentrations for primary other operations job 471 (feed prep, other, maintenance, operative) with 112 measurements

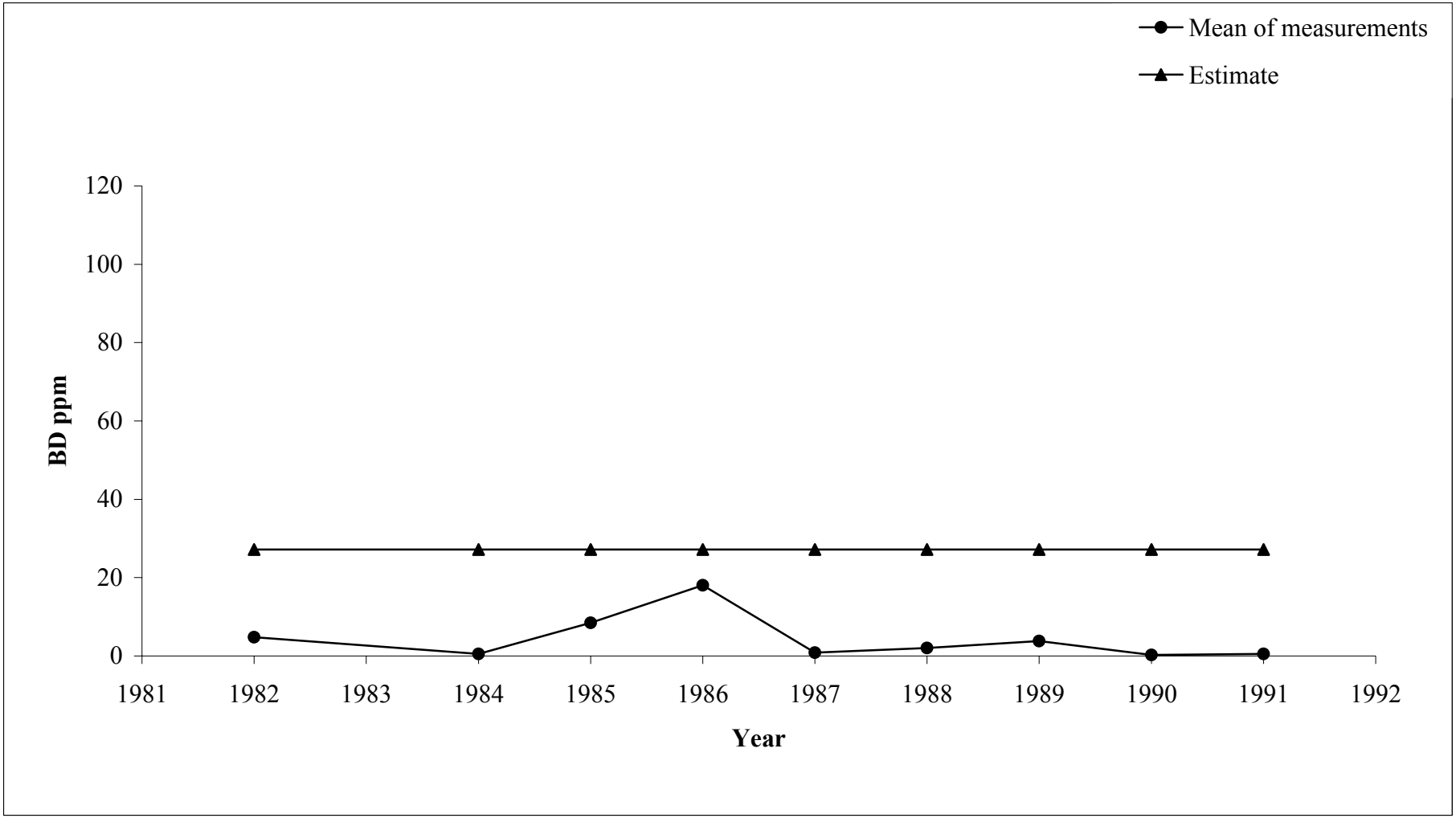

Figure D8. Year-specific measured and estimated BD concentrations for primary other operations job 704 (butadiene production, butadiene extraction, compressor house) with 136 measurements

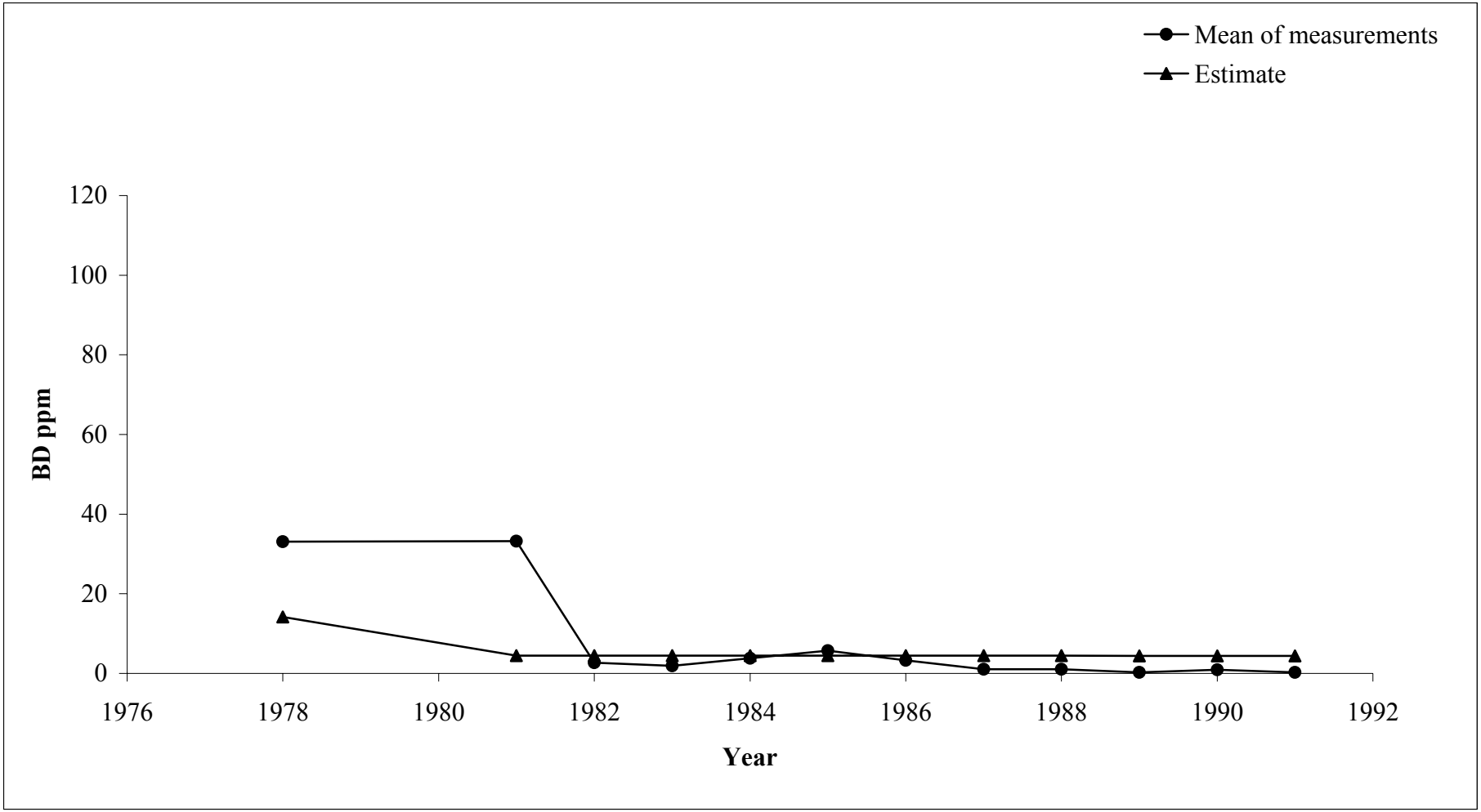

Figure D9. Year-specific measured and estimated BD concentrations for secondary typical job 513 (maintenance, production, maintenance field, pipefitter/oiler/mechanic/blacksmith/ boilermaker/outside machinist) with 250 measurements

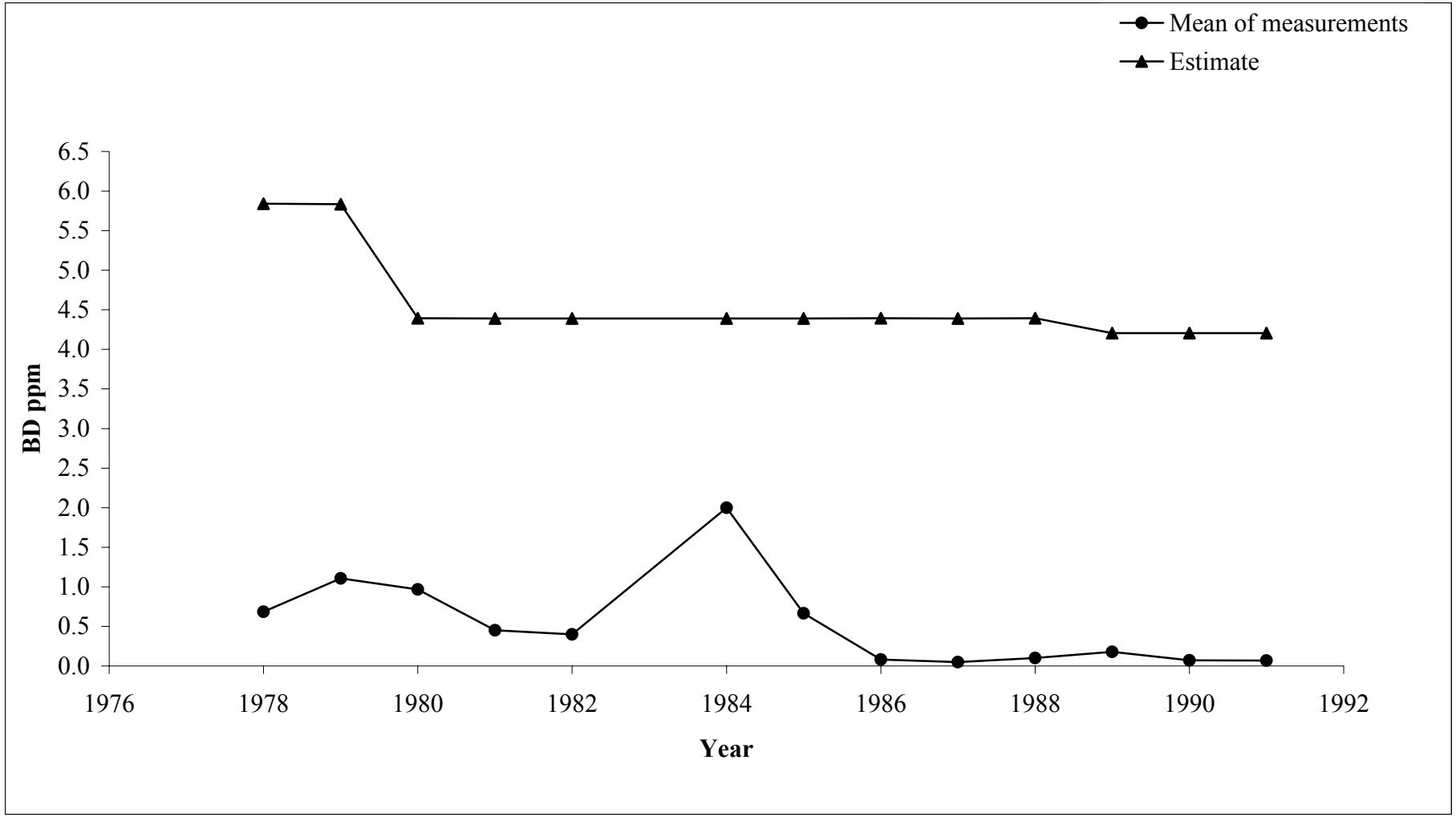

Figure D10. Year-specific measured and estimated BD concentrations for secondary typical job 605 (utilities, copolymer effluent operative) with 103 measurements

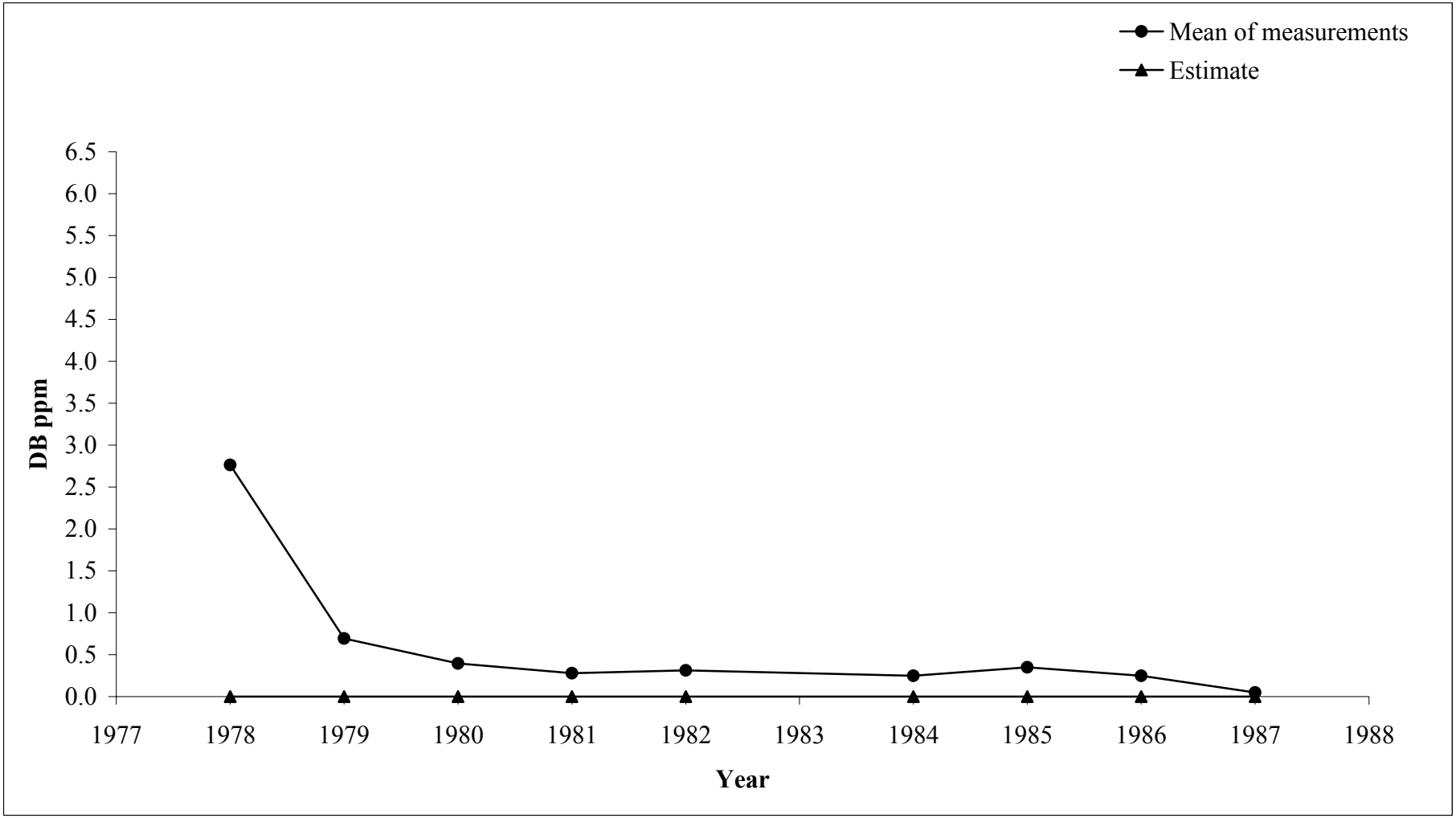

Figure D11. Year-specific measured and estimated BD concentrations for secondary typical job 834 (rubber production, polymerization (SBR), dryer, dryer baler, baler dryer) with 134 measurements

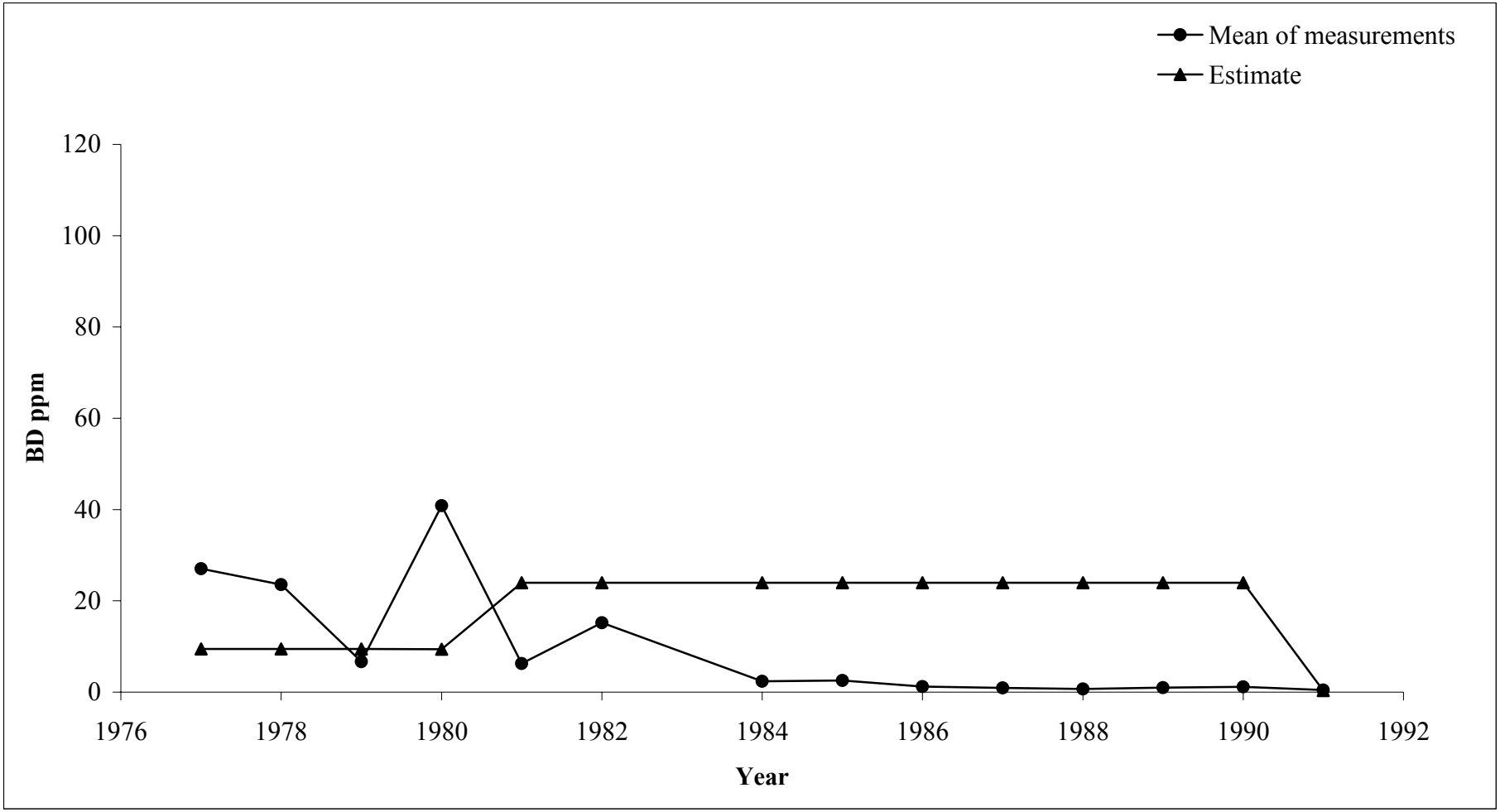

Figure D12. Year-specific measured and estimated BD concentrations for secondary typical job 910 (technical/lab, rubber control, technician) with 210 measurements

Figure D13. Year-specific measured and estimated BD concentrations for secondary other operations job 482 (stereo maintenance, operative) with 337 measurements

Figure D14. Year-specific measured and estimated BD concentrations for secondary other operations job523 (maintenance butadiene, maintenance field, minimum experience: foreman, engineer) with 136 measurements

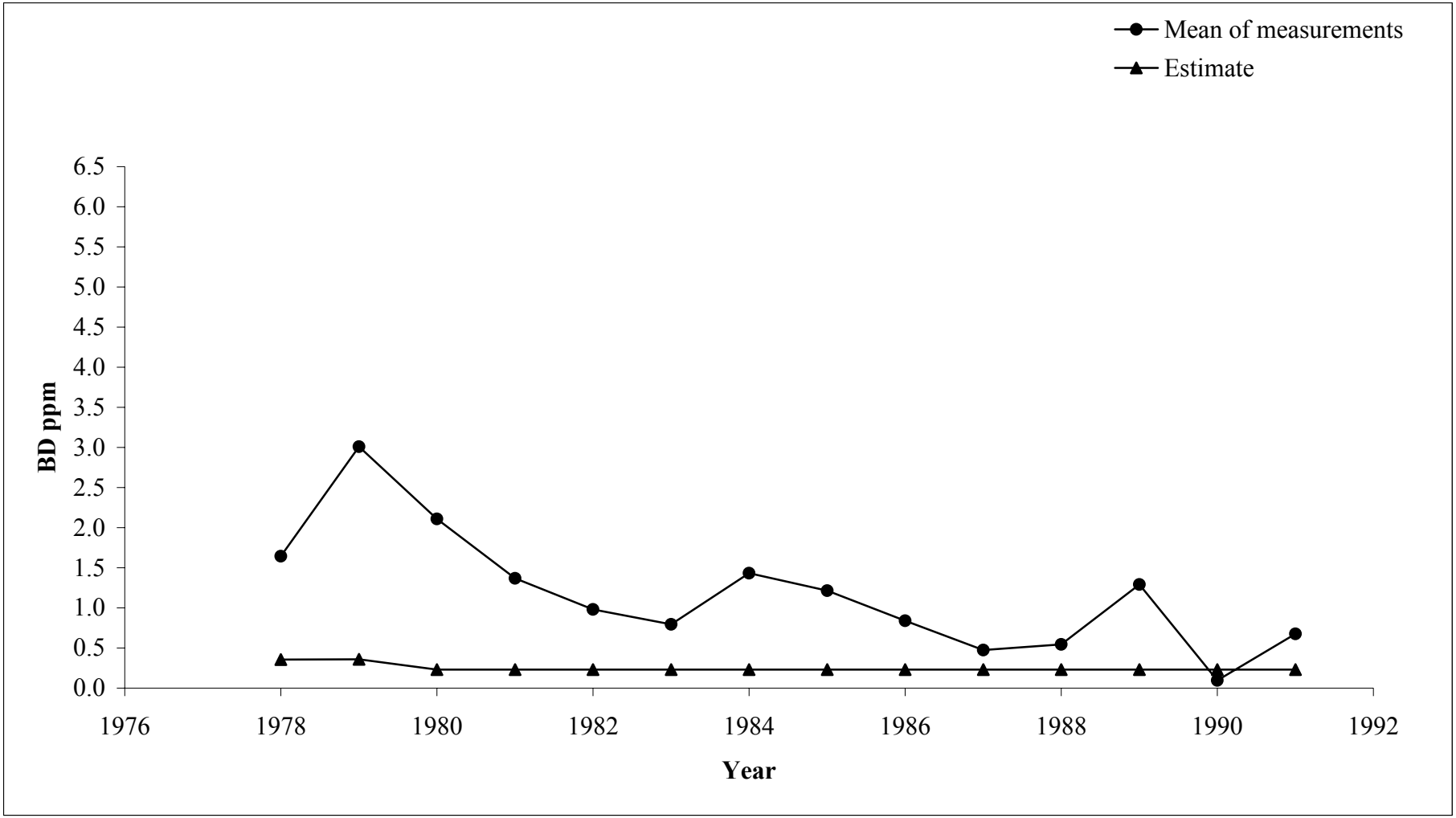

Figure D15. Year-specific measured and estimated BD concentrations for secondary other operations job 772 (stereo production, operative) with 1,392 measurements

APPENDIX E

Summary Data on Measured and Estimated BD ppm for 306 Job/Year Combinations

Table E. Summary data on measured and estimated BD ppm, for the 306 job/year combinations

Job	Year	N	Measurements		Estimate	Estimate minus mean (SD)	Estimate minus median	Weight†
			Mean (SD)*	Median				
300	1988	4	0.04 (0.03)	0.05	0.00	-0.04 (0.03)	-0.05	0.02490665
300	1989	8	0.13 (0.08)	0.13	0.00	-0.13 (0.08)	-0.13	0.025629983
300	1990	8	0.09 (0.02)	0.08	0.00	-0.09 (0.02)	-0.08	0.02593036
300	1991	4	0.07 (0.06)	0.07	0.00	-0.07 (0.06)	-0.07	0.025377108
330	1979	10	2.1 (2.0)	1.3	18.5	16.41 (1.9)	17.2	0.005291104
330	1980	10	3.8 (4.4)	2.1	4.5	0.76 (4.5)	2.5	0.005178634
330	1981	11	1.6 (0.72)	1.6	4.5	3.0 (0.72)	2.9	0.004631005
330	1982	8	6.6 (10.0)	2.2	4.5	-2.1 (10.3)	2.3	0.003378508
330	1983	1	1.0	1.0	4.5	3.5	3.5	0.002230944
330	1984	10	4.3 (3.3)	4.5	4.5	0.24 (3.4)	0.06	0.003035109
330	1985	7	1.9 (1.8)	1.1	4.5	2.6 (1.8)	3.4	0.002589119
330	1986	6	3.3 (3.3)	2.2	4.5	1.3 (3.3)	2.4	0.002682203
330	1987	4	5.4 (10.0)	0.52	4.5	-0.93 (10.1)	4.0	0.003327516
330	1988	8	0.55 (0.66)	0.28	4.5	4.0 (0.70)	4.2	0.002543109
330	1989	4	10.3 (13.0)	5.2	4.5	-5.8 (13.1)	-0.88	0.002413935
330	1990	4	0.28 (0.33)	0.13	4.5	4.2 (0.33)	4.4	0.003318449
330	1991	1	0.02	0.02	4.5	4.5	4.5	0.002405015
471	1984	24	2.8 (5.8)	0.45	0.00	-2.8 (5.8)	-0.45	0.001109626
471	1985	13	0.27 (0.41)	0.10	0.00	-0.27 (0.41)	-0.10	0.001114653
471	1986	22	0.82 (1.7)	0.05	0.00	-0.82 (1.7)	-0.05	0.001157899
471	1987	10	0.09 (0.05)	0.10	0.00	-0.09 (0.05)	-0.10	0.001200735
471	1988	12	0.05 (0.00)	0.05	0.00	-0.05 (0.00)	-0.05	0.00118119
471	1989	11	1.2 (2.2)	0.15	0.00	-1.2 (2.2)	-0.15	0.001160087
471	1990	6	4.6 (10.0)	0.26	0.00	-4.5 (10.4)	-0.26	0.001086658
471	1991	14	0.08 (0.15)	0.03	0.00	-0.08 (0.15)	-0.03	0.000613867
482	1979	1	2.8	2.8	4.7	1.9	1.9	0.008155924
482	1980	8	1.5 (1.4)	1.0	1.1	-0.44 (1.4)	0.07	0.007916512
482	1981	12	0.54 (0.43)	0.40	1.1	0.53 (0.43)	0.67	0.007540752
482	1982	79	0.58 (0.84)	0.30	1.1	0.49 (0.84)	0.77	0.006459215
482	1983	33	4.0 (7.9)	0.40	1.1	-3.0 (7.9)	0.67	0.006315915
482	1984	67	2.5 (11.0)	0.40	1.1	-1.5 (10.5)	0.67	0.007397508
482	1985	18	0.57 (0.48)	0.35	1.1	0.50 (0.48)	0.72	0.006635861
482	1986	29	3.1 (11.0)	0.10	1.1	-2.1 (10.9)	0.97	0.005435783
482	1987	17	0.09 (0.16)	0.05	1.1	0.98 (0.16)	1.0	0.007207699
482	1988	20	0.16 (0.38)	0.05	1.1	0.91 (0.38)	1.0	0.00622868
482	1989	22	0.31 (0.47)	0.13	1.1	0.76 (0.47)	0.94	0.004653062
482	1990	20	0.14 (0.24)	0.08	1.1	0.93 (0.24)	1.0	0.007262255
482	1991	11	0.24 (0.42)	0.11	1.1	0.83 (0.42)	0.97	0.008558824
489	1980	3	0.33 (0.06)	0.30	0.22	-0.11 (0.06)	-0.08	0.000496563
489	1981	7	0.86 (1.2)	0.50	0.22	-0.64 (1.2)	-0.28	0.000467455

Table E. Summary data on measured and estimated BD ppm, for the 306 job/year combinations

Job	Year	N	Measurements		Estimate	Estimate minus mean (SD)	Estimate minus median	Weight†
			Mean (SD)*	Median				
489	1982	7	0.31 (0.38)	0.10	0.22	-0.09 (0.38)	0.12	0.000468524
489	1983	3	2.5 (2.4)	1.8	0.22	-2.3 (2.4)	-1.6	0.000531177
489	1984	5	0.86 (0.63)	0.70	0.22	-0.64 (0.63)	-0.48	0.00020092
489	1985	2	0.70 (0.14)	0.70	0.22	-0.48 (0.14)	-0.48	0.000558858
489	1986	2	0.50 (0.28)	0.50	0.22	-0.28 (0.28)	-0.28	0.000358473
511	1986	1	0.70	0.70	1.2	0.48	0.48	0.000961215
511	1988	4	0.11 (0.13)	0.05	1.2	1.1 (0.13)	1.1	0.000590595
511	1989	4	0.19 (0.16)	0.18	1.2	0.96 (0.16)	0.97	0.000580044
511	1990	4	0.08 (0.04)	0.07	1.2	1.1 (0.04)	1.1	0.001067167
511	1991	2	0.38 (0.35)	0.38	1.2	0.78 (0.35)	0.78	0.000245547
512	1984	7	1.5 (2.1)	0.20	2.6	11.0 (2.1)	2.4	0
512	1985	7	0.70 (0.17)	0.70	2.6	1.9 (0.2)	1.8	0
512	1986	15	6.8 (16.0)	0.20	2.6	-4.2 (15.6)	2.4	0
512	1987	6	0.37 (0.75)	0.05	2.6	2.2 (0.75)	2.5	0
512	1988	5	0.30 (0.34)	0.10	2.6	2.3 (0.34)	2.4	0
512	1989	8	0.18 (0.12)	0.19	2.5	2.3 (0.12)	2.3	0
512	1990	5	0.32 (0.32)	0.09	2.5	2.1 (0.32)	2.4	0.001958908
512	1991	3	0.44 (0.36)	0.63	2.5	2.0 (0.36)	1.8	0.00233606
513	1978	6	33.1 (38.0)	18.6	14.2	-18.9 (37.6)	-4.7	0.017376468
513	1981	4	33.2 (49.0)	12.5	4.5	-28.7 (48.5)	-7.9	0.016820692
513	1982	2	2.7 (0.85)	2.7	4.5	1.8 (0.85)	1.8	0.01521099
513	1983	23	1.9 (3.9)	0.60	4.5	2.6 (3.9)	3.9	0.014085655
513	1984	88	3.8 (11.0)	1.0	4.5	0.70 (10.8)	3.5	0.013654947
513	1985	40	5.7 (7.2)	3.2	4.5	-1.3 (7.2)	1.3	0.012746548
513	1986	40	3.3 (4.8)	1.6	4.5	1.2 (4.8)	2.7	0.012381593
513	1987	12	1.1 (2.2)	0.20	4.5	3.4 (2.2)	4.3	0.008745627
513	1988	11	1.1 (2.1)	0.16	4.5	3.4 (2.1)	4.3	0.006772479
513	1989	8	0.25 (0.19)	0.20	4.4	4.1 (0.19)	4.2	0.004910506
513	1990	4	0.93 (1.7)	0.09	4.4	3.4 (1.7)	4.3	0.004189075
513	1991	12	0.26 (0.29)	0.04	4.4	4.1 (0.29)	4.3	0.004297071
519	1978	12	1.9 (1.8)	1.5	5.8	3.9 (1.8)	4.4	0
519	1979	3	2.4 (3.4)	0.50	5.8	3.4 (3.4)	5.3	0
519	1980	13	0.4 (0.27)	0.30	4.4	4 (0.27)	4.1	0
519	1981	8	1.9 (2.8)	0.60	4.4	2.5 (2.8)	3.8	0
519	1982	16	1.2 (0.86)	0.90	4.4	3.2 (0.86)	3.5	0
519	1983	9	3.1 (6.1)	0.20	4.4	1.3 (6.2)	4.2	0
519	1984	11	0.78 (0.9)	0.50	4.4	3.6 (0.90)	3.2	0
519	1986	2	0.05 (0.00)	0.05	4.4	4.3 (0.00)	4.3	0
521	1984	1	0.30	0.30	0.10	-0.03	-0.03	0.001225307
521	1985	2	0.75 (0.35)	0.75	0.10	-0.48 (0.35)	-0.48	0.000718094
521	1986	3	0.10 (0.09)	0.05	0.10	0.17 (0.09)	0.22	0.00057895
521	1987	3	0.05 (0.00)	0.05	0.10	0.22 (0.00)	0.22	0.000600367
521	1988	3	0.05 (0.00)	0.05	0.10	0.22 (0.00)	0.22	0.000590595

Table E. Summary data on measured and estimated BD ppm, for the 306 job/year combinations

Job	Year	N	Measurements		Estimate	Estimate minus mean (SD)	Estimate minus median	Weight†
			Mean (SD)*	Median				
521	1989	4	0.12 (0.09)	0.10	0.10	0.15 (0.09)	0.17	0.000580044
521	1990	2	0.16 (0.18)	0.16	0.10	0.11 (0.18)	0.11	0.000565257
523	1979	4	239.8 (449.0)	16.8	11.9	-227.9 (449.5)	-4.9	0.001569274
523	1980	5	16.5 (20.0)	4.5	2.8	-13.7 (20.1)	-1.7	0.002457036
523	1981	17	11.0 (19.0)	3.4	2.8	-8.3 (19.2)	-0.63	0.004290339
523	1982	5	22.9 (47.0)	2.0	2.8	-20.2 (47.3)	0.77	0.003370807
523	1983	3	7.3 (12.0)	0.70	2.8	-4.5 (11.6)	2.1	0.004661262
523	1984	34	4.1 (11.0)	0.70	2.8	-1.4 (10.7)	2.1	0.00563337
523	1985	17	15.6 (23.0)	1.7	2.8	-12.9 (22.9)	1.1	0.006433753
523	1986	10	0.33 (0.31)	0.20	2.8	2.4 (0.31)	2.6	0.004986898
523	1987	13	0.99 (2.7)	0.10	2.8	1.8 (2.7)	2.7	0.004881892
523	1988	9	0.28 (0.68)	0.05	2.8	2.5 (0.68)	2.7	0.004282621
523	1989	7	0.13 (0.10)	0.12	2.8	2.6 (0.10)	2.7	0.002332888
523	1990	5	0.15 (0.10)	0.10	2.8	0.10	2.7	0.002371481
523	1991	7	0.13 (0.21)	0.03	2.8	2.6 (0.21)	2.7	0.001205871
585	1984	24	0.60 (0.73)	0.40	13.9	13.3 (0.73)	13.5	0.003519144
585	1985	15	1.0 (1.8)	0.60	13.9	12.9 (1.8)	13.3	0.004233538
585	1986	14	0.15 (0.14)	0.10	13.9	13.8 (0.14)	13.8	0.004668079
585	1987	7	0.09 (0.06)	0.05	13.9	13.8 (0.06)	13.9	0.004000257
585	1988	3	0.60 (0.95)	0.05	13.9	13.3 (0.95)	13.9	0.001878286
586	1984	6	0.60 (0.79)	0.30	13.9	13.3 (0.79)	13.6	0.000172
586	1985	3	0.25 (0.18)	0.30	13.9	13.7 (0.18)	13.6	0.000154643
586	1986	6	0.11 (0.07)	0.08	13.9	13.8 (0.07)	13.8	0
593	1982	1	0.05	0.05	0.00	-0.05	-0.05	0.023326085
593	1986	16	0.09 (0.08)	0.05	0.00	-0.09 (0.08)	-0.05	0.024493538
593	1987	4	0.05 (0.00)	0.05	0.00	-0.05 (0.00)	-0.05	0.023981801
593	1989	2	0.16 (0.06)	0.16	0.00	-0.16 (0.06)	-0.16	0.023201746
593	1990	1	0.15	0.15	0.00	-0.15	-0.15	0.023383454
600	1983	8	0.41 (0.64)	0.15	0.00	-0.41 (0.64)	-0.15	0.009137703
600	1984	8	0.29 (0.22)	0.20	0.00	-0.29 (0.22)	-0.20	0.008883098
600	1985	12	0.32 (0.50)	0.10	0.00	-0.32 (0.50)	-0.10	0.008434923
600	1986	40	0.20 (0.29)	0.10	0.00	-0.2 (0.29)	-0.10	0.008768312
600	1987	19	0.05 (0.00)	0.05	0.00	-0.05 (0.00)	-0.05	0.009040054
600	1988	5	0.05 (0.00)	0.05	0.00	-0.05 (0.00)	-0.05	0.008712083
600	1989	4	0.22 (0.12)	0.21	0.00	-0.22 (0.12)	-0.21	0.009673221
600	1990	6	0.11 (0.07)	0.07	0.00	-0.11 (0.07)	-0.07	0.010621312
600	1991	12	0.10 (0.14)	0.04	0.00	-0.10 (0.14)	-0.04	0.011049612
605	1978	38	0.69 (0.49)	0.50	5.8	5.2 (0.49)	5.3	0.004403805
605	1979	13	1.1 (2.1)	0.50	5.8	4.7 (2.1)	5.3	0.004677726
605	1980	6	0.97 (0.73)	0.90	4.4	3.4 (0.73)	3.5	0.004272339
605	1981	7	0.45 (0.30)	0.40	4.4	3.9 (0.30)	4.0	0.003569306
605	1982	8	0.40 (0.20)	0.40	4.4	4.0 (0.20)	4.0	0.003458093
605	1984	2	2.0 (2.0)	2.0	4.4	2.4 (2.0)	2.4	0.003459781

Table E. Summary data on measured and estimated BD ppm, for the 306 job/year combinations

Job	Year	N	Measurements		Estimate	Estimate minus mean (SD)	Estimate minus median	Weight†
			Mean (SD)*	Median				
605	1985	3	0.67 (0.55)	0.40	4.4	3.7 (0.55)	4.0	0.003353146
605	1986	5	0.08 (0.03)	0.10	4.4	4.3 (0.03)	4.3	0.003494318
605	1987	4	0.05 (0.00)	0.05	4.4	4.3 (0.00)	4.3	0.003602205
605	1988	7	0.10(0.13)	0.05	4.4	4.3 (0.13)	4.3	0.00352582
605	1989	4	0.18 (0.22)	0.10	4.2	4.0 (0.22)	4.1	0.003480262
605	1990	2	0.07 (0.01)	0.07	4.2	4.1 (0.01)	4.1	0.003557222
605	1991	4	0.07 (0.10)	0.03	4.2	4.1 (0.10)	4.2	0.003683204
704	1982	3	4.8 (6.9)	1.1	27.2	22.4 (6.9)	26.1	0.009251106
704	1984	13	0.52 (0.41)	0.40	27.2	26.7 (0.41)	26.8	0.006097617
704	1985	20	8.5 (16.0)	0.60	27.2	18.7 (16.3)	26.6	0.006668014
704	1986	16	18.1 (49.0)	1.3	27.2	9.1 (49.4)	25.9	0.006692024
704	1987	18	0.88 (1.5)	0.05	27.2	26.3 (1.5)	27.2	0.007732404
704	1988	43	2.0 (5.4)	0.05	27.2	25.2 (5.4)	27.2	0.008368376
704	1989	11	3.8 (9.0)	0.44	27.2	23.4 (9.0)	26.8	0.008289062
704	1990	7	0.23 (0.26)	0.08	27.2	27.0 (0.26)	27.1	0.008300184
704	1991	5	0.53 (0.99)	0.10	27.2	27.0 (0.99)	27.1	0.009113828
731	1988	5	0.05 (0.00)	0.05	0.00	-0.05 (0.00)	-0.05	0
731	1989	1	0.15	0.15	0.00	-0.15	-0.15	0
731	1990	4	0.09 (0.08)	0.06	0.00	-0.09 (0.08)	-0.06	0.000126696
731	1991	1	0.09	0.09	0.00	-0.09	-0.09	0.000613867
732	1982	3	16.4 (2.2)	15.9	0.00	-16.4 (2.2)	-15.9	0
732	1984	11	0.85 (0.54)	0.80	0.00	-0.85 (0.54)	-0.80	0
732	1985	9	2.2 (6.2)	0.20	0.00	-2.2 (6.2)	-0.20	0
732	1986	5	0.28 (0.30)	0.10	0.00	-0.28 (0.30)	-0.10	0
732	1987	10	0.08 (0.07)	0.05	0.00	-0.08 (0.07)	-0.05	0
732	1988	18	2.1 (8.1)	0.05	0.00	-2.1 (8.1)	-0.05	0
732	1989	12	3.6 (6.2)	1.2	0.00	-3.6 (6.2)	-1.2	0
732	1990	10	4.1 (12.0)	0.09	0.00	-4.1 (12.5)	-0.09	0
732	1991	6	0.70 (1.6)	0.09	0.00	-0.70 (1.6)	-0.09	0
740	1985	3	0.92 (1.4)	0.20	0.00	-0.92 (1.4)	-0.20	0.00028785
740	1986	5	7.5 (16.0)	0.05	0.00	-7.5 (16.4)	-0.05	0.000282337
740	1987	1	3.8	3.8	0.00	-3.8	-3.8	0
740	1988	10	2.0 (3.4)	0.05	0.00	-2.0 (3.4)	-0.05	0.000371139
740	1989	4	2.0 (2.8)	0.81	0.00	-2.0 (2.8)	-0.81	0
740	1990	4	0.16 (0.08)	0.17	0.00	-0.16 (0.08)	-0.17	0
740	1991	2	0.06 (0.05)	0.06	0.00	-0.06 (0.05)	-0.06	0
762	1982	2	7.0 (7.4)	7.0	18.7	11.8 (7.4)	11.7	0.000468524
762	1984	7	2.4 (2.7)	1.2	18.7	16.3 (2.7)	17.5	0

Table E. Summary data on measured and estimated BD ppm, for the 306 job/year combinations

Job	Year	N	Measurements		Estimate	Estimate minus mean (SD)	Estimate minus median	Weight†
			Mean (SD)*	Median				
762	1985	8	0.34 (0.33)	0.15	18.7	18.4 (0.33)	18.5	0
762	1986	8	2.1 (3.0)	0.85	18.7	16.6 (3.0)	17.8	0
762	1987	12	1.1 (2.3)	0.10	18.7	17.6 (2.3)	18.6	0
762	1988	11	1.3 (2.6)	0.17	18.7	17.4 (2.6)	18.5	0
762	1989	11	5.1 (8.2)	0.60	18.7	13.6 (8.2)	18.1	0
762	1990	8	2.4 (5.5)	0.37	18.7	16.3 (5.5)	18.3	0
762	1991	4	0.16 (0.16)	0.11	18.7	18.5 (0.16)	18.6	0
772	1978	9	1.6 (2.6)	0.40	0.36	-1.3 (2.6)	-0.04	0.042079993
772	1979	75	3.0 (5.6)	1.1	0.36	-2.7 (5.6)	-0.74	0.039832324
772	1980	121	2.1 (5.3)	0.50	0.23	-1.9 (5.3)	-0.27	0.039029016
772	1981	129	1.4 (3.6)	0.40	0.23	-1.1 (3.6)	-0.17	0.040156296
772	1982	131	0.98 (2.0)	0.30	0.23	-0.75 (2.0)	-0.07	0.036067375
772	1983	16	0.79 (1.9)	0.20	0.23	-0.56 (1.9)	0.03	0.037162029
772	1984	208	1.4 (3.5)	0.30	0.23	-1.2 (3.5)	-0.07	0.040645197
772	1985	192	1.2 (2.1)	0.30	0.23	-0.99 (2.1)	-0.07	0.038959269
772	1986	155	0.84 (1.9)	0.10	0.23	-0.61 (1.9)	0.13	0.038943488
772	1987	81	0.48 (1.8)	0.05	0.23	-0.25 (1.8)	0.18	0.039652215
772	1988	129	0.55 (2.1)	0.05	0.23	-0.32 (2.1)	0.18	0.037973969
772	1989	58	1.3 (2.3)	0.37	0.23	-1.1 (2.3)	-0.14	0.038899474
772	1990	56	0.10 (0.11)	0.08	0.23	0.13 (0.11)	0.15	0.039707691
772	1991	32	0.68 (2.6)	0.09	0.23	-0.45 (2.6)	0.14	0.040754065
812	1984	6	0.73 (0.70)	0.50	3.6	2.9 (0.70)	3.1	0.010504157
812	1985	4	0.65 (0.58)	0.65	3.6	3.0 (0.58)	3.0	0.010249296
812	1986	3	0.37 (0.12)	0.30	3.6	3.3 (0.12)	3.3	0.008633488
812	1987	7	2.5 (5.8)	0.10	3.2	0.63 (5.8)	3.0	0.001263239
812	1988	4	1.1 (1.0)	1.1	3.2	2.1 (1.0)	2.1	0.00118119
812	1989	3	2.2 (1.3)	1.6	2.8	0.66 (1.3)	1.2	0.001563734
812	1990	4	0.10 (0.01)	0.10	2.8	2.7 (0.01)	2.7	0.000355722
812	1991	4	0.36 (0.36)	0.32	2.8	2.4 (0.36)	2.5	0
813	1977	22	39.0 (40.0)	27.6	26.0	-13.0 (40.0)	-1.5	0.003531047
813	1978	62	75.3 (79.0)	48.8	26.0	-49.3 (78.8)	-22.8	0.004368866
813	1979	17	67.7 (30.0)	53.8	26.0	-41.6 (29.9)	-27.8	0.004796675
813	1980	19	110.2 (145.0)	64.7	7.5	-102.7 (144.8)	-57.2	0.004606094
813	1981	11	39.1 (45.0)	22.4	7.5	-31.6 (44.9)	-14.9	0.003560341
813	1982	27	21.5 (26.0)	14.8	7.5	-14.1 (26.3)	-7.3	0.003512006
813	1983	1	63.5	63.5	7.5	-56.0	-56.0	0.00371824

Table E. Summary data on measured and estimated BD ppm, for the 306 job/year combinations

Job	Year	N	Measurements		Estimate	Estimate minus mean (SD)	Estimate minus median	Weight†
			Mean (SD)*	Median				
813	1984	8	37.0 (22.0)	29.6	7.5	-29.5 (22.5)	-22.1	0.003899674
813	1985	9	23.0 (22.0)	15.4	7.5	-15.5 (22.2)	-7.9	0.003902817
813	1986	11	16.0 (17.0)	12.2	7.5	-8.5 (17.4)	-4.7	0.003735415
813	1987	10	9.8 (7.7)	7.4	7.5	-2.6 (7.7)	0.10	0.003602205
813	1988	23	5.7 (11.0)	2.3	7.5	1.8 (11.1)	5.2	0.003635548
813	1989	4	5.0 (3.7)	4.8	5.1	0.14 (3.7)	0.33	0.003480262
813	1990	5	1.9 (2.5)	0.47	5.1	3.2 (2.5)	4.6	0.003557222
813	1991	2	0.78 (0.16)	0.78	5.1	4.3 (0.16)	4.3	0.003683204
815	1978	71	5.2 (9.4)	2.0	21.3	16.1 (9.4)	19.3	0.000531368
815	1979	15	3.5 (2.3)	3.4	21.3	17.8 (2.3)	17.9	0.000785353
815	1980	30	4.5 (7.9)	1.4	13.3	8.9 (7.9)	12.0	0.000496563
815	1981	21	10.4 (14.0)	4.4	0.23	-10.2 (13.9)	-4.2	0.000783787
815	1982	25	7.6 (9.1)	3.4	0.23	-7.3 (9.2)	-3.2	0.000937048
815	1983	7	11.4 (24.0)	2.9	0.23	-11.2 (24.2)	-2.7	0.001001233
815	1984	20	2.9 (4.9)	1.8	0.23	-2.7 (4.9)	-1.6	0.000557096
815	1985	8	0.63 (0.35)	0.70	0.23	-0.39 (0.35)	-0.47	0.000159236
815	1986	12	2.6 (4.1)	0.45	0.23	-2.3 (4.1)	-0.22	0
815	1987	17	0.49 (0.96)	0.05	0.23	-0.25 (0.96)	0.19	0
815	1988	14	0.78 (1.6)	0.35	0.23	-0.54 (1.6)	-0.12	0
815	1989	8	0.26 (0.18)	0.23	0.23	-0.02 (0.18)	0.00	0
815	1990	9	0.20 (0.23)	0.07	0.23	0.04 (0.23)	0.17	0
815	1991	4	0.52 (0.63)	0.35	0.23	-0.28 (0.63)	-0.11	0
817	1977	22	9.3 (14.0)	4.9	8.4	-0.94 (13.7)	3.5	0.012851433
817	1978	112	13.4 (21.0)	4.4	8.4	-5.0 (21.3)	4.0	0.012378695
817	1979	45	5.2 (9.1)	1.6	8.4	3.2 (9.1)	6.8	0.013660564
817	1980	33	29.1 (94.0)	4.3	8.0	-21.1 (94.5)	3.3	0.012433062
817	1981	28	7.1 (12.0)	4.4	6.9	-0.2 (11.9)	2.9	0.011688934
817	1982	19	3.8 (5.2)	1.9	6.7	2.9 (5.8)	4.5	0.009478308
817	1983	6	8.4 (8.5)	5.6	7.0	-1.3 (8.1)	1.1	0.00946223
817	1984	18	3.8 (7.5)	1.6	6.1	2.4 (7.5)	4.4	0.00891354
817	1985	13	1.4 (1.4)	1.0	5.8	4.4 (2.3)	4.0	0.008866698
817	1986	15	3.7 (5.6)	1.5	5.6	2.0 (5.5)	3.5	0.006503271
817	1987	6	0.40 (0.38)	0.29	3.5	3.1 (0.38)	3.2	3.94762E-05
817	1988	5	2.5 (2.7)	0.90	3.5	1.0 (2.7)	2.6	0
817	1989	4	2.1 (3.4)	0.61	3.5	1.3 (3.4)	2.9	0
817	1990	5	0.20 (0.29)	0.07	3.5	3.3 (0.29)	3.4	0

Table E. Summary data on measured and estimated BD ppm, for the 306 job/year combinations

Job	Year	N	Measurements		Estimate	Estimate minus mean (SD)	Estimate minus median	Weight†
			Mean (SD)*	Median				
817	1991	2	0.32 (0.42)	0.32	3.0	3.2 (0.42)	3.2	0
820	1978	105	1.3 (1.9)	0.90	0.00	-1.3 (1.9)	-0.90	0
820	1979	62	1.1 (1.7)	0.80	0.00	-1.1 (1.7)	-0.80	0
820	1980	21	2.1 (4.1)	0.90	0.00	-2.1 (4.1)	-0.90	0
820	1981	20	0.89 (1.0)	0.65	0.00	-0.89 (1.0)	-0.65	0
820	1982	21	0.55 (0.49)	0.40	0.00	-0.55 (0.49)	-0.40	0
820	1984	9	0.33 (0.23)	0.20	0.00	-0.33 (0.23)	-0.20	0
820	1985	11	0.48 (0.45)	0.50	0.00	-0.48 (0.45)	-0.50	0
820	1986	14	0.22 (0.16)	0.20	0.00	-0.22 (0.16)	-0.20	0
820	1987	11	0.05 (0.00)	0.05	0.00	-0.05 (0.00)	-0.05	0
820	1988	16	0.05 (0.01)	0.05	0.00	-0.05 (0.01)	-0.05	0
820	1989	9	0.13 (0.15)	0.10	0.00	-0.13 (0.15)	-0.10	0
820	1990	10	0.14 (0.26)	0.07	0.00	-0.14 (0.26)	-0.07	0
820	1991	5	0.27 (0.29)	0.15	0.00	-0.27 (0.29)	-0.15	0
832	1982	5	0.36 (0.21)	0.30	0.00	-0.36 (0.21)	-0.30	0.04653536
832	1988	12	0.05 (0.00)	0.05	0.00	-0.05 (0.00)	-0.05	0.001934763
832	1989	8	0.10 (0.09)	0.07	0.00	-0.10 (0.09)	-0.07	0.001916528
832	1990	10	0.07 (0.02)	0.07	0.00	-0.07 (0.02)	-0.07	0.001651915
832	1991	4	0.32 (0.35)	0.32	0.00	-0.32 (0.35)	-0.32	0.001227735
834	1978	53	2.8 (17.0)	0.40	0.00	-2.8 (16.8)	-0.40	0
834	1979	15	0.69 (1.0)	0.30	0.00	-0.69 (1.04)	-0.30	0
834	1980	14	0.40 (0.26)	0.30	0.00	-0.40 (0.26)	-0.30	0
834	1981	20	0.28 (0.25)	0.20	0.00	-0.28 (0.25)	-0.20	0
834	1982	18	0.31 (0.27)	0.20	0.00	-0.31 (0.27)	-0.20	0
834	1984	4	0.25 (0.17)	0.20	0.00	-0.25 (0.17)	-0.20	0
834	1985	2	0.35 (0.35)	0.35	0.00	-0.35 (0.35)	-0.35	0
834	1986	3	0.25 (0.30)	0.10	0.00	-0.25 (0.30)	-0.10	0
834	1987	5	0.05 (0.00)	0.05	0.00	-0.05 (0.00)	-0.05	0
835	1978	1	0.05	0.05	0.00	-0.05	-0.05	0.017474007
835	1981	5	0.64 (0.66)	0.40	0.00	-0.64 (0.66)	-0.40	0.012678914
835	1982	5	0.19 (0.09)	0.20	0.00	-0.19 (0.09)	-0.20	0.011763166
835	1983	1	0.20	0.20	0.00	-0.20	-0.20	0.010105464
835	1984	37	0.34 (0.40)	0.20	0.00	-0.34 (0.40)	-0.20	0.008534532
835	1985	21	0.40 (0.29)	0.40	0.00	-0.40 (0.29)	-0.40	0.008509948
835	1986	18	0.31 (0.31)	0.20	0.00	-0.31 (0.31)	-0.20	0.007848337
835	1987	8	0.05 (0.00)	0.05	0.00	-0.05 (0.00)	-0.05	0.007855767

Table E. Summary data on measured and estimated BD ppm, for the 306 job/year combinations

Job	Year	N	Measurements		Estimate	Estimate minus mean (SD)	Estimate minus median	Weight†
			Mean (SD)*	Median				
835	1988	5	0.05 (0.00)	0.05	0.00	-0.05 (0.00)	-0.05	0.007179118
835	1989	4	0.14 (0.14)	0.09	0.00	-0.14 (0.14)	-0.09	0.00668401
835	1990	4	0.09 (0.01)	0.08	0.00	-0.09 (0.01)	-0.08	0.006476093
835	1991	2	0.07 (0.06)	0.07	0.00	-0.07 (0.06)	-0.07	0.006653313
852	1982	7	0.69 (0.57)	0.40	14.4	13.7 (0.57)	14.0	0.017712781
852	1984	15	0.65 (0.61)	0.60	14.4	13.8 (0.61)	13.8	0.018295894
852	1985	28	0.51 (0.59)	0.30	14.4	13.9 (0.59)	14.1	0.019567674
852	1986	16	0.77 (1.5)	0.10	14.4	13.6 (1.5)	14.3	0.020848534
852	1987	11	0.06 (0.04)	0.05	14.4	14.4 (0.04)	14.4	0.020642771
852	1988	15	0.22 (0.63)	0.05	14.4	14.2 (0.63)	14.4	0.015607199
910	1977	12	27.0 (35.0)	11.0	9.4	-17.6 (35.3)	-1.5	0.013834156
910	1978	58	23.6 (77.0)	4.5	9.4	-14.1 (76.6)	4.9	0.013667081
910	1979	10	6.7 (6.0)	5.3	9.4	2.8 (6.0)	4.1	0.014282541
910	1980	18	40.9 (122.0)	5.1	9.4	-31.5 (121.6)	4.3	0.014629606
910	1981	7	6.3 (3.6)	6.1	24.0	17.7 (3.6)	17.9	0.013338473
910	1982	14	15.2 (22.0)	5.1	24.0	8.8 (21.7)	18.9	0.012488415
910	1984	11	2.4 (3.6)	0.60	24.0	21.6 (3.6)	23.4	0.011590951
910	1985	10	2.5 (4.1)	1.3	24.0	21.5 (4.1)	22.7	0.011890654
910	1986	8	1.2 (2.3)	0.40	24.0	22.8 (2.3)	23.6	0.010673295
910	1987	9	0.90 (1.9)	0.10	24.0	23.1 (1.9)	23.9	0.010740821
910	1988	15	0.70 (0.72)	0.46	24.0	23.3 (0.72)	23.5	0.010861462
910	1989	11	1.0 (1.9)	0.27	24.0	23.0 (1.9)	23.7	0.00814127
910	1990	15	1.2 (1.8)	0.45	24.0	22.8 (1.8)	23.5	0.007171294
910	1991	12	0.45 (0.31)	0.55	0.34	-0.11 (0.31)	-0.21	0.007366408
920	1979	4	20.6 (12.0)	24.2	18.5	-2.1 (11.8)	-5.7	0.014999104
920	1983	2	0.05 (0.00)	0.05	18.5	18.4 (0.00)	18.4	0.012610001
920	1984	4	0.14 (0.11)	0.10	18.5	18.3 (0.11)	18.4	0.01255902
920	1985	5	0.11 (0.11)	0.05	2.3	2.2 (0.11)	2.3	0.013584069
920	1986	4	0.06 (0.03)	0.05	2.3	2.3 (0.03)	2.3	0.014337333
920	1987	5	0.05 (0.00)	0.05	2.3	2.3 (0.00)	2.3	0.014912141
920	1988	1	0.05	0.05	2.3	2.3	2.3	0.014756807
920	1989	4	0.53 (0.58)	0.26	2.3	1.8 (0.58)	2.1	0.015081135
920	1990	5	0.22 (0.28)	0.09	2.3	2.1 (0.28)	2.3	0.015032916
920	1991	7	0.13 (0.11)	0.12	2.3	2.2 (0.11)	2.2	0.013412581

*SD=standard deviation.

† Weight is the proportions of person-years for a specific job/year combination in employees' work histories to total person-years in all job/year combinations in that year.