MHETA 80-109 US BORAX AND CHEMICAL CORP Boron, California May, 1983	Contract Agreement with University of Southern California Los Angeles, California

I. SUMMARY

In September 1981 a contract was awarded by the National Institute for Occupational Safety and Health (NIOSH) to the Division of Occupational Health, School of Medicine, USC, to conduct a study of respiratory complaints at the U.S. Borax facility in Boron, California. This hazard evaluation had previously been requested by the Mine, Mineral, and Processing Workers' Union, Local 30, which represents workers at this facility.

The medical survey was performed in December 1981, and included administration of an occupational-respiratory questionnaire, chest radiography, and simple spirometry. The study population included all mine and refining facility workers with at least 5 years tenure, as well as all workers currently employed in the fusing or granulating plant regardless of tenure. To assess the relation between medical findings and exposure to borax (pentahydrate, decahydrate) and boric acid, management, labor and investigators developed a dust exposure index based on company dust measurements and subjective impressions of dustiness of each job.

Ninety-three percent of targeted workers (629/676) participated in the study. The study group was predominantly white and male (92%), and exhibited a mean "borax" tenure of 11.4 years. Symptoms of mucosal (mouth, nose, throat) and ocular irritation were common, and were significantly related to dust exposures at the plant ($p < 0.001$). Symptoms were largely nonexistent at dust levels of 1 mg/M^3 and were present with increasing frequency above 4.1 mg/M^3. Both smokers and never smokers were affected. Lung function tests revealed a small but statistically non-significant dust effect on lung function. Chest radiography showed evidence of pneumoconiosis in 3.4% (21/621) and pleural thickening in 2.6% (16/621). Dust exposure at US Borax was not associated with these radiographic findings.

The current study indicates that symptoms of mucosal and respiratory tract irritation were associated with borax and boric acid exposure at this workplace. The limited environmental data suggest that total suspended particulate (TSP) levels at or below 1 mg/M^3 cause few symptoms, and levels at and above 4.1 mg/M^3 are associated with increasing symptomatology. Since the data do not permit assessment of symptoms between these two levels, it is recommended that TSP levels be reduced below 4 mg/M^3, and as close to 1 mg/M^3 as is feasible.

II. INTRODUCTION

In March 1980 the Mine, Mineral, and Processing Workers' Union Local 30, an affiliate of the International Longshoreman's and Warehouseman's Union, and the management of the United States Borax and Chemical Corporation jointly requested NIOSH to evaluate the health effects of borax at the U.S. Borax mine and refining facility in Boron, California. The Union contended that workers suffered an excess of respiratory disease as a result of their exposures to dust in this facility. In April 1980, NIOSH conducted a walk-through inspection of the facility and distributed health questionnaires to the workers.

One hundred fifty one of the 1,100 hourly employees returned questionnaires, and of those who returned the questionnaires 34 had health complaints. Sixty two percent of the health complaints referred to the respiratory system (1). Based on these findings, a recommendation was made for a respiratory disease survey, and in September 1981 a contract was awarded to the Division of Occupational Health at the University of Southern California School of Medicine. The survey was performed in December 1981.

III. BACKGROUND

A. Manufacturing Process

Two principal forms of borax ore, borax ($Na_2B_4O_7.10H_2O$) and kernite ($Na_2B_4O_7.4H_2O$) are mined in a large open pit mine near Boron, California. This mine has been in operation since 1927, when it was opened as an underground mine. In 1957, open pit mining methods were begun and the mine gradually expanded to its present dimensions of two miles in greatest diameter by 600 feet deep. The ore is transported by large dump trucks to a primary crusher located in the mine and is then carried to the surface by converyor. A large refining facility is located adjacent to the mine. The ore passes through a secondary crusher, then is conveyed to tanks where the soluble borax is dissolved with steam and the insoluble wastes, such as shale, are removed by sedimentation. The borax liquor is pumped through a series of thickening tanks where the remaining fine insolubles are removed and the liquor is thickened. Excess water is removed in a vaccuum evaporator; the resulting slush of crystals passes through centrifugal separators, and is dried in a rotary kiln. The product is a fine white crystalline powder. Depending on the temperature maintained during crystallization, the borax may be produced as borax pentahydrate ($Na_2B_4O_7.5H_2O$) or borax decahydrate ($Na_2B_4O_7.10H_2O$). These products are conveyed to the shipping area where they are bulk loaded in railroad cars or packaged in 50 pound paper sacks. Part of the product stream coming from the rotary kilns is conveyed to the fusing plant where it is heated in gas furnaces to about 1600^{o}F. This drives off the water of hydration, and creates anhydrous borax in the form of a molten glass. The glass is cooled on chill rollers and pulverized in hammer mills. The resulting anhydrous borax product is a fine white powder which absorbs moisture spontaneously. It is conveyed to the shipping department for packaging or bulk loading in railroad cars.

The refinery also produces boric acid and anhydrous boric acid. In this process borax ore is dissolved and reacted with sulfuric acid to produce boric acid (H_3BO_3) and sodium sulfate. The boric acid is crystallized and dried to a white powder. Anhydrous boric acid (HBO_2) is produced in a fusing process similar to the anydrous borax process.

The refinery produces about 5,000 tons of products per operating day, of which 300 tons are anhydrous borax, 500 tons are boric acid, 50 tons are anhydrous boric acid, and the remainder is borax. The production rate has been relatively stable since 1976. In 1967, the earliest year for which figures are available, production was about 2,300 tons per operating day, and rose gradually until 1976.

B. Population

Approximately 1,380 people are employed at the Boron facility. Of these, approximately 280 are salaried employees. The hourly employees are assigned to the plant areas as follows: fusing plant (100 employees); shipping (170 employees); boric acid plant (70 employees); dissolving, thickening, and granulating (130 employees); construction and repair shops (340 employees); mine (150 employees), and supportive services such as the steam plant, analytic laboratory, engineering, safety and accounting (140 employees).

C. Industrial Uses of Products

Borax and boric acid are used in glass manufacturing to impart heat and stress resistance and in porcelain enamel manufacturing. Borax is used in soaps and cleansing products because of its surfactant and buffering properties. Hydrated forms of borax are added to building materials such as lumber, particleboard, and ground paper insulation to impart flame resistance and to retard the growth of fungi (2).

D. Metabolism and Toxicity of Borax and Boric Acid

Borax and boric acid are soluble in water. Borax is mildly alkaline in solution and is an effective buffer. Boric acid is a weak acid. The average human daily intake of boron in the diet is 10 to 20 milligrams, chiefly from fruits and vegetables (4). Orally ingested borates are rapidly absorbed from the gastrointestinal tract. Absorption through intact skin is negligible, but systemic toxicity can result from absorption through abraded or damaged skin (4). It is likely that borates, like other small, ionized molecules, are absorbed through the respiratory tract, but there is no direct information on this subject. Borates are excreted unchanged via the kidneys, appearing in the urine within minutes after an intravenous dose and requiring as long as 18 days to be completely cleared after long term administration (5).

Boric acid ingestion of 20-45 grams in a single dose has been fatal in adults (4). Adults have survived intravenous doses of 25 mg/kg of borax; toxicity was manifested primarily as CNS depression and hypotension followed by the development of skin erythema and desquamation over a period of days (6).

Respiratory toxicity due to borax or boric acid has not been adequately defined. NIOSH evaluated nine workers exposed to anhydrous borax dust at concentrations of 2.9 to 29.9 mg/m^3 in 1977 (7). Complaints of eye irritation, nosebleeds and sore throat were noted. The California State Department of Public Health, which performed a respiratory disease survey of 629 borax workers in 1963, demonstrated a slight excess of episodes of respiratory illness among workers exposed to anhydrous borax, when compared to non-exposed workers (8).

IV. EVALUATION CRITERIA

A. Medical

The medical assessment of the study population consisted of administering questionnaires on respiratory tract symptoms, pulmonary function testing, and chest x-rays in accordance with the criteria specified by the American Thoracic Society (9). Predicted values for pulmonary function (FEV1 and FVC) were derived from the regression equations of Knudson, et al (10).

B. Environmental

The American Conference of Governmental Industrial Hygienists recommends a total suspended particulate TLV of 1 mg/m^3 for anhydrous borax ($NA_2B_4O_7$) and borax pentahydrate ($Na_2B_4O_7.5H_2O$) and 5 mg/m^3 for borax decahydrate ($Na_2B_4O_7.10H_2O$), based on an 8 hour time weighted average exposure (11). California OSHA considers borax and boric acid as nuisance particulates and lists a standard of 10 mg/m^3 for total suspended particulate.

V. METHODS AND MATERIALS

A. Study Population

The group selected for study was composed of all workers who had been actively employed for five years or more in any area of the Boron facility and all workers who were presently employed in the fusing or granulating plant regardless of the length of time they had been employed. These criteria were applied to hourly and salaried workers and to workers on long term disability. The participation rate was 95.4 percent among hourly workers, 93.6 percent among salaried workers, and 63.5 percent among 130 workers on long term disability.

Interview

The American Thoracic Society Epidemiology Standardization Project questionnaire on respiratory disease (9) was administered by interview to the 629 study participants to obtain information on persistent respiratory symptoms. Additional questions about acute irritation of the eyes and upper respiratory tract, nosebleeds, coughing, hemoptysis, shortness of breath, chest tightness and chest pain were asked. A history of past exposure to respiratory hazards was also obtained by interview. Subjects were instructed to take a deep breath and cough hard; the interviewer judged the cough to be loose (productive) or dry (unproductive) by its sound, using the method of Gandevia (12).

Pulmonary Function Tests

Spirometry was performed using an Ohio 840 rolling seal spirometer wired to an analog processor and tape recorder. Each forced expiration generated a flow-volume curve which was recorded directly on magnestic tape. Barometric pressure was recorded daily and temperature was recorded at the start of each session and after each change of one degree centigrade. The spirometer was calibrated at the start of each session.

Six hundred and twenty subjects participated in spirometry (nine refused) and completed a minimum of five blows, at least three of which were of acceptable quality. Ninety eight per cent of the particpants' spirograms met the ATS criteria for spirometry. In the analysis of the data only the subjects best FVC, FEV_1, peak flow rate, and FEF_{75} were used.

B. Exposure Evaluation

Occupational histories were obtained by reviewing each participant's personnel file at U.S. Borax. The job title, plant assignment, starting date, and stopping date were recorded for each job held. Starting and stopping dates were recorded to the nearest month. The personnel files also contained the participant's original job applications which listed all jobs held before joining U.S. Borax. These jobs and their dates (to the nearest year) were also recorded.

The results of industrial hygiene surveys made by U.S. Borax and by the Mine Safety and Health Administration (MSHA) between 1977 and 1981 were used to estimate the exposures in the mine and refinery. The majority of the data came from the company and were supplemented by a small amount of data from MSHA. Sampling data were available on 42 jobs from six areas of the facility. All samples were collected by the same technique: total particulate was collected in closed-face filter cassettes attached to the worker's collar; respirable particulate was collected at the worker's collar on a filter after the nonrespirable particulates were removed by a 10mm nylon cyclone. Both collectors used PVC membrane filters with a 5 micron diameter pore size. Dust collected was weighed. Only full shift sampling data were used in the analysis. A total of 103 total dust and 21 respirable dust samples were collected.

The environmental samples were not collected for assessing exposure in an epidemiological study, but had been obtained to determine company compliance with legal requirements. As a result, the jobs with the highest exposures represent most of the data and those with moderate or low exposures have little or no data. To obtain information on exposure levels in the numerous jobs with no samples, three groups of people familiar with the working conditions (senior management, union representatives, and the company industrial hygiene and safety professionals) were asked to rate independently the dustiness of all jobs at U.S. Borax. Each job was rated on a four point scale: 1 = little or no dust, 2 = moderately dusty, 3 = dusty, 4 = very dusty. The rating from the three groups were combined by taking a simple average. All jobs which had average rating of less than 2 were designated as low exposure, jobs with ratings of at least 2 but less than 3 were designated as medium exposure and jobs with ratings of at least 3 were designated as high exposure. The mean dust exposure of each rating group was determined by calculating the geometric mean of all the dust measurements taken on the jobs which were in the rating group. In this way jobs for which no sampling data was available were assigned to dust exposure of jobs which had sampling data and which were felt by knowledgeable observers to have comparable exposures. Table 1 shows the geometric mean dust levels based on the dust measurements for jobs within the 3 ranges of ratings.

Each participant's cumulative dust exposure was calculated by multiplying the amount of time spent in each job by the dust level for that job and summing over all jobs held. This was done separately for total suspended particulates (TSP) and respirable particulates. Each individual's total time spent in high, medium and low exposure job was also calculated. Estimates of the mean dust exposure for individual buildings and plant areas were calculated by a weighted average of the dust exposures in all jobs in the area. The weight given to each job was proportional to the number of subjects who had ever worked in that job. Thus, the mean dust exposure estimated for an area reflected the actual exposure of the study participants who had worked in that area. These estimates were used in the analysis of acute respiratory tract symptoms. The areas and their weighted mean dust levels are presented in Table 2.

Statistical Analysis

Each acute respiratory tract symptom was analyzed by determining the proportion of participants ever having worked in a given area who indicated having experienced the symptom in that work area. In order to assess whether the proportion of participants noting symptoms increased with exposure level, a test for trend was performed (14).

For each presistent respiratory system we calculated age-standardized risk estimates by the indirect method in each of six smoking-exposure categories. The risks were obtained by dividing the observed number of subjects with symptom (or condition) by the sum of the expected numbers in each age group derived by multiplying the age specific rate in the total study population by the number of subjects at risk in the age-smoking-exposure category. Five age categories (less than 25,25-34,35-44,45-54,55+) and two smoking categories (ever smokers and never smokers) were used. For presistent respiratory symptoms, exposure was defined on the basis of the exposure level of the job held at the time of the interview. Relative risks for each smoking-exposure category were estimated using non-smokers at low exposure as the referent group. Tests for trend across exposure levels in each smoking category were performed by adapting the method of Mantel (13) to accomodate adjustment for age.

Multiple regression techniques were used to analyze the relationship between the pulmonary function test results (FEV_1, FVC_1 FEV_1/FVC, Vmax and FEF_{75}) and age, height, smoking status, years smoked and various indicators of exposure (years actively employed, cumulative TSP, cumulative respirable particulates, and years in various job groups). In addition, the ratios of observed to predicted FEV_1 and FVC were calculated using the equations of Knudson (10) to obtain predicted values. These values as a percent of predicted were analyzed in relation to categories of exposure.

All analyses were performed on the DEC PDP-11-45 computer. Multiple regression and T-tests procedures were implemented using the SPSS Batch System (16).

VI. RESULTS

The study participants were predominantly white males (92%). They had an average age of 40.2 and had worked in the borax industry for an average of 11.4 years (Table 3). Their smoking habits are presented in Table 4. Roughly one quarter of the participants had never smoked, one half were present smokers, and one quarter were ex-smokers. The occupational histories, obtained by interview and by review of the personnel files, indicated that some workers had been employed in other dusty industries, such as mining, or had potential exposure to silica, cotton dust, asbestos, or beryllium. The numbers of participants and their average length of employment in these industries are presented in Table 5.

Acute Symptoms

Acute respiratory tract symptoms were analyzed in relation to total particulate exposure in borax exposed areas and in boric acid exposed areas. The areas were grouped into the five exposure categories shown in Table 2. The proportions of workers who had ever worked in each borax exposure category who noted symptoms at that exposure level are presented in Figure 1. Thirty three percent of the workers noted dryness of the mouth, nose, or throat and 28 percent noted eye irritation at exposures of 14.9 mg/m^3. Nosebleeds and dry cough were noted by 15 percent, and sore throats and productive cough were noted by 8 percent at this exposure. Shortness of breath and chest tightness were noted by 5 percent, while chest pain and hemoptysis were noted by less than 2 percent. Based on a test for trend, the proportion of workers noting each symptom significantly increased as exposure increased, with the exception of chest pain and hemoptysis. At an exposure level of 4.0 mg/m^3 no symptom except eye irritation was noted by more than 5 percent of the exposed participants.

The proportions of workers who had ever worked in the boric acid exposed areas (weighted mean TSP = 4.1 mg/m^3) who noted symptoms in those areas are presented in Table 6. Eye irritation and dryness of the mouth, nose, or throat were noted by 12 and 11 percent of the participants, respectively. Sore throat, dry cough, and productive cough were noted by 4 to 5 percent of the participants. Shortness of breath, chest tightness, nosebleeds, chest pain, and hemoptysis were noted by 3 percent or less of the participants.

Persistent Symptoms

For each persistent symptom, the risk of developing the symptom was estimated separately for ever and non-smokers in relation to the exposure level of the job at the time of interview by indirect standardization to the age-specific rates of the total study population. Individuals on disability were excluded from this analysis. The results are presented in Table 7 for non-smokers and Table 8 for past and present smokers. For each exposure level and smoking status, the risk of developing each symptom is presented relative to that of non-smokers in low exposure jobs.

Non smokers - The risk of cough, phlegm production, and chronic bronchitis (defined as a productive cough present on most days at least 3 months of the year for at least 2 consecutive years) increased with increasing dust exposure. At exposures of 1.4 mg/m^3 the risk of phlegm production was 1.85, and of chronic bronchitis was 5.9 times the risk at 0.9 mg/m^3. There was a statistically significant dose-response relationship for both of these symptoms. At exposures of 14.9 mg/m^3 the risk of objective cough, judged to be loose (productive) by the interviewer, was 1.7 times more than at exposures of 0.9 mg/m^3, and the trend was statistically significant. Breathlessness did not show a clear relationship to exposure. The risk of wheezing decreased as exposure increased, but not significantly.

Smokers - Compared to non-smokers at low exposure, the risks of cough, phlegm production, chronic bronchitis, breathlessness, and loose objective cough were higher among smokers at low exposure (Table 8). As exposure increased, the risks of phlegm production, chronic bronchitis and loose objective cough increased, but these trends did not achieve statistical significance. Beathlessness increased with exposure and the trend was statistically significant. Wheezing showed no clear relationship to exposure.

Pulmonary Function Tests Regression Analysis

The FVC, FEV_1, FEV_1/FVC, Vmax, and FEF_{75} were analyzed by stepwise multiple regression. The analysis was restricted to the 567 white males who completed spirometry. The regression equations, which are presented in Table 9 are based on those variables for which the coefficients had p-values less than 0.10. The variables for which the p-values were at least 0.10 are not presented. The variables are listed in Table 9 in the order in which they entered the equations. For each regression the variables considered were age, height, smoking status, years smoked, total years worked in the borax industry, years worked at high exposure, years worked at medium exposure, years worked at low exposure, cumulative total suspended particulate and cumulative respirable particulate. No exposure variable was significantly related to any of the pulmonary function indices.

FVC

The FVC was significantly related to height, age, and years smoked. For smokers, the effect of the number of years smoked was to decrease the FVC by 7.7 ml per year when age and height are held constant.

FEV1

The FEV_1 was significantly related to age, height, and years smoked. For smokers, the effects of the number of years smoked was to decrease the FEV_1 by 15 ml per year when age and height are held constant.

FEV1/FVC

The FEV_1/FVC was significantly related to years smoked, age, height, and smoking status.

Vmax and FEF75

For Vmax and FEV_{75} the correlation coefficients obtained after all significant variables had entered the equations were 0.204 and 0.187, respectively, indicating that the regression equations explained a relatively small part of the variability of these measurements. The Vmax was significantly related to age, height, and years smoked. The FEF_{75} was significantly related to years smoked, height, age and smoking status.

Pulmonary Function Tests Percent Predicted Analysis

Additional analyses of the FVC and FEV_1 were performed in comparison to predicted values derived from the regression equation of Knudson (10). The white male participants were divided into 5 categories based on the number of years they had been actively employed in the borax industry and the mean percent predicted FVC and FEV_1 were calculated for each exposure group. The subjects were divided into 2 groups based on smoking status. The results are present in Table 10.

Among non-smokers there was no consistent decrease in the percent predicted FVC as the duration of employment increased. However, for the 29 subjects who had been employed for at least 20 years the mean percent predicted FVC was 106.7, which was slightly less than the mean of 108.1 seen among all never smokers who had been employed for less than 20 years. Similar findings were present for the percent predicted FEV_1 among non-smokers. Although there was no consistent decrease in the percent predicted FEV_1 as the duration of employment increased, the 29 subjects who had been employed for at least 20 years had a mean percent predicted FEV_1 of 103.0, which was slightly less than the mean of 104.2 seen among those employed for less than 20 years.

Among smokers, the percent predicted FVC declined slightly as the duration of employment increased. For subjects employed less than 20 years the mean percent predicted FVC was 104.5, in comparison to 103.1 for subjects employed 20 years or more. The percent predicted FEV_1 declined sharply as the duration of employment increased. The mean precent predicted FEV_1 was 99.4 for subjects employed less than 5 years, and fell to 90.7 for subject employed at least 20 years.

The percent predicted FVC and FEV_1 were also analyzed in relation to cumulative TSP (Table 11). Among non-smokers there was no appreciable decline in either percent predicted FVC or FEV_1 with increasing cumulative TSP. The mean percent predicted FVC was 107.9 for non-smokers having less than 120 mg/m^3.yrs cumulative exposure, and was 107.8 for those having at least 120 mg/m^3.yr. The mean percent predicted FEV_1 was 104.0 for non-smokers having less than 120 mg/m^3.yrs cumulative exposure and was 103.6 for those having at least 120 mg/m^3.yrs.

Among smokers, the mean percent predicted FVC was 104.6 for those having less than 120 mg/m^3.yrs cumulative exposure and was 102.5 for those having at least 120 mg/m^3.yrs cumulative exposure. The mean percent predicted FEV_1 was 97.7 for those having less than 120 mg/m^3.yrs cumulative exposure and was 90.6 for those having at least 120 mg/m^3.yrs cumulative exposure.

The decline in the precent predicted FEV_1 among smokers was further analyzed to look for interaction between dust exposure and smoking (Table 12). Among subjects who had smoked for less than 10 years, those whose cumulative dust exposure was less than 60 mg/m^3.yrs and a mean percent predicted FEV_1 of 105.2, while those whose exposure was 60 or more had a percent predicted FEV_1 of 100.7. Among subject who had smoked for 10 to 25 years, those whose cumulative exposure was under 60 had a mean percent predicted FEV_1 of 99.6, while those whose exposure was over 60 had a value of 97.4. Among subjects who had smoked at least 25 years, those whose exposure was under 60 had a mean of 88.4, while those whose exposure was over 60 had a mean of 87.2. This analysis demonstrated that for a given duration of smoking, there was a small decline in percent predicted FEV_1 associated with increasing dust exposure. These declines did not achieve statistical significance.

<u>Chest X-rays</u>

Small linear opacities of profusion 1/0 or greater were present in 17 of the participants (2.7 percent). Sixteen of these individuals were smokers. No borax related exposure variable was of statistical significance when related to linear opacities.

Small round opacities of profusion 1/0 or greater were present in four of the participants (0.6 percent), all of whom were smokers. A review of the work histories of these four subjects did not show any consistent pattern of exposure. None of the subjects who had round opacities had been employed elsewhere in dusty occupations.

Pleural thickening was present in 16 of the participants (2.6 percent) and was not associated with any of the exposure variables (years employed, years employed at high exposure, or cumulative TSP). Thirteen of these subjects had positive smoking histories. Pleural thickening was significantly associated with age ($p < 0.001$) and was significantly associated with previous asbestos exposure (odds ratio 4.2, $p = 0.036$).

VII. DISCUSSION

Acute symptoms of the upper respiratory tract and eye irritation were common in areas in which exposure to borax was 8.5 mg/m^3 and above, and were infrequent at exposure levels of 1.1 mg/m^3. The prevalence of these symptoms demonstrated a dose-response relationship to total dust exposures. Symptoms related to irritation of the airways of the lung also increased in prevalence as exposure increased but were less common than symptoms of upper respiratory tract irritation.

In the boric acid exposed areas acute symptoms of upper respiratory tract and eye irritation were also seen. Eye irritation and dryness of the mouth, nose, or throat were most commonly reported, while sore throat, dry cough and productive cough were less common. The limited amount of exposure information available indicated that the mean total dust concentration in the boric acid exposed areas was 4.1 mg/m^3. There was not enough exposure information to allow us to evaluate symptom prevalences at different exposure levels, so we cannot determine the dose response relationship for these symptoms in relation to boric acid exposure. However, for a given total dust concentration, the symptom prevalence for each of the above mentioned symptoms is higher in the boric acid exposed areas than in the borax exposed areas. We believe this indicates that boric acid has a greater irritant effect on the respiratory tract than borax.

Among never smokers, persistent repsiratory symptoms, such as cough, phlegm production, and chronic bronchitis were related to the exposure level of the job at the time of interview. The risk of phlegm production in high exposure jobs was nearly twice that in low exposure jobs, and the risk of symptoms which satisfied the definition of chronic bronchitis in high exposure jobs was nearly six times that in low exposure jobs. This pattern of symptoms was confirmed by the interviewers' ratings of loose objective cough, for which the risk was 1.7 times greater in high exposure than in low exposure jobs.

Smokers, who had a higher risk of cough, phlegm production, and chronic bronchitis than non-smokers at each exposure level, also experienced slight increases in the risks of these symptoms at increasing exposures. Loose objective cough, which was more common in smokers than non-smokers, also increased with increasing exposure.

The results of our study of respiratory tract symptoms are similar to the findings of a smaller study conducted by NIOSH among borax workers in a plant in Trona, California in 1978. Acute symptoms of eye and throat irritation were common at dust exposures that ranged from 2.9 to 29.9 mg/m^3 (7). However, the prevalence of presistent respiratory symptoms was not reported in this study. Our results are also supported by the California State Department of Public Health 1963 evaluation of the same Boron plant, in which episodes of respiratory illness were studied in relation of work exposures (8). In that study, subjects who had worked in fusing or in the razorite anhydrous (RA) plant for at least 1 year out of the previous 6 years were compared to all workers who had never worked in fusing or in RA. In spite of being younger, having worked a shorter time at U.S. Borax, and having been employed less in other dusty occupations, the men who had worked in fusing and RA had 16 percent more episodes of respiratory illness than those not exposed. Dust levels were not reported.

Although many of our results deal with the participants' subjective responses to questions about respiratory symptoms, we do not believe that biased reporting could adequately explain the pattern of symptoms we have presented. Although the workers are well aware of which areas of the plant are dusty, the participants could not have known at the time of interview which symptoms would later be analyzed in relation to acute exposures and which in relation to cumulative exposures. The participants were also extremely unlikely to have been aware of their cumulative dust exposures in relation to the distribution of the exposures of the other participants and could not have biased their responses to produce a dose-response relationship. A general over reporting of symptoms would obscure their true relationship to exposures. The pattern of acute and presistent upper airway irritation and bronchitis which we have observed is consistent with the effects produced by chemical irritants that are water soluble and are deposited primarily in the upper respiratory trace and large airways. Symptoms suggesting asthma or airway reactivity were notably infrequent and were not related to exposure. Individuals with asthma may have chosen not to work in this dusty environment.

In our study chest x-ray findings bore no relation to the various indices of dust exposure employed. Pulmonary function tests showed a small but statiscally insignificant dust exposure effect. Among non-smokers employed 20 years or more there was a small decline in FVC and FEV_1. Among smokers, after stratifying for the level of smoking, a small effect of dust exposure on FEV_1 was demonstrated.

Selection factors may have influenced the results we obtained. Workers who developed pulmonary impairment or symptoms of lung disease would have been more likely to leave employment or leave exposed jobs than unaffected workers. This would decrease the apparent effect of exposure. Our study was designed to minimize this effect by including workers who were on long term disability.

The information on exposures was provided predominantly by U.S. Borax and in small part by MSHA. There was not enough information from MSHA to allow us to look for systematic differences between the two data sources. However, U.S. Borax gave us copies of their original sampling reports with the hygienist's comments and methods. We reviewed these with our own certified industrial hygienist, who found no errors or inconsistencies in the reports. We believe that these materials were accurate. The majority of the sampling data was taken in high exposure job and plant areas, and we believe that the mean exposures we have presented accurately reflect the exposures in these areas. For the jobs which we defined as low exposure (Table 1) and the plant areas to which we assigned a mean TSP of 1.1 mg/m^3 (Table 2), there was little exposure information. The exposure estimates were based on samples from the highest exposure jobs in these areas and may, in fact, have overestimated the exposures in many of the jobs with which they were equated. It is impossible that the true exposures in these areas are less than 1.1 mg/m^3.

The measured dust levels in the U.S. Borax plant are considerably higher than the dust levels in the adjacent community. High volume 24 hour air samples of TSP taken outside the Boron Fire Station by the Kern County Air Pollution Control Board have ranged from an average of 0.11 mg/m^3 in 1972 to 0.053 mg/m^3 in 1979, with intermediate values in the years between 1972 and 1980 (17). We believe that dust from sources other than borax mining and refining does not contribute significantly to the dust levels in the plant.

VIII. CONCLUSION

1. Symptoms of irritation of the mucous membranes of the eyes, nose, and throat, nosebleeds, dry cough, and productive cough were statistically significantly related to dust exposures in the borax plant. They began to appear at particulate exposures of 4..0 mg/m^3, and were common at 8.5 mg/m^3 and above. Symptoms were infrequent at exposure of 1.1 mg/m^3.

2. Symptoms of eye, nose, and throat irritation were common in the boric acid exposed areas at exposures of 4.1 mg/m^3.

3. The prevalence of presistent respiratory symptoms such as chronic cough, sputum production, and chronic bronchitis increased with increasing dust exposure in smokers and non-smokers. Sputum production and chronic bronchitis were statistically significantly related to dust exposure among non-smokers.

4. Loose objective cough was statistically significantly related to dust exposure among non-smokers.

5. This study did not find statistically significant evidence of pulmonary function or chest x-ray abnormalities related to exposure within the limits of exposures studied.

6. This study provides evidence that exposure to borax dust at a level of 1.1 mg/m^3 is not associated with acute or chronic symptoms of respiratory disease, pulmonary function abnormalities, or chest x-ray abnormalities. Exposures to borax dust at 4.0 mg/m^3 and boric acid dust at 4.1 mg/m^3 are associated with symptoms of respiratory tract irritation.

7. This study does not provide evidence of the effects of borax and boric acid dusts on individuals with asthma or other chronic respiratory disease because few of them were present at the time of the study. Individuals with these conditions may respond differently to dust exposures than the subjects who were studied.

IX. RECOMMENTATIONS

Exposures to total dust in this plant should be reduced to levels that are not associated with ocular and respiratory tract symptoms. The data indicated that these symptoms are present at and above 4 mg/m^3 (TSP) and are virtually absent at 1 mg/m^3. Since the data do not permit evaluation of respiratory complaints between these two levels, it is recommended that total suspended particulate levels be reduced below 4 mg/m^3. Health complaints should be monitored at the reduced levels to insure that workers are free of irritative symptoms.

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TABLE 1

GEOMETRIC MEAN PARTICULATE CONCENTRATION OF JOBS IN EXPOSURE GROUPS

	Exposure Group		
	Low	Medium	High
Average Exposure Rating	1.0-1.9	2.0-2.9	3.0-4.0
Total Particulate, mg/m^3	0.9 (2)*	4.5 (12)	14.9 (23)
Respirable Particulate, mg/m^3	0.2 (2)	0.5 (3)	0.7 (8)

*Parentheses indicate the number of jobs for which samples were available.

TABLE 2

MEAN DUST EXPOSURES IN PLANT AREAS

Borax Exposed Areas	Weighted Mean TSP (mg/m^3)
Anhydrous Borax Production	14.9
Shipping Department	8.5
Mine, Maintenance Shops, Other Production Areas	4.0
Accounting, Laboratory, Safety Department, other non production areas	1.1
Boric Acid Exposed Areas	
Boric Acid and Anhydrous Boric Acid Production	4.1

TABLE 3

CHARACTERISTICS OF STUDY PARTICIPANTS

	N	%
White Males	576	92
Other Males	27	4
Females	26	4
TOTAL	629	100

	Mean	S.D.
Age (yr)	40.2	11.5
Height (cm), White Males Only	176.8	6.6
Education (yrs)	12.5	5.6
Years Employed in Borax Industry	11.4	8.1

Distribution of Length of Employment in Borax Industry (yrs)	N	%
<5	112	18
5-9	238	38
10-14	122	19
15-19	42	7
20-24	67	11
25-29	26	4
≥30	22	3

TABLE 4

SMOKING HABITS

	N	%
Non-Smoker	165	26
Ex-smoker	165	26
Present smoker	299	48
TOTAL	629	100

	Mean	S.D.
Years Smoked (N = 464)	19.5	11.4
Pack Years (N = 464)	23.6	20.4

TABLE 5

PREVIOUS DUSTY OCCUPATIONS
OTHER THAN BORAX INDUSTRY

	N	Mean Years Worked
Mining or Quarrying	65	4.6
Rock Drilling or Tunnelling	25	3.5
Foundry or Sandblasting	34	3.7
Brick or Ceramic	7	2.9
Cotton	15	5.4
Asbestos	49	5.8
Beryllium	6	8.0

FIGURE 1

BORAX EXPOSURE AND ACUTE RESPIRATORY TRACT SYMPTOMS

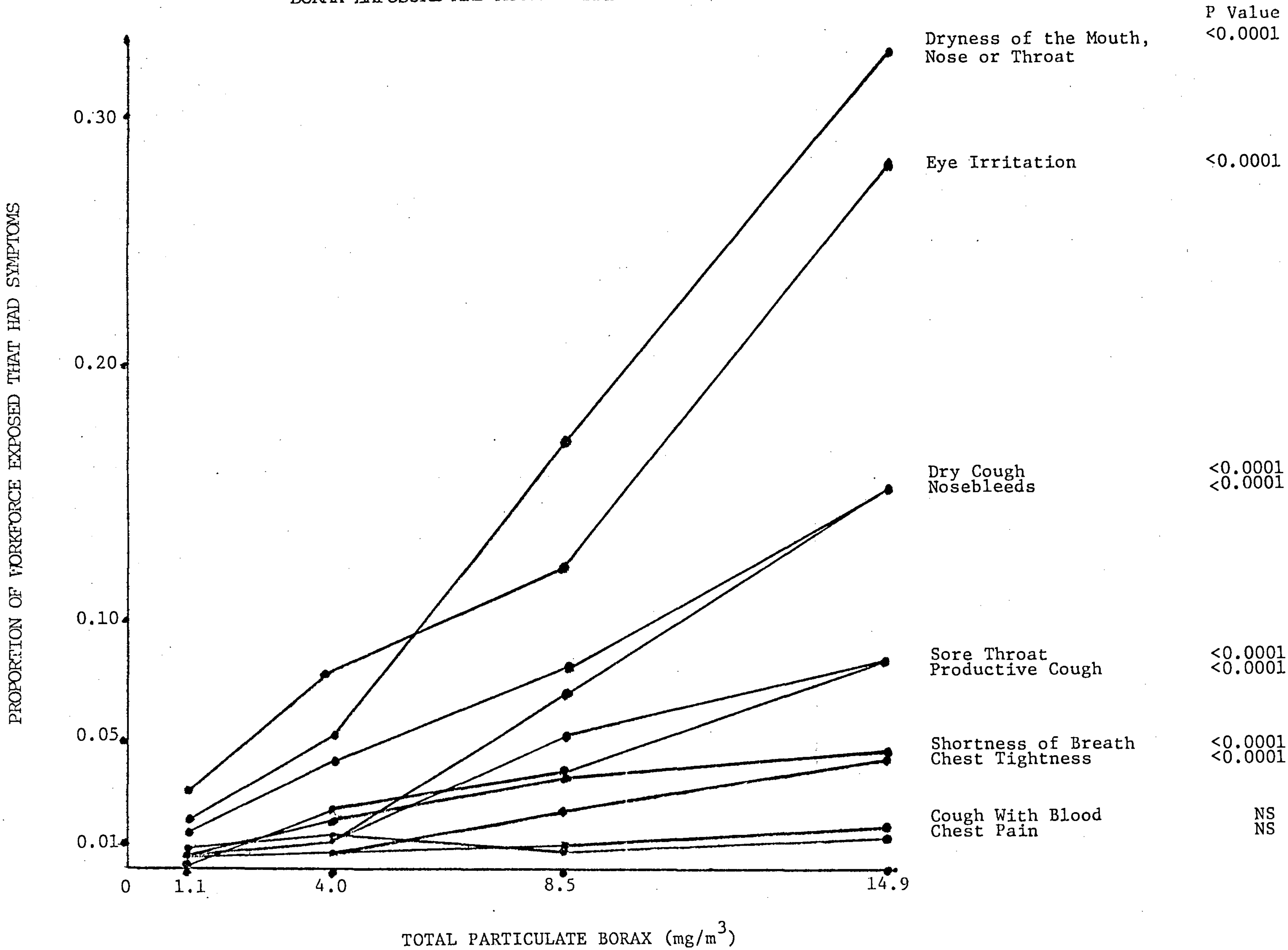

TABLE 6

BORIC ACID EXPOSURE AND ACUTE RESPIRATORY TRACT SYMPTOMS

Weighted mean total suspended particulate in boric acid and anhydrous boric acid plants = 4.1 mg/m^3

Symptom	Proportion of Population Exposed that had Symptom
Eye Irritation	.12
Dryness of Mouth, Nose, or Throat	.11
Sore Throat	.05
Dry Cough	.04
Productive Cough	.04
Shortness of Breath	.03
Chest Tightness	.03
Nosebleeds	.02
Chest Pain	.03
Cough With Blood	.01

TABLE 7

RISK OF PERSISTENT SYMPTOMS ACCORDING TO EXPOSURE LEVEL OF JOB AT TIME OF INTERVIEW: NON SMOKERS

	Job Exposure (TSP)			Test For Trend
	Low (0.9)	Medium (4.5)	High (14.9)	1-Sided P-value
	Risk	Ratios*		
Cough	1.00	0.76	1.40	NS
Phlegm	1.00	1.09	1.85	.01
Chronic Bronchitis	1.00	2.82	5.91	.006
Wheezing	1.00	0.63	0.46	NS
Breathlessness	1.00	0.75	1.27	NS
Loose Objective Cough	1.00	0.67	1.71	.03

*Relative to non smokers at low exposure.

TABLE 8

RISK OF PERSISTENT SYMPTOMS ACCORDING TO
EXPOSURE LEVEL OF JOB AT TIME OF INTERVIEW: SMOKERS

Job Exposure (TSP)	Low (0.9)	Medium (4.5)	High (14.9)	Test For Trend 1-Sided P-value
	Risk	Ratios*		
Cough	1.98	2.78	2.00	NS
Phlegm	3.24	3.97	3.67	NS
Chronic Bronchitis	9.00	13.45	10.27	NS
Wheezing	1.02	1.12	0.99	NS
Breathlessness	1.82	2.15	2.78	.04
Loose Objective Cough	2.10	3.21	3.64	.09

*Relative to non smokers at low exposure.

TABLE 9

REGRESSION ANALYSIS OF PULMONARY FUNCTION:
567 WHITE MALES

	Variable	Coefficient	P-value	R^2
FVC	Height (cm)	0.0674	$< .001$	0.538
	Age (yrs)	-0.0295	$< .001$	
	Yrs Smoked	-0.0077	$< .001$	
	Constant	-5.5109		
FEV_1	Age (yrs)	-0.0325	$< .001$	0.584
	Height (cm)	0.0456	$< .001$	
	Yrs Smoked	-0.0155	$< .001$	
	Constant	-2.6678		
FEV_1/FVC	Yrs Smoked	-0.0269	$< .001$	0.296
	Age (yrs)	-0.0191	$< .001$	
	Height (cm)	-0.0101	$.025 < p < .05$	
	Smoking Status (ever=1, never=0)	0.2081	$.025 < p < .05$	
	Constant	10.3198		
Vmax	Age (yrs)	-0.0393	$< .001$	0.204
	Height (cm)	0.0682	$< .001$	
	Yrs Smoked	-0.0290	$< .001$	
	Constant	-0.2546		
FEF75	Yrs Smoked	-0.0533	$< .001$	0.187
	Height (cm)	0.0486	$< .001$	
	Age (yrs)	-0.0253	$< .001$	
	Smoking Status (ever=1, never=0)	0.5472	$.025 < p < .05$	
	Constant	0.8831		

TABLE 10

ANALYSIS OF PERCENT PREDICTED FVC AND FEV1
BY DURATION OF EMPLOYMENT;
567 WHITE MALES

FVC	Non-Smokers	Smokers
Years Actively Employed	Percent Predicted FVC (n)	Percent Predicted FVC (n)
< 5	106.4 (25)	105.2 (71)
5-9	107.0 (59)	105.7 (148)
10-14	112.6 (25)	103.2 (87)
15-19	108.9 (7)	101.0 (34)
≥ 20	106.7 (29)	103.1 (82)

FEV1	Non-Smokers	Smokers
Years Actively Employed	Percent Predicted FEV1 (n)	Percent Predicted FEV1 (n)
< 5	104.0 (25)	99.4 (71)
5-9	103.0 (59)	98.6 (148)
10-14	106.9 (25)	97.5 (87)
15-19	106.0 (7)	91.5 (34)
≥ 20	103.0 (29)	90.7 (82)

TABLE 11

ANALYSIS OF PERCENT PREDICTED FVC AND FEV1
BY CUMULATIVE TSP EXPOSURE; 567 WHITE MALES

FVC	Non-Smokers	Smokers
Cumulative TSP in mg/m^3•yrs	Percent Predicted FVC (n)	Percent Predicted FVC (n)
<20	104.4 (33)	103.8 (83)
20-39	107.3 (35)	106.2 (99)
40-79	110.8 (39)	105.0 (106)
80-119	109.1 (19)	102.3 (56)
≥120	107.8 (19)	102.5 (78)

FEV1	Non-Smokers	Smokers
Cumulative TSP in mg/m^3•yrs	Percent Predicted FEV1 (n)	Percent Predicted FEV1 (n)
<20	101.3 (33)	95.1 (83)
20-39	103.0 (35)	99.8 (99)
40-79	106.2 (39)	100.2 (106)
80-119	106.1 (19)	93.3 (56)
≥120	103.6 (19)	90.6 (78)

TABLE 12

ANALYSIS OF PERCENT PREDICTED FEV1 BY
CUMULATIVE TSP EXPOSURE; 422 WHITE MALE SMOKERS

Cumulative TSP ($mg/m^3 \cdot yrs$)	Years Smoked		
	< 10	10-25	≥25
<60			
% predicted FEV1	105.2	99.6	88.4
n	64	116	60
mean years smoked	5.5	16.2	34.6
≥60			
% predicted FEV1	100.7	97.4	87.2
n	25	87	70
mean years smoked	5.2	17.0	33.2