FOREWORD

This study was initiated by the Biomedical Laboratory of the 6570th Aerospace Medical Research Laboratorie., Wright-Patterson Air Force Base, Ohio. The investigation was conducted by the Callery Chemical Company at DOD Plant 504 in Muskogee, Oklahoma, under Contract No. AF 33(616)-7728. Bartis M. Kent, M. D., provided local direction of the program with corporate direction provided by George Roush, Jr., M. D. Capt. Alan B. Cooper of the Toxic Hazards Section, Physiology Branch, Biomedical Laboratory, 6570th Aerospace Medical Research Laboratories, was the contract monitor. The work was performed in support of Project No. 6302, "Toxic Hazards of Propellants and Materials," Task No. 630205, "Toxic Hazards Evaluation." The research sponsored by this contract was started in December 1960 and completed in December 1961.

The authors gratefully acknowledge the assistance of Perry Hewitt, M. D., for his electroencephalograph (EEG) examinations; Max Glaze, M. D., for his neurological examinations; and E. M. Scaggs, Jr., Safety Engineer for the Callery Chemical Company at the Muskogee Plant for the monitoring of environments and other contributions of the Safety Department.

ABSTRACT

At a plant producing pentaborane, sixty workers were potentially exposed to the boranes. The purpose of this investigation was to measure these workers' exposure with the Blood Borane Test of Miller, to measure the contamination of the workers' environment, and to relate the data to observed biologic effects in the workers. The atmospheric monitoring revealed that the work area was usually not contaminated. Thirty-one cases of possible borane poisoning were seen. The Blood Borane Test was negative in each of these cases but these results may be due to the mild nature of the poisonings. The lung, liver, and kidney studies used revealed no abnormalities in these cases. A clinical evaluation on all of the exposed workers at the end of a year's production revealed no observable effects. The protective gear worn provided good, though not complete, protection. Further study of the hazards of the boranes will require a monitoring instrument of wider range of sensitivity to evaluate the acute poisonings and the protective gear worn.

PUBLICATION REVIEW

This technical documentary report has been reviewed and is approved.

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INTRODUCTION

Many reports have been written concerning the toxic effects of the boron hydrides. Interest in the biologic effects of the boron hydrides was stimulated during the rapid development and production of these chemicals when it became apparent that they are highly toxic. The reports well describe the various clinical effects of poisoning, but they do not clarify how often, nor under what circumstances intoxication occurs. This information is essential to the handlers of these chemicals.

The clinical reports published on pentaborane and decaborane described damage to the central nervous system, liver, and kidney (refs. 4,7), and animal studies have shown that they have a primary effect on the heart (ref. 10). Several workers have found that abnormal electroencephalograms are produced in borane intoxication (refs. 7,8). Abnormal electroencephalograms have also been produced in animals (ref. 11). Similarly, diborane has been reported to act as a pulmonary irritant (ref.3). Further evaluation is required to establish how often and under what circumstances these changes do occur with borane intoxication.

The quantitative aspects of exposure up to this time have been given little attention because the necessary tools to make these measurements were not available. Information was needed concerning the concentration of boranes found in the workers' environment. The current threshold limits on the boranes are based entirely on animal studies.

Prior to this study, the tools necessary to secure the above information has been developed. Miller (ref. 5) recently reported that a blood boron test measured the magnitude of exposure to boron hydrides for each worker. The test had been perfected and only needed to be given an adequate clinical trial. In addition, instruments had become available to measure the atmospheric contamination by the boranes.

At the Muskogee Plant operated by the Callery Chemical Company, men producing pentaborane were potentially exposed to the boranes on a continuous basis. They had been given careful preexposure medical examinations and were given regular check-ups as needed to insure that they remained in excellent health. The data obtained from these examinations were available for comparison with the blood boron tests and with the apparent exposures as determined by the measurement of atmospheric contamination. The purpose of this study has been to utilize the information obtained from these medical examinations, by the use of the blood boron data, and by monitoring the atmospheric levels of boranes to answer the following questions:

1. What level of atmospheric contamination can be tolerated by workers without clinical effects?

2. Is the severity of clinical intoxication correlated with the blood boron level?

3. Are there electroencephalographic changes associated with borane exposure and are they correlated with the atmospheric contamination?

4. Are there personality changes, and are they correlated with the electroencephalographic changes or other clinical findings?

PROGRAM APPROACH

EVALUATION OF THE EXPOSED WORKER

Before the production of pentaborane was begun, sixty production workers who were going to be potentially exposed to the boranes on a continuous basis were selected to be the study group. Each man was subjected to a comprehensive medical examination with special emphasis on the heart, lungs, liver, kidneys and the nervous system. Any man found to have any physical abnormality was eliminated from the study. Forty workers were selected for the control group. They were doing jobs which would not subject them to possible exposure to the boranes and they were given the same examinations and studies as the sixty potentially exposed workers.

The evaluation of these workers, in addition to the history and the physical examinations, included the following: Hemogram (hemoglobin, hematocrit and white blood count); urinalysis including determinations of pH, specific gravity, albumin, and glucose; non-protein nitrogen; cephalin flocculation; serum protein and albumin; thymol turbidity; blood borane according to the method of Miller; 14" x 17" teleoroentgenograms, electrocardiograms; and vitalometry studies including a tidal volume, vital capacity, timed vital capacity, and maximum breathing capacity. In addition, each worker was evaluated with an electroencephalogram.

During the investigation, effort was made to insure that all borane intoxications were carefully studied. All workers coming to the dispensary with medical complaints, those referred by responsible supervisory personnel, or employees who missed work were considered as potential borane intoxications. Each of these cases was treated by the nurse or first aid man according to the method outlined by the plant physician. If there was any question of poisoning by a borane, the worker was seen by the plant physician. The evaluation at this time included all or any appropriate part of the pre-exposure examination as well as other tests indicated to rule out infection or other diseases. If a personality change was detected, it was evaluated by a consultant neuropsychologist. Then, using all available data, a decision was made as to whether the case represented a definite, a probable, a questionable poisoning, or whether no poisoning had occurred. The following classification of exposures was used. A case was classified as a definite intoxication if there had been a chance of exposure plus a typical clinical syndrome unique to the boranes. (See Appendix I) A probable intoxication had occurred if there was a chance of exposure but the symptoms were not specific (that is, headache, fatigue, lightheadedness, personality change, etc.). A questionable intoxication had occurred if an exposure had been possible but unlikely and the symptoms were non-specific. A "no-exposure" classification was used if any exposure could not have occurred, if the symptoms were atypical, or if another definite diagnosis had been made, such as upper-respiratory infection, or some other infection, etc. These intoxications were also classified as to severity. A poisoning was classified as severe if convulsions, cyanosis, weight loss, liver or kidney changes occurred, or if the symptoms lasted more than three days for pentaborane or more than one day for diborane. The case was classified as a mild poisoning if there were symptoms of lightheadedness, headache, anorexia and if these symptoms persisted only for several hours. A classification of a moderate poisoning was used to include all cases not categorized as mild or severe.

When a case was recognized as a possible borane intoxication, blood was collected for boron analysis at 4-hour, 24-hour, 48-hour, and 72-hour intervals whenever possible.

The treatment used for pentaborane intoxication consisted of either methocarbamol, phenothiazine, barbiturates, meprobamates, or combined therapy of phenothiazine, demerol, and phenergan. An evaluation of these therapies was made on the basis of the clinical response. The cases were given indicated threatment and were observed until they were symptom-free and then were sent back to regular duty.

During the study period, the production workers from the exposure area were observed on a continuous basis. Any absence from work because of illness was investigated as well as any incident reported by supervisory personnel which might have indicated an exposure. Any worker who reported to the dispensary for any reason was evaluated, checking the organ systems discussed above. These men were also evaluated for any possible effects, other than those previously mentioned, which might be produced by the boranes.

Approximately midway through this investigation all production workers were subjected to a re-evaluation including history, physical examination, and blood and urine studies. Where indicated, the examination included respirometry studies, electrocardiograms, and teleoroentgenograms.

At the end of the investigation, a complete comprehensive examination identical to the initial examination was done both on the production group and the control group.

EVALUATION OF THE ENVIRONMENT

The pentaborane production unit (Figure 1) where these men were exposed consisted of an open area approximately 300' deep by 600' long enclosed on the west and north sides by substantial concrete walls 20' high. The equipment within this area was arranged as required by process considerations. A Control Room for remote operation was located west of the concrete wall. It was air conditioned and had an air purification system. The operation of this unit was controlled by remote instrumentation from the Control Room and only a few specific operations required the men to enter the production area. The Operators did check the mechanical operation of the various components on an unscheduled basis to insure proper functioning.

The workers who entered the production area from the Control Room put on specified types of clothing, footwear, and gas masks. Appendix IV describes the safety practices, protective apparel, and protective equipment required for specified work assignments.

The monitoring program using the MSA portable boranes detector required monitoring twelve locations in the operating area on each shift. These twelve locations were chosen on the basis of the grouping of equipment in the area and are shown in figure 1. Each sample was taken at waist height which was the level of the intake of the canisters used with the gas masks. An attempt was made to monitor the point of highest concentration (the site of a previous leak, at a valve, or at a site of accumulation of boric acid).

The personnel working in or passing through the monitored area could have been but were not necessarily exposed to the concentrations monitored. Only the person actually doing the monitoring was necessarily exposed to these concentrations.

After five months, the monitoring program was redirected to supply environmental data that might be usefully correlated with acute exposures. The program was designed to determine the time weighted average exposures for the various operations and for groups of workers. The operations that were selected for study were those which were apparently hazardous.

All samples were taken with standardized instrument techniques using the MSA portable boranes detector. Necessity for evaluation the intrinsic accuracy and reproducibility of the sampling technique was discounted. It was assumed that the source of boron hydrides would be sufficiently continuous to provide a constant source allowing completion of a five point sub-sample pattern.

The data were recorded for a single operation for an intermittent air contamination and consisted of the following:

1. A prescribed sub-sample pattern of at least five air samples taken at mask canister elevation. If time involved was sufficiently long, duplicates were run. The results of samples were recorded on blank pattern sheets, such as figure 2.

2. A written and tabular form was completed which corresponded to the pattern data. It included the names of the men in the potentially contaminated area, the type of clothing, mask (canister or air line) that they wore, and time of exposure to approximated boron hydride level.

The individual sub-patterns were combined after a period of time to give a composite pattern for each operation. These composites were intended to be the approximate boron hydride concentration - distance diagram.

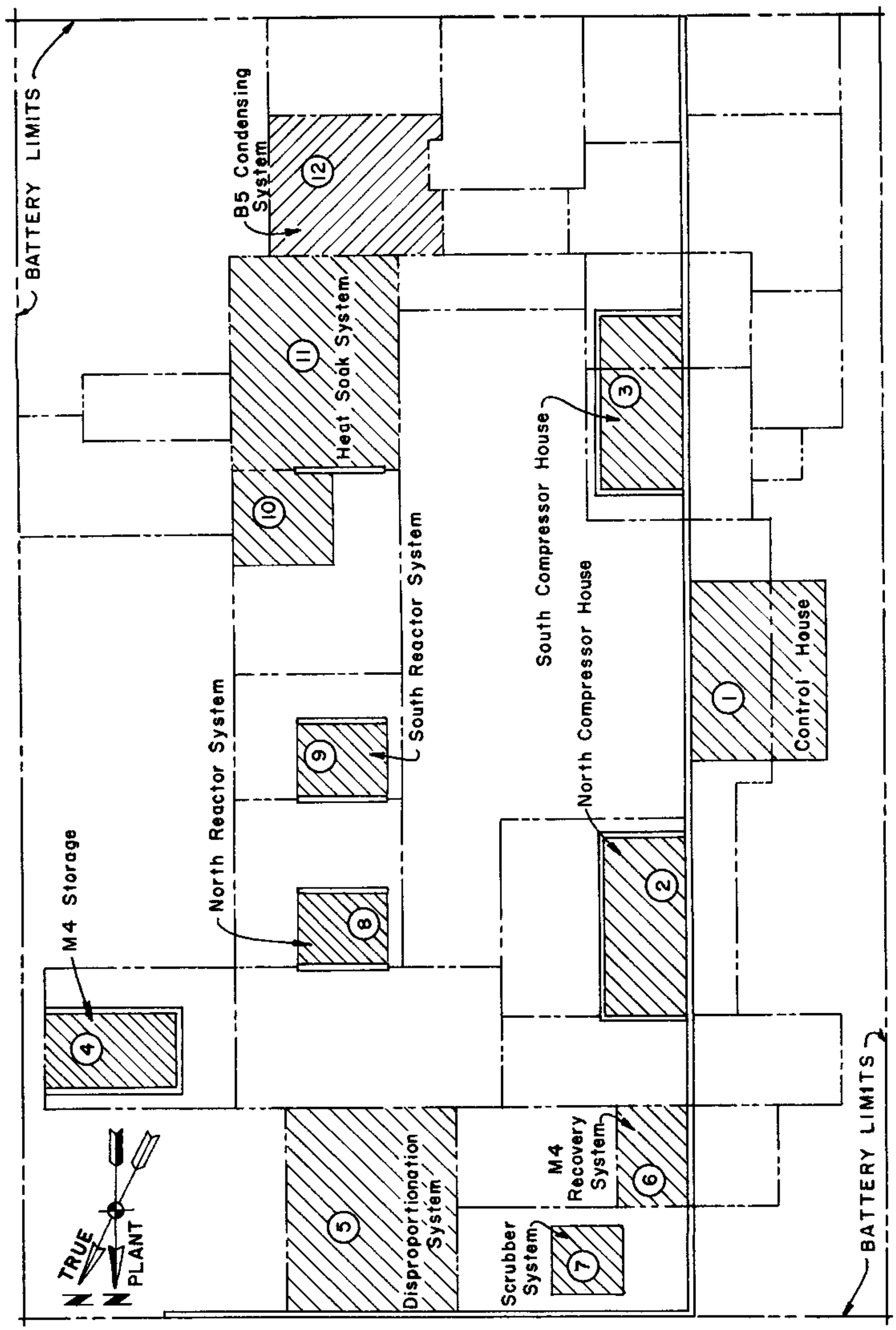


FIG. I
ORIGINAL MONITOR POINTS
BORON HYDRIDE UNIT

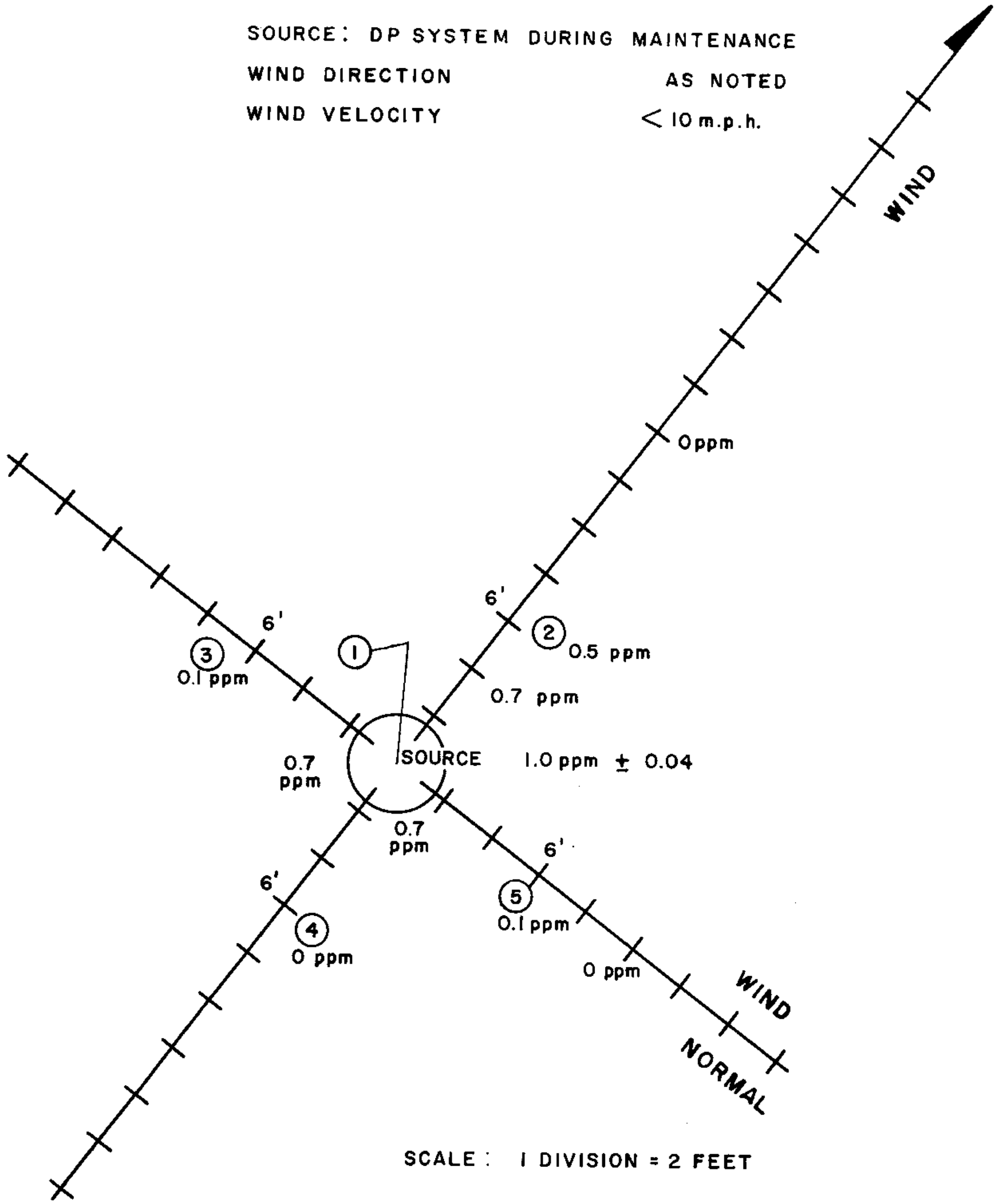
FIGURE 2

A TYPICAL UNIT 400 SAMPLE PATTERN OF BORANE CONCENTRATIONS BASED ON AVERAGE OF ALL TESTS

SOURCE: DP SYSTEM DURING MAINTENANCE

WIND DIRECTION AS NOTED

WIND VELOCITY < 10 m.p.h.



SCALE: 1 DIVISION = 2 FEET

DISCUSSION

ACUTE BORANE INTOXICATION

During the investigation there were thirty-one cases evaluated for acute exposures. Of these cases, ten were classified as definite pentaborane, three were probable pentaborane exposures, three were questionable pentaborane exposures and four who were evaluated as possible exposures were classified as no exposure. There were six definite and four questionable diborane poisonings. In addition, one was either a diborane or decaborane exposure. This worker had been exposed to a mixture of boron hydrides and the case was classified as questionable exposure.

The symptoms and findings in these cases were generally typical of those described in the literature for pentaborane poisonings (ref. 4). The most common finding was the complaint of dizziness and lethargy in cases of pentaborane intoxication whereas the diborane cases presented most frequently a complaint of tightness in the chest with a cough. The more severe cases of pentaborane exposures usually had some type of muscle involvement with tightness in the muscles, and in some cases, actual clonic spasms of muscle groups. The neck muscles were frequently involved. The reaction appeared to have a very self-limited course of three to five days duration, and subsided regardless of therapy (Figures 3 and 4). The cases were treated from a symptomatic approach. An attempt was made to evaluate various sedatives and muscle relaxants. However, no specific drug was found to have any particular advantage. Generally the symptoms were well controlled with methocarbamol, phenothiazine, barbiturates, meprobamates, meperidine or phenergan. A combination of these drugs which seemed to suit the particular case was used with about equal results (Appendix I).

Although there were ten cases classified as definite pentaborane poisonings, there were no severe cases by this classification. There were no convulsions or embarrassment of respiration. Several cases were hospitalized, primarily for study or to allay anxiety, and not because of the severity of the case. This relatively small series of cases occurred while large quantities of pentaborane were being produced and was apparently due to good safety procedures plus the wearing of appropriate protective gear.

The entire battery of laboratory studies was done at the time of each probable poisoning and was again repeated at the end of this study. There was no instance of abnormal results in these tests which could be attributed to the toxic effects of the boranes.

The men working in the exposed areas learned to recognize the symptoms of exposure and reported to the medical service without being alarmed. In most cases, after therapy had been started, they continued working, in a non-hazardous area, without losing time from their job because of the exposure.

FIGURE 3
DEFINITE PENTABORANE EXPOSURES

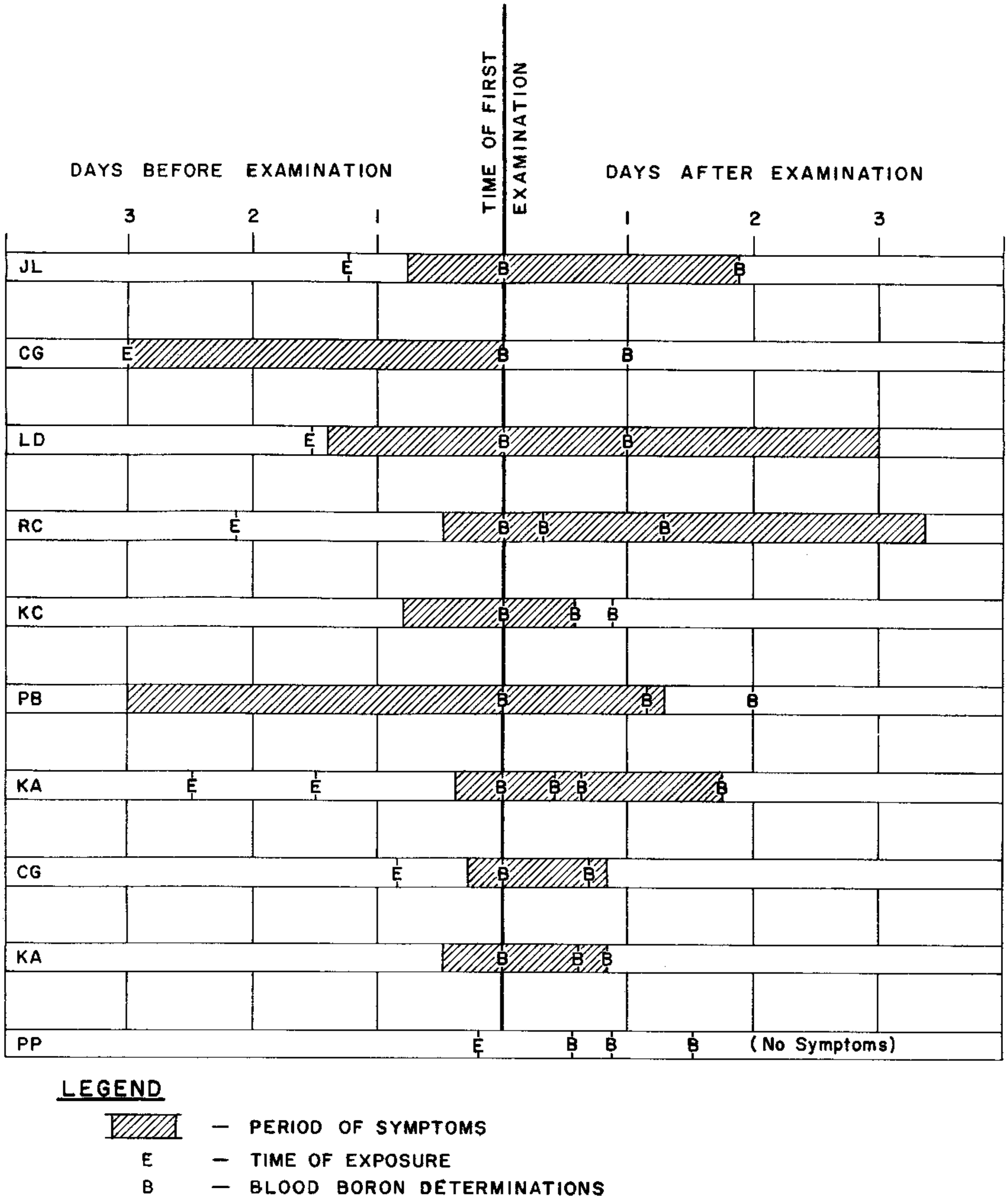
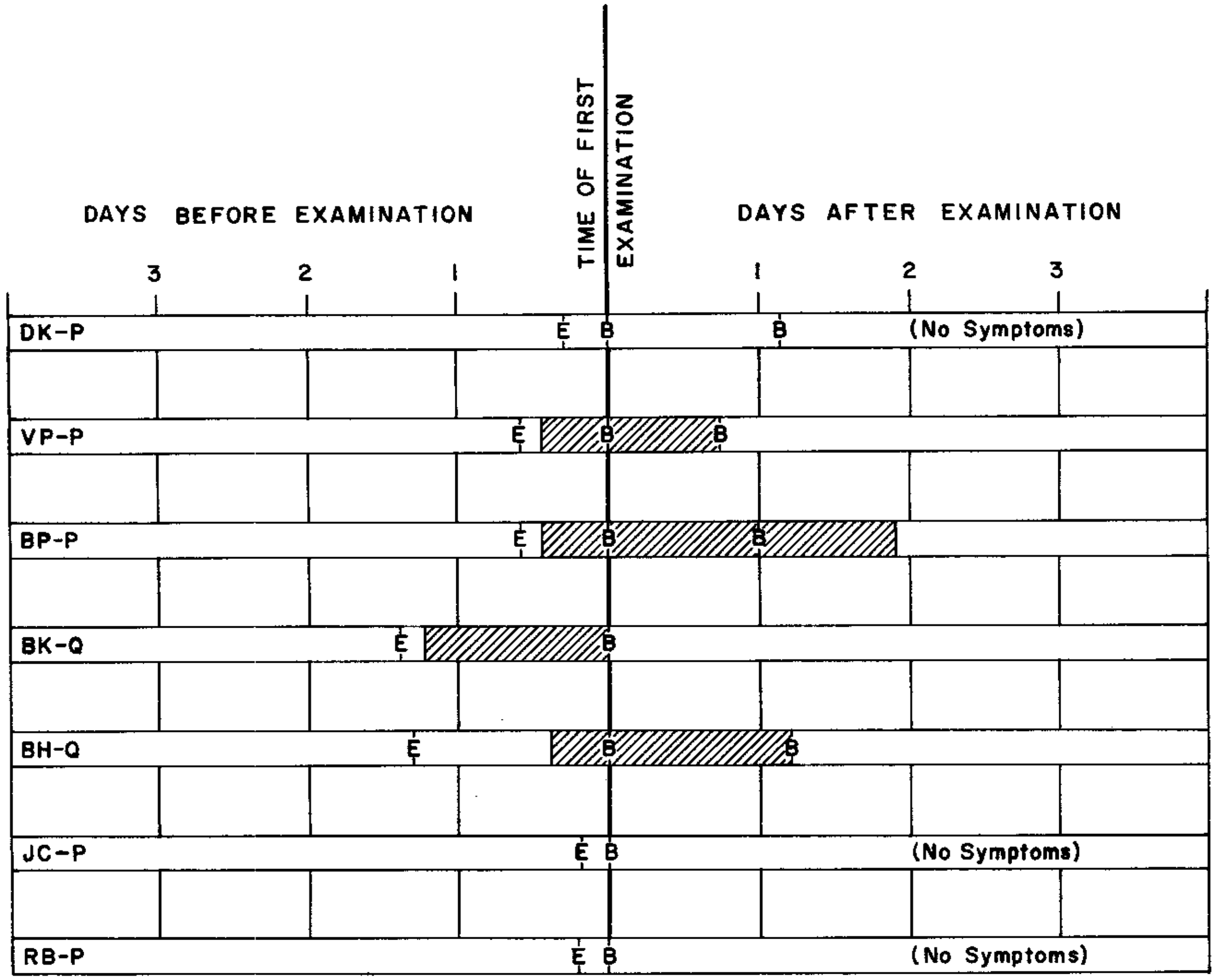


FIGURE 4

PROBABLE AND QUESTIONABLE PENTABORANE EXPOSURES



LEGEND

- [hatched box] — PERIOD OF SYMPTOMS
- E — TIME OF EXPOSURE
- B — BLOOD BORON DETERMINATIONS
- -P — PROBABLE EXPOSURE
- -Q — QUESTIONABLE EXPOSURE

The cases of diborane exposure were very self-limited. These workers frequently did not report to the clinic until the following morning. At that time the symptoms were already beginning to subside (Figure 5). The treatment here again consisted of symptomatic measures with supportive care. These cases were given an expectorant cough mixture with some form of antihistamine, usually chlortrimeton.

It is felt that sufficient data were accumulated to warrant the conclusion that the battery of laboratory studies as outlined in this program did not contribute to the diagnosis or the care of these cases, and that they are not indicated at the time of the acute poisonings in cases of this severity.

In the case of pentaborane exposures, the symptomatology (See Table 1) and the objective findings were limited to the neuro-muscular system and none of these cases showed any evidence of permanent injury. The only psychiatric manifestations in these cases were lethargy reported in nine cases of pentaborane poisoning and acute depression in one pentaborane case. This depression persisted for several weeks and gradually subsided after the employee was removed from the potential hazard area. It is not clear, however, that this case did not represent an anxiety state which had been present and was independent of the pentaborane effect. There were no cases of delirium, confusion, or amnesia reported in this group.

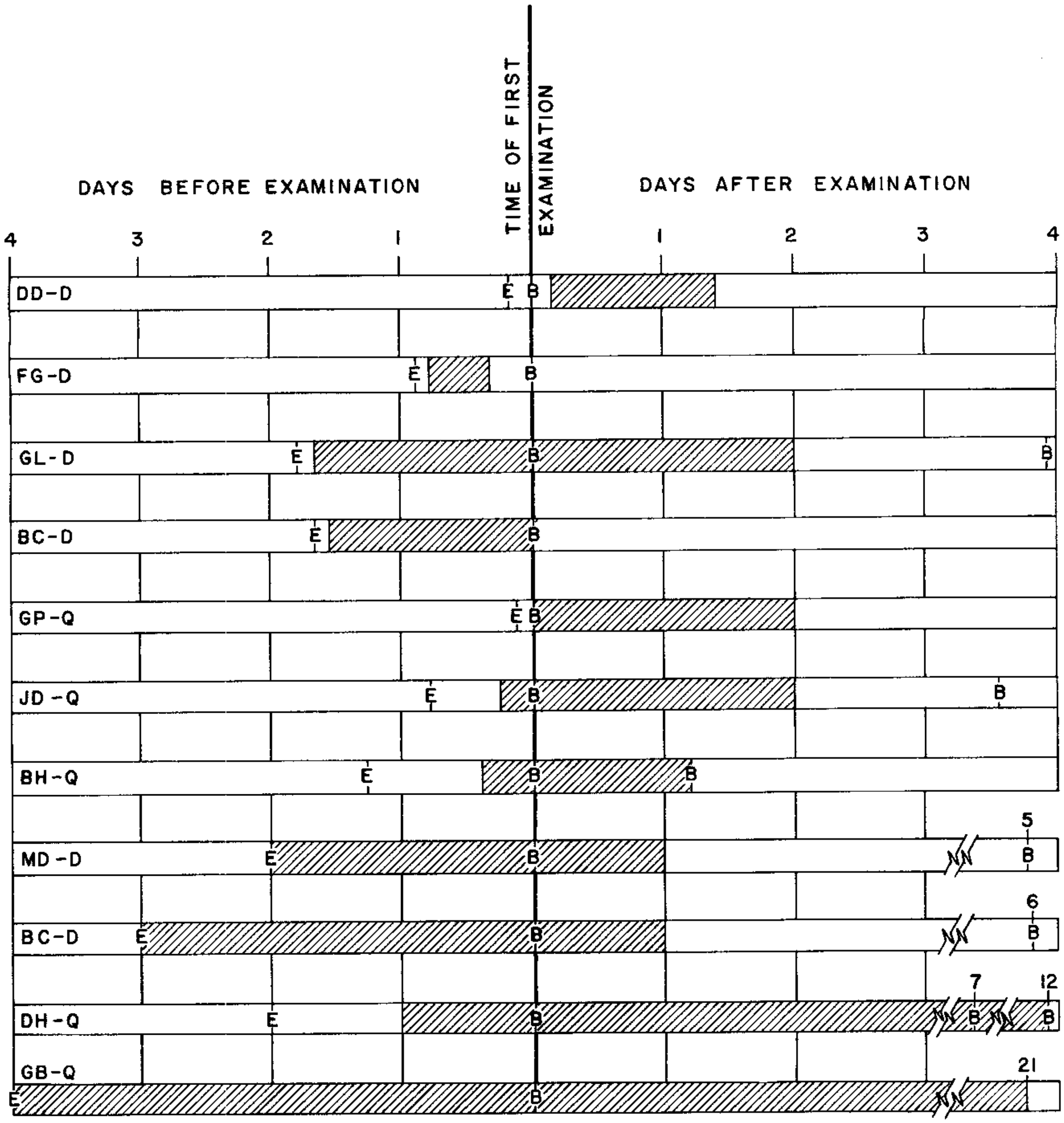
CHRONIC EXPOSURE

During this investigation, there were sixty men whose work potentially exposed them to the boranes on a continuous basis. They wore protective gear but the occurrence of the acute syndromes previously described demonstrate that protection was not completely adequate either because of safety rule infraction or the inadequacy of the protective gear. This portion of the study was designed to determine what chronic effects are produced by the acute syndromes and whether exposure, insufficient to produce symptoms, would produce measurable effects in these workers.

These sixty workers, representing potential exposures to pentaborane, had been carefully screened by history, physical examinations, and initial laboratory studies prior to exposure to the boranes so that there was reasonable assurance that each of these workers was in good health. The pulmonary function studies were not completed until three months after the start of the program; that is, after the workers had been potentially exposed to pentaborane for three months. No electroencephalograms were done on this group until the second month of the program but the electroencephalograms were completed on the entire group during the third month.

The initial study revealed no abnormalities in the exposure group as evidenced by any of the methods outlined in the procedure. Of course, this is not surprising since the workers were chosen for this study only if there were in excellent health. Although the respirometry studies were not really a pre-exposure test, when the results in the exposure group were compared with the control group, there was no real difference.

FIGURE 5
DIBORANE EXPOSURES



LEGEND

[hatched box] — PERIOD OF SYMPTOMS
E — TIME OF EXPOSURE
B — BLOOD BORON DETERMINATIONS
-D — DEFINITE EXPOSURE
-Q — QUESTIONABLE EXPOSURE

T A B L E 1

FREQUENCY OF SYMPTOMS IN PENTABORANE AND DIBORANE EXPOSURES

Symptoms	Pentaborane 13 cases *	Diborane 10 cases **
Anorexia	1	
Headache	5	1
Tightness in chest	1	8
Stiff Neck	5	
Dizziness	12	5
Weakness	5	3
Chills	1	
Myalgia	2	2
Shortness of breath	3	5
Tinnitus	1	
Chest pain	1	1
Poor coordination	4	
Cough		9
Nausea and vomiting	2	5
Blurring of vision	2	
Malaise		1
Eyes burning		1
Nervousness and apprehension	4	
Hiccoughs	1	
Thickness of tongue	1	
Fixed expression	1	
Sleeplessness	1	
Inability to swallow	1	
Dysphagia	1	
Drowsiness and Lethargy	9	
Objective Findings		
Muscle fasciculations	3	
Muscle spasms	8	
Lethargy	7	
Apprehension	3	
Slurring of speech	3	
Poor coordination	2	
Stiffness of neck	1	
Hyperactive reflexes	1	

* Includes 10 Definite and 3 Questionable
** Includes 6 Definite and 4 Questionable

Similarly, electroencephalograms recorded no difference between the control and exposure groups. The conclusions drawn from this initial survey were that there were no differences between the exposure and control groups before there was any contact with pentaborane as determined by history, physical examination, chest x-ray, electrocardiogram, and clinical laboratory tests.

A repeat survey was run on the exposed group during the seventh month of the study period. The men had been in potentially continuous exposure to pentaborane and related boranes. They had been using canisters and full-face masks or air line masks when possible atmospheric contamination could occur, and they also wore gloves, rubber covering for their feet, cotton coveralls, and hard hats. During this time period there had been seven definite and six questionable intoxications due to pentaborane, and five definite and three questionable intoxications due to diborane. This survey recorded no abnormalities by the testing procedure used. Vitalometry, chest x-rays, electrocardiograms, and electroencephalograms were run at this time where indicated.

At the end of the study period, after the plant had been in operation for approximately fifteen months and the workers had been in potential exposure to the boranes for close to twelve months, ten definite and six questionable cases of pentaborane poisonings had occurred, and six definite and four questionable cases of diborane poisonings had occurred. The complete survey as outlined in the procedure was again run on the exposed and control groups.

Again, none of the test procedures used showed any difference between the control and exposed groups. None of these tests revealed that exposure to the boranes under the conditions of the study caused any adverse effects as a result of the exposure. It has been suggested that sub-clinical exposures may occur which might be discovered only by the clinical laboratory procedures as used in this study (ref. 4). No such changes were observed and it would be indeed unusual if such did occur subclinically but did not occur in the definite clinical poisonings. These evaluations of the exposed population lead to the following conclusions. No permanent or persistent injury could be detected in the exposed population after a twelve month observation period although obvious exposures were occurring. There is little reason for doing these tests on a periodic basis if obvious exposures are not occurring. No subclinical cases were discovered and so the question of whether such a syndrome occurs remains in doubt.

The screening procedures used in this study would be of value in the following ways:

1. To insure that no man would be exposed who had a pre-existing disease state that could be aggravated by exposure. This is only hypothetical since it had never been established that such aggravation does occur.

2. When it is decided that worker is no longer to work in the exposure area, a clinical evaluation at that time will avoid possible incrimination of pentaborane at a later date.

BORANE TEST

The clinician is often faced with the difficult decision as to whether a possible borane poisoning is really due to a borane. The non-specificity of the mild case makes this decision difficult. If the blood or urine of such a case were analyzed for boron it would probably always be positive because of the boron content of food, particularly in plant origin. The borane test of Miller because of its selective nature, eliminates this borate ion in the blood. In animal study it has been shown to give blood levels proportional to the dose administered. Several blood samples from human borane poisonings have produced significant blood levels (ref. 6).

The purpose of this investigation was to give the test an adequate clinical trial. The borane test was run at frequent intervals in all possible borane poisonings. The results of the tests were then correlated with the definite poisonings to determine whether a positive test would be found in all of these cases, whether the level was correlated with the clinical severity of the poisoning, and whether the test would be negative in all "no poisoning" cases. The test was then to be used in each of the probable and questionable cases of poisoning to determine whether the test was helpful in deciding if a definite poisoning had occurred.

All the subjects in both groups were given the blood boron test as a part of the pre-exposure examination and the test consistently produced low levels (0 - 0.13 gamma/milliliter). It was apparent from this first sample of one hundred individuals, that levels would need to be above 0.15 gamma or preferable 0.2 gamma/ml. in order to be significantly increased above normal.

In each of the cases where the question was raised as to whether an exposure had occurred, blood boron tests were run at 4, 24 and at 72 hours whenever possible. The typical problems were met in securing samples that occur in any work population. Exposure cases did not report in at the onset of symptoms because early symptoms were nonspecific and it was not until the typical syndrome of borane poisoning developed that he reported to the medical department.

During the study period there were ten cases classified as definite pentaborane poisonings, six questionable, and four no exposure cases. Blood tests were done on all of these cases on an identical schedule.

A positive blood test was obtained in only one of these cases and this case showed evidence of only minimal intoxication by the classification in this study. It seemed most likely that the one positive finding represented a laboratory error.

The animal studies reported using this blood borane test showed a sharp peak in blood levels with acute exposures and then the blood level fell rapidly within twenty-four hours (ref. 6). Figure 4 shows that only six of the ten cases studied at the Muskogee plant had symptoms less than twenty-four hours before the first blood sample was drawn. Of these six cases, only three had symptoms lasting more than twenty-four hours, and of these three, two had serial samples drawn so that a positive test could not have been missed.

Of course, since all of the blood tests were negative in the cases of definite intoxications, the tests were of no value in the questionable cases. A negative test, therefore, did not necessarily mean that there was no exposure in any of these cases. Similarly, since all of the blood tests in the acute syndromes were negative, no conclusions can be drawn regarding the negative results in the periodic and final examinations.

The conclusion drawn from this study of the borane test (and because of the few definite cases, the experience is limited) is that the test is not positive with the moderate poisonings as described in this study. Although the theoretical peak had been missed frequently in this study, this will undoubtedly be a similar problem in future cases because of the nature of borane poisoning. It would appear that as a result of this study this borane test cannot be used as a diagnostic tool in questionable cases of poisoning. It can still be postulated, however, that this test has the potential value of singling out the severe cases, in case of an accident, that will require careful scrutiny.

ENVIRONMENTAL MONITORING

The original monitoring program required continuous monitoring of specific areas of the production unit. Two Mine Safety Appliances Company boranes-in-air continuous analyzers and one Olin Mathieson Chemical Company continuous instrument were to be used for this purpose. These were developmental models that had not been designed for, or proven to be, production plant instruments. From the time that the instruments were made available and instructions for their use furnished, efforts to make them operable failed.

The Mine Safety Appliances Company portable boranes-in-air monitor (of the hand pump type) performed satisfactorily during the entire period of the study. The results are semi-quantitative and are subject to human interpretation. The instrument is not selective for one borane or another nor is it sensitive only to the boranes. Actually, it operates as a function of the reducing power of the material being monitored.

One check of the hand monitoring device was made with a sample concentration of 1 ppm pentaborane and the results obtained agreed with the prepared sample.

The program in its initial phases was designed so that boranes-in-air monitoring data would be collected according to a time schedule from certain specified areas in order to establish the general air concentrations. In mid-May 1961, the monitoring program was revised to include a careful study of places known to be providing area contamination. Sufficient sampling was to be done for each operation to provide data showing borane concentration in the area of its source. These data then would be correlated to account for wind velocity, wind direction, relative humidity, temperature, and time. When developed, the data would enable one to predict the contamination to which operating personnel would be exposed after being in an area for a certain length of time.

On the initial monitoring program, 3,400 samples were made. Analyses of these data revealed that all areas were free of contamination in the great majority of the samples taken. It is apparent from these analyses that the workers in the production were not exposed to a chronic significant concentration while in the production area.

From an analysis of these original samplings, from a knowledge of the operation, and by a study of the poisonings that had occurred, it was decided to concentrate on sites and certain operations from which contamination might be expected in an attempt to better understand the exposures that may account for acute syndromes. Manpower scheduling in the operating unit precluded obtaining data on individuals. Rotating assignments were made in scheduling personnel in order to have a versatile operating force. Since it was impossible to have complete histories on each individual as to the relationship between time and borane concentration for any job, a relationship for each job assignment was made, based upon accumulated boranes-in-air data and the time that an individual in a certain job assignment was in a given zone. These data are presented as averages but any one specific shift may be different from that shown to be the average experience. Data for this compilation are presented in Tables 2 through 6 attached. Table 2 "Average Borane Concentration at Contamination Sources in the Pentaborane Production Unit Operating Area", shows the breakdown by area for the unit and the corresponding borane contamination for the times that some unusual operation or event took place. All areas normally have no boranes present or just a trace amount (less than 0.01 ppm). An unusual operation or event is defined as maintenance work which requires a process line or vessel to be opened, or as those occasions when some known process leak or irregularity does exist. Confidence limits of the contamination levels at the source in these areas were calculated by standard formulas for determining data reliability.

For the extreme conditions, the lower concentrations of boranes were found in the B5 loading area and the highest concentrations during these periods were in the Disproportionation System. Of course, the fractional part of the time that these concentrations exist varies widely from area to area in the unit as determined by the operating experience.

Table 3, "Range of Boron Hydrides Concentration vs Time of Exposure of Production Personnel During an Eight Hour Shift" is calculated by use of Table 4, "Time Spent in Various Areas of the Pentaborane Production Unit by Production Personnel", Table 5, "Borane Concentrations in

TABLE 2

AVERAGE BORANE CONCENTRATIONS AT CONTAMINATION SOURCES IN THE PENTABORANE PRODUCTION UNIT OPERATING AREAS

Area	Borane Concentrations @ 95% Confidence Levels
M4 Recovery	0.5 ppm *
Disproportionation System	1.0 ppm ± 0.04
B5 Reactors	0.4 ppm ± 0.4
North Compressor House	0.8 ppm ± 0.3
South Compressor House	0.6 ppm ± 0.4
B5 Condensing System	1.0 ± ppm
Heat Soaking	0.4 ppm ± 0.4
B5 Loading Area	0.3 ppm ± 0.2

* estimated

TABLE 3

RANGE OF BORON HYDRIDES EXPOSURE TO PRODUCTION PERSONNEL

VS

TIME DURING 8-HOUR SHIFT

Job Assignment	Hours of Exposure at Various Boron Concentrations*						
	0 ppm	0–0.2 ppm	0.2–0.4 ppm	0.4–0.6 ppm	0.6–0.8 ppm	0.8–1.0 ppm	1.0∠ ppm
1. Foreman	7.6		0.1	0.1		0.1	0.1
2. North Panel Board Operator	8.0						
3. Outside North End "A"	6.6		0.9			0.5	
4. Outside North End "B1"	6.2		1.1	0.4		0.3	
5. Outside North End "B2"	6.9		1.1				
6. South Panel Board Operator	8.0						
7. Outside South End "A"	7.3		0.3	0.1			0.3
8. Outside South End "B"	7.0			1.0			
9. B5 Loading	6.4		1.6				

*"Normal" concentration throughout the unit is 0 ppm. The above tabulation represents levels to be generally expected as localized contamination occurs in routine running maintenance.

TABLE 4

TIME SPENT IN VARIOUS AREAS OF PENTABORANE PRODUCTION UNIT BY PRODUCTION PERSONNEL

Job Assignment	Inside Control Room	M4 Recovery Area	Disproportionation System	B5 Reactors	North Compressor House	B5 Condensing System	Heat Soaking	South Compressor House	B5 Loading Area	Out of Area	Total
1. Foreman	6.4	0.2	0.2	0.3	0.2	0.2	0.3	0.2			8
2. North Panel Board Operator	8.0										8
3. Outside North "A"	1.6	1.1	1.1	3.8	0.4						8
4. Outside North End "B"	1.6	0.8	0.6	4.5	0.5						8
5. Outside North End "B2"	1.6	0.8	0.6	4.5	0.5						8
6. South Panel Board Operator	8.0										8
7. Outside South End "A"	1.6					2.9	2.9	0.6			8
8. Outside South End "B"	1.6					2.2	2.3	1.9			8
9. B5 Loading	1.6								4.0	2.4	8

TABLE 5

BORANE CONCENTRATIONS IN OPERATING AREA OF PENTABORANE PRODUCTION UNIT

BORANE CONCENTRATIONS, PPM	Inside Control Room	M4 Recovery Area	Disproportionation System	B5 Reactors	North Compressor House	B5 Condensing System	Heat Soaking	South Compressor House	B5 Loading Area
Normal Operating Level	0	0	0	0	0	0	0	0	0
Expected level for Periods of Non-Routine	0	*0.5	1.0	0.4	0.8	1.0+	0.4	0.6	0.3

*estimated

Operating Areas of Pentaborane Production Unit", and Table 6, "Tabulation of the Percentage of Time on a Job Assignment in a Specific Area at the Increased Borane Concentration Level During Periods of Non-Routine Operation".

Since it is impossible to calculate a time-borane concentration relationship relating potential exposure habits for each individual due to flexibility of scheduling assignments, it was necessary to calculate time-borane concentration relationships for each job assignment as presented in Table 3. The basis for this tabulation begins with the time spent in each area of the unit in each assignment as shown in Table 4. Coupled with this information, data from Table 6 tells the average percentage of time for each job assignment to account for handling usual problems which arise causing individuals to be in an area of higher than normal borane concentration. Over a period of several days this breakdown on time will be correct, but for any given day it may not be an accurate picture of an individual's time usage. Each routine day will include some time in at least one area at the higher borane concentration. Thorough knowledge of the performance of the production unit is necessary to evaluate the time usage for each job. From these tabulations of data, then, one arrives at Table 3 setting forth the number of hours each individual spends in atmospheres of different borane concentrations.

It must be remembered that each individual had gas mask protection while in areas of borane contamination and, therefore, no boranes should have been inhaled by the individual. A study of Table 3 shows that men wearing masks are frequently exposed to concentrations up to 1 ppm. For example, the operator on the north end Area A was regularly exposed to .8 to 1.0 ppm for one half hour per day and to concentrations of .2 to .4 ppm for 9/10 of an hour. These concentrations did not produce symptoms when the man wore his protective gear. The hand monitor used in this study had a maximum reading of 1 ppm and so Table 3 only shows 1 ppm when the worker was actually exposed to concentrations of 1 ppm or more. The sporadic infrequent acute syndromes observed were not monitored directly. The monitoring data in this study were accumulated on a spot sampling basis and these data were not applicable to the acute cases. Rather, the purpose of Table 3 is to present a statistical approach to the concentrations tolerated under the conditions of exposure in this study and must be evaluated in terms of the many assumptions made in developing this table.

This monitoring program was also designed to evaluate the effect of prevailing wind velocity, wind direction, humidity, ambient temperature, and the time function relating to the duration that a concentration will exist in the area once it is introduced. Figure 2 shows the spread of borane contamination from a point source for one of the areas in the operating unit. These data and similar data for the other areas reveal that only a small portion of any area would be effected by a source of contamination. No quantitative amount of borane contamination would be found further than 15 feet down wind from the source. On the up wind side of the contamination source, any distance over four feet from the source would be free of the boranes. Air movement in the immediate area promotes dispersal. It appears that mixing with the oxygen in the air promotes relatively rapid oxidation to nontoxic materials (ref. 1).

TABLE 6

TABULATION OF A PERCENTAGE OF TIME ON A JOB ASSIGNMENT IN A SPECIFIC AREA AT THE INCREASED BORANE CONCENTRATION LEVEL DURING PERIODS OF NON-ROUTINE OPERATION

Job Assignment	Inside Control Room	M4 Recovery Area	Disproportionation System	B5 Reactors	North Compressor House	B5 Condensing System	Heat Soaking	South Compressor House	B5 Loading Area
1. Foreman	0	0	50%	30%	0	50%	0	40%	0
2. North Panel Board Operator	0	0	0	0	0	0	0	0	0
3. Outside North End "A"	0	0	50%	25%	0	0	0	0	0
4. Outside North End "B"	0	40%	40%	25%	0	0	0	0	0
5. Outside North End "B2"	0	0	0	25%	0	0	0	0	0
6. South Panel Board Operator	0	0	0	0	0	0	0	0	0
7. Outside South End "A"	0	0	0	0	0	10%	10%	20%	0
8. Outside South End "B"	0	0	0	0	0	0	0	50%	0
9. B5 Loading	0	0	0	0	0	0	0	0	40%

Use of gas masks prevents inhalation of toxic materials to a large extent. However, a few people in the operating area have reported smelling odors while wearing the mask working around these sources. It would appear that exposure resulting in symptoms may be due to canister penetration, inadequate protective clothing, failure of the worker to properly use respiratory protection, or neglect of personal decontamination. Preliminary evaluation of the gas mask canister suggests that penetration by pentaborane does not occur (ref. 9).

SUMMARY AND CONCLUSIONS

Sixty men who had no previous exposure to the boranes but who had job assignments that would require potentially continuous contact with pentaborane were given careful, comprehensive clinical examinations.

During the study period (twelve months), they worked in an area that was intermittently in small areas, but not continuously, contaminated with pentaborane and diborane. The area was never contaminated throughout at any one time and usually there was no contamination. The upper level of contamination could frequently not be determined because the monitoring instrument available had upper limits of 1 ppm for pentaborane, and 3 ppm for diborane.

The actual level of exposure of these men could not be determined because they wore full face masks with canister or air line and wore protective gloves, coveralls with full sleeves, and rubber foot covering.

It was apparent that these workers were not exposed on a continuous or chronic basis, and therefore no threshold limits (while wearing a mask) could be established. Because of the nature of the work schedule, actual acute or subacute tolerances could not be evaluated, and instead average levels of exposure were calculated and are listed in table 3 (i.e., workers are regularly in areas that have more than 1 ppm for .3 hour without developing symptoms). Since the table lists average time spent on the job and average contamination, it is obvious that higher levels of concentration occurred as well as longer times of exposure. Since these concentrations (Table 3) are a measure of the concentrations at the source, they are higher than at the canister intake or mask level. Table 3 is an approach to evaluating the acute and subacute tolerance levels of workers when protected as they were in this work situation.

During this study period there were twenty cases evaluated as possible pentaborane intoxication and of these, ten were classified as definite pentaborane poisonings.

The pentaborane cases were typical pentaborane poisonings and none were considered severe by our classification. All had primarily neurologic manifestations without apparent liver, kidney, heart, or lung involvement. The only psychiatric manifestation noted in these cases was lethargy and this was seen only as part of the acute syndrome. One case did have an acute depression with the acute phase, but this may well have been the result of an anxiety state brought on by concern for his safety. Treatment did seem to give symptomatic relief in all cases.

There were eleven cases of possible diborane poisoning and six of these were definite diborane poisoning. These cases were all typical diborane cases and were self-limited.

At the end of the study period a repeat comprehensive clinical examination revealed no evidence of chronic effect in those who had

had acute syndromes, nor in others who had had potential exposures. The examination included careful history, physical examination, chest x-ray, liver function, urinalysis, non-protein nitrogen, electrocardiogram, electroencephalogram and respirometry.

The blood borane test was done on all possible intoxications. This limited experience indicates that low level exposures producing minimal symptomatology will not yield blood concentrations above the sensitivity of the test.

APPENDIX I

A TYPICAL CASE OF PENTABORANE INTOXICATION

In most cases of pentaborane poisoning, the victim stated he had been wearing a full face gas mask, leather gloves, cotton coveralls, and rubber footwear. He could invariably recall an incident within the previous 48 hours when he had noted the distinct odor of pentaborane through his mask. He further related the odor to a definite leak or spill of pentaborane.

When first seen, he complained only of nervousness, drowsiness, and tight muscles. During the 24 hours prior to being seen, he had been sleeping most of the time. His family had some difficulty arousing him but he ate normally and had come to work, fully expecting to do his accustomed job. Shortly before reporting for examination, he had noted tightness in large muscles and usually had a drawing of his neck muscles that rotated his head. These muscle spasms were extremely painful.

At the time of examination, he was lethargic and he appeared somewhat pale. The only positive physical findings were the following. There was tightness of the neck muscles with occasional slow turning of the head. Scattered fasciculations of muscles were seen over the shoulders, thighs, hands, and about the face. There was marked slurring of his speech and coordination was poor. The deep tendon reflexes were hyperactive.

Laboratory studies were all within normal limits. When first seen, the patient was given an injection of meperidine and chlorpromazine. He was put at bed rest and started on chlorpromazine by mouth, 25 mg. every four hours and methocarbamol, one gram by mouth every four hours. On this medication, he slept almost continuously for 12 to 24 hours. By the following day his symptoms had subsided, but he was kept on the same therapy for two to three days. He had no further symptoms.

More severely poisoned cases were not seen in this series. The more severe cases were characterized by almost continuous generalized muscle tremor and spasm, including the chest muscles. Respiration is embarrassed. When treated with intermittent oxygen by mask, cyanosis is not evident.

APPENDIX II

SUMMARY OF TYPICAL PENTABORANE EXPOSURE (CASE K. C.)

DATE	6-14-60	3-6-61	3-7-61	3-10-61	5-18-61	11-8-61
Purpose of Visit	Init. Exam.	Exp.	Follow-up		Lab.	Final
Symptoms	No	Yes	Yes	No	No	No
Physical Findings	No	Yes	No	No	No	No
Laboratory Urinalysis	N	N			N	N
Hematology Hemoglobin (Gm%)	13	14.7			13.9	16.4
Hematocrit (%)	50	48.5			50	43
WBC	7,900	7,650			6,450	10,750
Blood Chemistry Ceph. Floc. (48 hrs.)	0/1+	0/1+	0/1+		0/1+	0/0
Thymol turbidity	2.7	1.0	QNS		1.0	4.8
Total Protein (Gm %)	6.8	6.9	6.6		6.1	8.5
Albumin (Gm %)	5.0	5.0	4.6		4.0	5.12
NPN (Mg %)	29	29	22		27	26
Boron (Gamma/cc)	0	<0.1	<0.1		<0.1	0.05
Electrocardiogram	N	N				N
Chest X-ray	N	N				N
Respirometry Tidal Volume (cc)	500	800				680
Vital Cap. (cc)	3700	4050				4270
1 Sec. TVC (%)	99	86				81.82
Max. Breath. Cap. (liter/min)	150	102				143
Electroencephalogram				N (3-21-61)		

APPENDIX III

CLINICAL STUDIES ON A TYPICAL PRODUCTION WORKER DURING THE INVESTIGATION

		Pre-exposure	Interim	Final
Hematologic:	Hematocrit (%)	50	50	43
	Hemoglobin (Gm/100cc)	13.1	13.9	16.4
	W B C (wbc/cmm)	7900	6450	10,750
Urinalysis:	Reaction (pH)	6.5	5.0	5.5
	Specific Gravity	1.021	QNS	1.027
	Protein	0	0	0
	Sugar	0	0	0
Blood Chemistries:	Ceph. Floc. (48 hr)	1+	1+	0
	Thymol Turbidity (Units)	2.7	1.0	4.8
	Total Protein (gm%)	6.8	6.1	8.5
	Albumin (gm%)	5.0	4.0	5.1
	N P N (mg%)	29	27	26
Electrocardiogram:	P R Interval (Sec)	.14	-	.16
	QRS Interval (Sec)	.06	-	.08
	Mean Axis	+60	-	+60
	Impression	Normal	-	Normal
Respirometry:	Tidal Volume (cc)	500		680
	Vital Capacity (cc)	3700		4270
	1 Sec. Timed Vital Capacity (%)	99		81.82
	Maximum Breathing Capacity (1/Min)	150		143
Blood Boron:	(Gamma/cc)	0.0	0.1	0.05

Similar studies were done on each production worker. The same studies were done on control workers except that the interim examination was omitted.

APPENDIX IV

SAFE PRACTICE PROCEDURE WHEN WORKING WITH BORANES

Purpose: To establish safe practices, protective apparel, and protective equipment for specific work assignments when working with the boranes.

I. Personnel

A. All personnel who regularly are potentially exposed to the boron hydrides shall be in excellent health as determined by the Medical Department.

B. When personnel outlined in "A" above are suffering from head or chest colds, sore throat, etc., they shall be sent to the Medical Department promptly. The physician will determine if employee should be assigned outside of the boron hydride exposure area.

II. Protective Apparel

A. Changes of clothing from the skin out in various sizes, including footwear, will be available for emergency use or as described in specific procedures.

B. Clean foul weather gear will be kept in a convenient location on special racks.

C. Approved foot protection, i.e., boots or rubbers, will be furnished and replaced as often as indicated by wear.

D. Approved gloves will be furnished and replaced as often as indicated by wear.

E. Protective apparel will be replaced as often as wear indicates holes or voids.

F. Safety portion of training employees on B5 operations will cover protective apparel, wearing of, caring for, etc.

G. Additional protective apparel will be furnished as deemed necessary.

H. Contaminated clothing will be picked up daily by the laundry and returned the following day.

III. Protective Equipment

A. Each employee assigned to the boron hydride exposure area full time will have a personal gas mask assigned to him permanently. Each employee will be responsible for keeping his mask decontaminated, sanitary and in proper working order at all times. A representative of the Safety Department will check each gas mask monthly for proper operation of valves, leaks, etc. Any known malfunction of a gas mask, other than those detected on inspections, should be called to the attention of the shift fireman. He in turn will immediately repair or replace the mask.

B. Gas masks furnished are the full view type and are designed for use on canister and plant air. Masks are equipped with a special valve and plant air quick coupling connection, so when plant air line is connected to the masks, it automatically stops flow of air through the canister and the mask then has a demand, positive pressure air flow.

C. All personnel must test their gas mask to be sure they fit tight and are free from leaks prior to each entry into the exposure area. This test is performed by putting the mask on the face, squeezing off the breathing tube between the mask and the canister, and inhaling. If the mask collapses on the face, it is tight and free from leaks.

D. In cleaning and sanitizing gas masks, never use solvents, alcohol, or other hydrocarbons. Use only the detergents supplied for that purpose. Hydrocarbons and solvents tend to deteriorate rubber materials.

E. Special or additional protective equipment or apparel, other than hard hat, gas mask, coveralls, gloves, and boots, necessary to performing maintenance work will be specified for each job.

F. The exposure area will be constantly monitored with portable analyzers by the Safety Department.

IV. Decontamination - Equipment

A. Decontamination of any equipment removed from service in the boron hydride area will be carried out only in the waste disposal unit. Hazardous work permit will be required and will specify protective apparel to be used.

B. Decontamination of the B5 closed system will be in accordance with published washout procedure.

C. Decontamination materials adopted for use will be applied in the manner prescribed in the unit operating manual.

D. Vehicle floor boards shall be decontaminated in the waste disposal unit as often as necessary.

V. Decontamination - Personnel

A. Employees assigned to or required to work in the exposed area shall take as many showers and make as many complete apparel changes as instructed by their foreman, on each shift, after exposure to toxic materials. If personal clothing becomes contaminated, it will be laundered.

B. The nature of the process liquids and solids handled are such that in the case of contact with small amounts on the skin or clothing, they must be removed immediately by changing clothes and showering in the shower room. Any person who may have his skin or clothing come in contact with large amounts of liquids or solids shall get into the nearest emergency shower as quickly as possible. The entire body and clothes must be water flushed for not less than five minutes. Following the emergency shower in the field, the person will then go to the decontamination facility, remove all clothing and take a hot shower using plenty of soap. At this point, he puts on clean clothes from skin out.

C. Contaminated clothing is to be placed in the provided containers outside of the decontamination facility. Contaminated clothing is not to be left in the uncontaminated room or decontamination room under any circumstances.

D. All personnel leaving the exposure area must decontaminate footwear in triethanolamine foot bath provided.

VI. Traffic Control

A. No vehicle traffic will be permitted in the boron hydride area except by Hazardous Work Permit.

B. Personnel traffic into the boron hydride area shall be limited to authorized personnel and emergency personnel who have specific work assignments in the area. All persons will log in and out in log book provided in control room.

VII. Additional Requirements

A. Wearing of complete gas mask (on the face), hard hat, coveralls, approved gloves, and footwear (boots) is required, at all times, in the exposure area.

B. All personnel going into the boron hydride area must connect their gas mask to plant air line immediately on arriving at work point or area and remain on plant air until time to leave the exposure area. Air line stations are located to cover all areas. Personnel going from one area to another must disconnect their air line and recoil it on the wall hanger.

C. When it is necessary to perform work more than 50 feet from the nearest air station, the Safety representative on duty is to be summoned to provide additional air hose lengths to reach the work site.

D. Air line stations are equipped for six hose connections (6 man) each. In the event there is an inadequate number of hose lines at a given station, for the number of men performing work in that area hose lines may be borrowed from a nearby station that is not in use. However, when hose is borrowed from an air line station, it is to be returned to that station as soon as it has served its borrowed purpose.

E. Air line hoses are not to be dropped or left on the ground after use. Such practice results in damaged and/or contaminated couplings, possible cutting or damage to hose and provides tripping hazards to other workers. Air line hose is to be recoiled and placed on pegs provided at each station after each use.

F. Personnel involved in B5 loading and sampling must wear foul weather gear in addition to the items mentioned in Paragraph "A" of this section.

G. Deliberate venting or spilling of B5 to the atmosphere or ground is prohibited. This includes sampling and cylinder loading.

VIII. Housekeeping

A. Good housekeeping is a requirement for all areas. Housekeeping is especially important in areas where toxic materials are handled.

B. Clothing and equipment which is not in service must be stored in its proper location.

C. All tools must be decontaminated and returned to their proper location at the end of each shift.

D. The control room, lunch room, locker room, shower room, and decontamination facility should be kept neat and clean and free from discarded material at all times.

IX. Personal Hygiene

A. All lunches shall be stored and eaten only in the lunch room.

B. All personnel who eat their lunches in the boron hydride unit lunch room must be sure that their skin and clothing is free from contamination prior to eating.

C. All persons entering the exposure area must continually guard against ingestion (swallowing) of toxic materials. Do not carry cigarettes, chewing tobacco, gum candy, or any other food. Keep in mind the possibility that anything you touch in this area may be contaminated with toxic materials. Wash hands frequently. Keep fingers, pencils, etc., out of your mouth, even when out of the exposure area. Always wash your hands and face before going for a smoke. Do not put your feet on chairs, tables or desks.

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