TECHNICAL REPORT

EFFECTS ON MENTAL FUNCTIONING OF PERSONNEL WORKING WITH PENTABORANE AS A ROCKET ENGINE FUEL

AUGUST 1961

Liquid Systems Division
Directorate of Rocket Propulsion
6593d Test Group (Development)
AFSC Edwards AFB, California

Prepared For

Headquarters
6593d Test Group (Development) AFSC

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By

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EFFECTS ON MENTAL FUNCTIONING OF

PERSONNEL WORKING WITH PENTABORANE

AS A ROCKET ENGINE FUEL

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ABSTRACT

This research effort represents an attempt to apply experimental methodology in a study designed to determine cumulative effects on mental functioning of personnel working with pentaborane as a rocket engine fuel. The results statistically showed that there were no significant changes in mental performance as measured by the Wechsler Adult Intelligence Scale following a period of 10 months duty as engine mechanics.

As a supplementary investigation, psychodiagnostic testing was administered to personnel with a work history on this pentaborane project. These tests consisted of questions referring to neuropsychiatric and psychosomatic symptoms, the results of which were related to job adjustment as measured by several criteria. While the analysis of findings did not reveal statistically significant relationships, at least in a critical sense, there was some evidence suggestive of the practical usefulness of such tests. Information obtained from these psychological measuring tools was seen to serve a purpose as part of the personal medical history to assist physicians in diagnosing complaints of propellant intoxication, the symptomatology of which is not often clear. Secondly, there is their suggested use as reference material for job placement purposes in R and D programs having a potentially hazardous environment.

INTRODUCTION

Basic research and experimentation with high energy fuels has been in answer to military needs for higher performance propellant systems suitable for ballistic missiles and other space applications. Of the high energy chemicals whose energy potential is significantly superior to the conventional hydrocarbon fuels, the boron compounds offer promising applicability as a propellant fuel for air breathing and rocket engines. The relative superiority of boron as a fuel element is based on the nature of its chemical properties and ready availability. One unfortunate characteristic of the boron hydrides, however, is their toxicity.

Only during the past decade with the increasing use in laboratories, industries, and in their development as high energy fuels has attention been directed to determining extent and nature of specific toxic properties of the various members of the borohydrides. A great deal of the early toxicity studies were undertaken concurrently with the development work on borane high energy fuels initiated under Project ZIP by the Department of the Navy in 1952. Since 1956 when the Air Force took over an active developmental role in this program, toxicological investigations have been included as an integral and significant part of research programming.

The Aeronautical Systems Division, Air Force Systems Command, is presently conducting an on-going comprehensive borane toxicity research program through coordinated in-house and contractual efforts. This work includes pharmacological and neuropathological studies; studies on organic pathology of exposed animals; toxicological and clinical research on cases of industrial accidental exposure; acute toxicity screening studies on animals; enzymatic aspects of borane intoxication; research on borane compounds and their chemical reactivity with body fluids and proteins, etc. In addition, monitoring devices are under development and are being tested for detection of low concentrations of boranes.

While a body of scientific knowledge is growing on the toxicological effects of the boron compounds, controlled investigations have been confined to animal studies. As to toxicity in humans, there is little else in the literature other than reports of clinical observations made of cases following accidental exposure the incidence of which has been low, at least, when speaking in terms of acute toxicity. But with the increasing interest in the use of boron compounds as propellant fuels, there is the consequent military responsibility to obtain controlled experimental evidence for making conclusive determinations of the effects on personnel handling these "exotic fuels" during normal operational duties.

The study reported here is devoted to such a task. More specifically, it is concerned with the cumulative effects on mental functioning of personnel working with pentaborane under the operational and environmental setting of Project Joshua. Project Joshua is an R and D program designed to determine the feasibility and operating characteristics of pentaborane for use as a high energy propellant for advanced military propulsion systems.

While there is no research material to report falling within the specific subject area of this study, it may be relevant to preface this presentation with some reference to the chemical nature and observed toxicological effects of the boron hydrides, particularly pentaborane.

The boron hydrides or boranes are composed of boron and hydrogen. They are strong reducing agents and react readily with ammonia, organic amines, unsaturated hydrocarbons and various heterocyclic amines. "The possibilities for chemical interference in biological processes are therefore manifold."[1]

Pentaborane (B_5H_9) is a volatile liquid, is pyrophoric and slowly hydrolyzed. It is an extremely toxic compound and attacks the central nervous system rather than the pulmonary system as does diborane. With B_5H_9 pulmonary symptoms are rare. The effects of acute inhalation exposures for animals are a function of concentration level and exposure time. For example, in a study with mice, all of six experimental animals exposed to a concentration of 10 ppm were dead within a period of 90 minutes. For mice

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1. Tamas, A. D., Smith, D. L., "State-of-the-Art Report on Health Hazards of Borane Fuels and Their Control," Aero Medical Laboratory, WADD, ARDC, USAF, Wright-Patterson AFB, Ohio, October 1958, p. 6. (Informal publication)

exposed to a concentration of 5 ppm, none died during an exposure of 177 minutes, although two had convulsive seizures.[2]

In animal studies of subacute concentrations of pentaborane (about 3 ppm), behavior after repeated exposure was characterized by belligerency, hyperexcitability and persistence of tremors.[3] An important finding in this area of investigation was than an accumulative toxic effect appeared to be built up in rats with repeated subacute exposures as judged by the observations recorded and the mortality found among animals. In fact, this type of exposure might be potentially more serious than single acute exposures.[4]

While research has been undertaken to determine pharmacological action of the boron hydrides and their findings reported, for purposes of this presentation brief reference will be made only to routes of intoxication and symptomatology. The boron hydrides have sufficient vapor pressure to produce toxic concentration in the atmosphere. Inhalation of toxic fumes is, therefore, the major hazard. The American Conference of Governmental Industrial Hygienists adopted in 1960 a tentative TLV (threshold limit value) for daily exposure to pentaborane of 0.005 ppm.[5] Only tentative values have been established as no detection method has yet been developed which can reliably measure such low concentrations.

In working with a toxic propellant, the question arises concerning olfactory sensitivity, i.e., the detectable concentration by odor. In an Army Chemical Corps study the median (50th percentile) detectable concentration of pentaborane by odor for man is given as 2.5 mg./m.^{3}, with a range of

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2. Chemical Corps Project No. 4-61-14-002, Progress Report from Dept of Pharmacology, Medical College of Virginia, 15 July 1957.

3. Svirbely, J. L., "Subacute Toxicity of Decaborane and Pentaborane Vapors," AMA Archives of Industrial Hygiene and Occupational Medicine, Vol. 10, October 1954, pp. 305-311.

4. Ibid., p. 311

5. American Medical Association Archives of Environmental Health, Vol. 1, No. 2, August 1960, "Threshold Limit Values for 1960," pp. 140-144.

1.7-3.6.[6] Converting this median value to ppm by volume gives .76, with a range of .52 - 1.1.[*]

Another hazard is skin contamination. In a liquid state pentaborane can readily penetrate the skin. While local effects on the skin are negligible, subsequent absorption can cause systemic poisoning. With contamination of the eye local effects are severe, and if not washed away immediately, systemic poisoning follows. While skin contamination is not uncommon, inhalation is by far the main route of intoxication and the one which presents the greatest hazard.

Initial symptoms of pentaborane intoxication might include headache, nausea, hiccups, with such subjective feelings as drowsiness, dizziness, and light-headedness. Depending upon degree and time element of exposure, this might be followed by nervousness and shivering progressing into tremors, muscular pain and cramps, involuntary muscle contractions, and in very severe cases, general convulsions have been observed. Other effects on the central nervous system may be manifest in a temporary impairment of higher mental functions, lack of coordination, transient amnesia for recent events, certain perceptual disturbances and vague feelings of depression, fatigue, and anorexia.

The onset of symptoms has been reported variously from one-half hour to several hours after exposure. Time of onset is undoubtedly dependent upon extent of exposure. One study reports that neurologic signs may ensue or may not appear for 48 hours.[7] While the clinical picture of an incident of

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6. Comstock, C.C., Oberst, F.W., "The Median Detectable Concentration of Diborane, Pentaborane and Decaborane by Odor for Man," Research Report No. 206, Army Chemical Center, Maryland, August 1953.

* The reader should be cautious when reviewing the literature in noting the units in which these values are sometimes given. Some of the literature gives the same numerical values for the MDC and MAC for boranes as are reported in the Army study but are not given in the same units, e.g., 2.5 mg./m.^{3} is given as 2.5 ppm, the latter of which is very likely in error.

7. Lowe, H.J., Freeman, G., "Symptoms of Boron Hydride Poisoning," Mod. Med. 26, No. 4, 128 (1958), National Institute of Health, Bethesda, Md.

pentaborane poisoning is the most vividly severe of the boron hydrides, response to therapy is satisfactory and recovery is complete within a few days with no noticeable after effects.[8] But as previously suggested, the absence of any overt symptomatology does not rule out the presence of chronic intoxication. In a recently published study by WADD, it was concluded that "a negative test does not exclude the presence of chronic borane intoxication, especially when low-level, daily occupational exposures have led to tissue saturation with boranes."[9]

Only a brief and certainly unsophisticated technical discussion of the chemical nature of pentaborane has been attempted and the same might be said for the rather sketchy outline presented of the rich and dramatic symptomatological picture revealed in cases of borane intoxication. This introduction is meant only to initiate the inexperienced reader into a relatively new joint scientific and military research effort - that of the borane hydrides. For purposes of this presentation, specific reference has been made only briefly to the potential military usefulness of these chemical compounds and to their accompanying potential health problems which must be experimentally and clinically identified and described if we are to achieve the necessary high standards of preventive medicine.

Apart from the relatively small study reported here, a comprehensive research program is being conducted at the Directorate of Rocket Propulsion which is concerned with the identification and control of potential hazards inherent in several propellants, one of which is pentaborane. This program has included (1) investigation of the physical and chemical properties of the propellants, (2) development of environmental detection methods, (3) development of facilities, equipment and procedures for propellant safety handling and (4) toxicological studies. Here an effort is being made to determine changes in blood borane level of personnel subjected to potential exposure to

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8. Tamas, op, cit.

9. Miller, D. F., et al., "Cumulative Effects of Borane Toxicity as Revealed by a Clinical Test," WADD Technical Report 60-604 (Biomedical Laboratory, Aerospace Medical Division), August 1960.

pentaborane. A report of findings to date was recently presented at the American Industrial Health Conference of 1961.[10]

Of particular interest has been the test and evaluation of instruments to detect pentaborane in air. Several are presently under study, each of which is based on a different system of detection. One, for example, operates on gaseous conduction phenomena (ion currents) as affected by aerosols, another employs coulometric titration cells for detection, etc. A full description of these instruments is reported in a recently published AFFTC Technical Report.[11] The detector presently being used in field operations under Project Joshua is described in the next section.

Specific effort is also being devoted toward the improvement of personal protective clothing and equipment. At the present time there is no commercially available single unit which is resistant or impermeable to all of the propellants currently in the Air Force inventory or in the R and D stage of development. Also, the available suits are usually hot and uncomfortable to wear, possess little if any heat resistance in event of fire and require an external breathing air supply. Research and development (contract) work will soon be completed on a propellant safety suit which will eliminate or correct these negative features. It is anticipated that a prototype suit will be available for testing before the end of the year.[12]

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10. Bratt, H.R., Kittilstad, O.H., "Industrial Hygiene Support to Rocket Test Operations," AFFTC, Edwards AFB, Calif. Paper presented at American Industrial Health Conference, Los Angeles, Calif., 13 April 1961.

11. Goshgarian, B.B., Jensen, A.V., "A Study of Pentaborane," AFFTC Technical Report 61-34, Edwards AFB, ARDC, USAF, May 1961.

12. Bratt, op. cit.

DESCRIPTION OF STUDY

The primary purpose of this study was to determine possible cumulative effects on mental functioning of crew personnel working under those operational and environmental conditions as exist under Project Joshua at the Rocket Site, Edwards AFB.

A. Method

1. Measuring Instrument

The testing device used to measure mental functioning was the Wechsler Adult Intelligence Scale (Revised 1955). The WAIS provides a Verbal IQ (Intelligence Quotient), a Performance IQ and a Full Scale IQ (combined Performance and Verbal subtests). Other than providing a numerical score, this scale also makes possible an examination of patterns of intellectual disturbance. Questions are grouped into various subtests, each of which (presumptively) measures a different kind of mental function. Intellectual patterning can also be analyzed from performance as measured separately by Verbal, Performance and Full Scale scores.

Observations and performance data, i.e., subjective-type responses, were recorded on the test Record Forms as fully and in as much detail as the testing session permitted and that which was thought to be of clinical value. The purpose for having done this was to note any possible qualitative changes in test performance whether or not anything statistically significant could be identified. Any good intelligence scale when administered individually furnishes more than just a quantitative measure, i.e., an IQ. It makes available a certain amount of data regarding the testee's mode of reaction, special abilities and disabilities, and, not infrequently, some indication of personality traits.[13]

Both this qualitative and quantitative examination of performance seemed of value as there is some evidence from case histories reported

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13. Wechsler, D., "The Measurement and Appraisal of Adult Intelligence," Williams and Wilkins, Baltimore, 1958

in the literature of pentaborane toxic poisoning that, while only temporary, emotional as well as intellectual disturbances have been manifest. These cases occurred from exposure incidences, i.e., situational conditions and accidents. The question then arises as to whether similar psychological behavior problems might not develop in some insidious manner from the cumulative effect of normal day-to-day working conditions.

2. Procedure

Subjects included in this study represent personnel whose daily jobs subjected them to potential exposure of pentaborane. Initial testing included 55 subjects in the experimental group. As a result of transfers, discharges, and other unavoidable problems, the group administered retesting was reduced to 16 engine mechanics.

Initial testing was conducted during the months of June - September 1960. Retesting was administered approximately 10 months later to determine if there was a quantitatively significant difference in performance. While the original test design scheduled the time between test and retest to be a period longer than 10 months, practical problems subsequently occurring did not make this possible. However, Wechsler states that this interval of time would be sufficient in eliminating the greater portion of the practice effect, and that in any case, with the use of experimental controls, it would not be too difficult to differentiate differences primarily resulting from practice from those more likely resulting from impaired performance.[14] It should also be pointed out that initial testing does not represent base-line data. That is, personnel included in this study had had varying periods of experience working with pentaborane prior to initial testing. Ten mechanics had had six months' experience, and the remaining six of the experimental group had had from one to five months' prior work experience on the test stands.

14. Letter from Dr. David Wechsler, New York University College of Medicine, to Capt Glory Sturiale, AFFTC (FTRLD), not dated.

A control group was used consisting of 12 subjects, none of whom had had any history of work experience in an immediate environment in which experimental studies were being conducted using pentaborane. Some effort was also made to choose subjects comprising a control group similar in distribution of performance to the experimental group. A statistical comparison is given in the next section.

B. Supplementary Investigation

As the symptoms of mild cases of pentaborane exposure are not necessarily diagnostic of toxic poisoning, the question not infrequently remains open as to the underlying cause of physical complaints which are referred to the physician as suspected cases of exposure. While such complaints, e.g., headache, sense of fatigue, loss of appetite, naturally could be indicative of pentaborane poisoning, they might also possibly refer to problems of a psychiatric nature.

Unfortunately, there is no specific way of determining the exact etiological factors underlying these physical complaints, i.e., the extent to which, if at all, their origin is psychological. The importance of making an accurate diagnosis is readily apparent. If physical complaints have a psychological origin such a determination is valuable for solving problems of work adjustment, not only for the person concerned but also for those with whom he works. Anxiety can be contagious within small working units. On the other hand, if there is no evidence to indicate that physical complaints of personnel are not the result of exposure to toxic propellants, then possibly the working environment and safety program require reappraisal. These considerations are relevant not only to those working directly with a toxic propellant but also those in adjoining test areas as well.

What must be found then are the tools to use for providing the most meaningful kind of diagnostic picture of the individual. Certainly the medical examination, personal history and interview require no explanation as valuable diagnostic tools. But apart from these there remains the possibility of using what might loosely be categorized as psychodiagnostic testing.

In addition to the use of such tests for diagnostic purposes, they might also serve as an additional working tool for job placement purposes. In other words, they may help in the identification of employees whose psychological makeup is predictive of faulty work adjustment in programs such as Project Joshua where environmental conditions are novel and present some potential health hazards. Specific predictive measures of interest here would be those concerning hypochondriasis, asthenia, psychosomatic symptoms, and nervousness and anxiety.

As an exploratory investigation, two psychodiagnostic tests were administered in an attempt to determine if test performance could in any way be related to job adjustment as measured by number and nature of sick-calls, job performance and work attitudes. The tests chosen were those which could be simply administered and the data from which could be subjected to statistical analysis. They are the Cornell Index and the Seitz-McFarland PsychoSomatic Inventory. The latter was recommended by Wechsler.[14]

These tests consist of a series of questions referring to neuropsychiatric and psychosomatic symptoms. They were originally designed to serve as part of the psychiatric history and could, in addition, be used to differentiate statistically those persons with "mental" and "physical" disturbances from the rest of the population.

There is, of course, the full appreciation that no one piece of psychiatric data is conclusively diagnostic as a clinical technique. The measuring tools used in this study are merely for exploratory purposes to determine whether the kind of data they provide might serve a purpose as part of the medical history, and, secondly, to determine the feasibility of using standardized, simply administered objective-type tests as reference material for job placement purposes in certain R and D programs.

1. Procedure

The subjects to whom these tests were administered include almost all military and civilian personnel assigned to Project Joshua who worked steadily for some period of time during the first six months of 1961. Those who are not included (4) were not conveniently available for testing.

A total of 35 subjects were tested who held job positions as engine mechanics (32), electronic technicians (1), general foreman (1), and inspector (1).

This period of time was chosen, i.e., six months prior to the cut-off date of this study, in order to provide a minimum number of subjects and concerning whom there would still be enough data available. The first day of the year was chosen in an attempt to avoid introducing a bias in the selection of a cut-off date, and consequently, the selection of subjects.

Scores obtained on these two tests were measured against performance on the job. This was done by categorizing job performance into two groups called, for purposes of this study, the "critical group" and the "noncritical group." The criteria used for identifying individuals making up the "critical group" were as follows:

a. Hospitalized cases or those referred to the Flight Surgeon where the medical diagnosis was considered "questionable PB exposure."

b. Those expressing some anxiety or uneasiness about the work environment during personal interviewing. (There was no problem here as subjects appeared to be either indifferent or verbalized some concern.)

c. Those identified by supervisors as being somewhat concerned and easily alarmed, e.g., smelling PB when other personnel did not. (These proved to be the same individuals as those identified in (b).)

This limited the group to four who were easily differentiated from the others, three of them falling in three of the subcategories just described and one falling in two of them. Tests were administered as instructed in the test manuals with no assistance given except when specific questions were asked.

A control group was thought to be experimentally advisable as there existed the possibility that for some reason persons on Project Joshua, being fully aware that they constituted an experimental group and were under close observation, may have been hesitant in giving honest answers. The control group was matched by job assignment (mechanics) and approximately by ages of subjects in the experimental group. None had ever worked on projects associated with pentaborane. A statistical comparison between control and experimental group distributions is given in the next section.

C. Operational Environment

1. Physical Environment

Project Joshua is conducted in a test area (1-40) which is composed of three major complexes and one annex. The major complexes are defined as Test Stand A and B complex complete with work trailer, Test Stand C and D complex complete with two work trailers, and the operation complex consisting of four control and instrumentation trailers. The Annex is defined as the decontamination building for personnel.

Test Stand A and B complex consists of the two firing positions, Pad A and B (see Figure 1), a small gas generator firing position, fuel (see Figure 2) and oxidizer bunkers and gas storage area. The complex also contains an instrumentation trailer (see Figure 3), a work trailer, a crew shack and an observation tank. The flush drum and burn pit are used for handling waste propellants. The burn pit is approximately 200 feet from the test stands, a view of which is shown in Figure 4. An over-all view of this complex can be seen in Figure 5.

The work trailer contains work benches, hardware, machines, etc., where minor repair work on engine hardware is performed. Along the outside of the work trailer is a row of lockers and cabinets. The lockers provide storage for the safety suits for the Red Crew, and the cabinets provide storage for safety equipment and engine hardware. An old World War II tank is used as an observation post during firings.

Test Stand C and D complex is similar to the A and B complex except that it is on a larger and more elaborate scale (Figure 6). Test Stands C and D are designed for full scale missions whereas A and B are used for subscale testing.

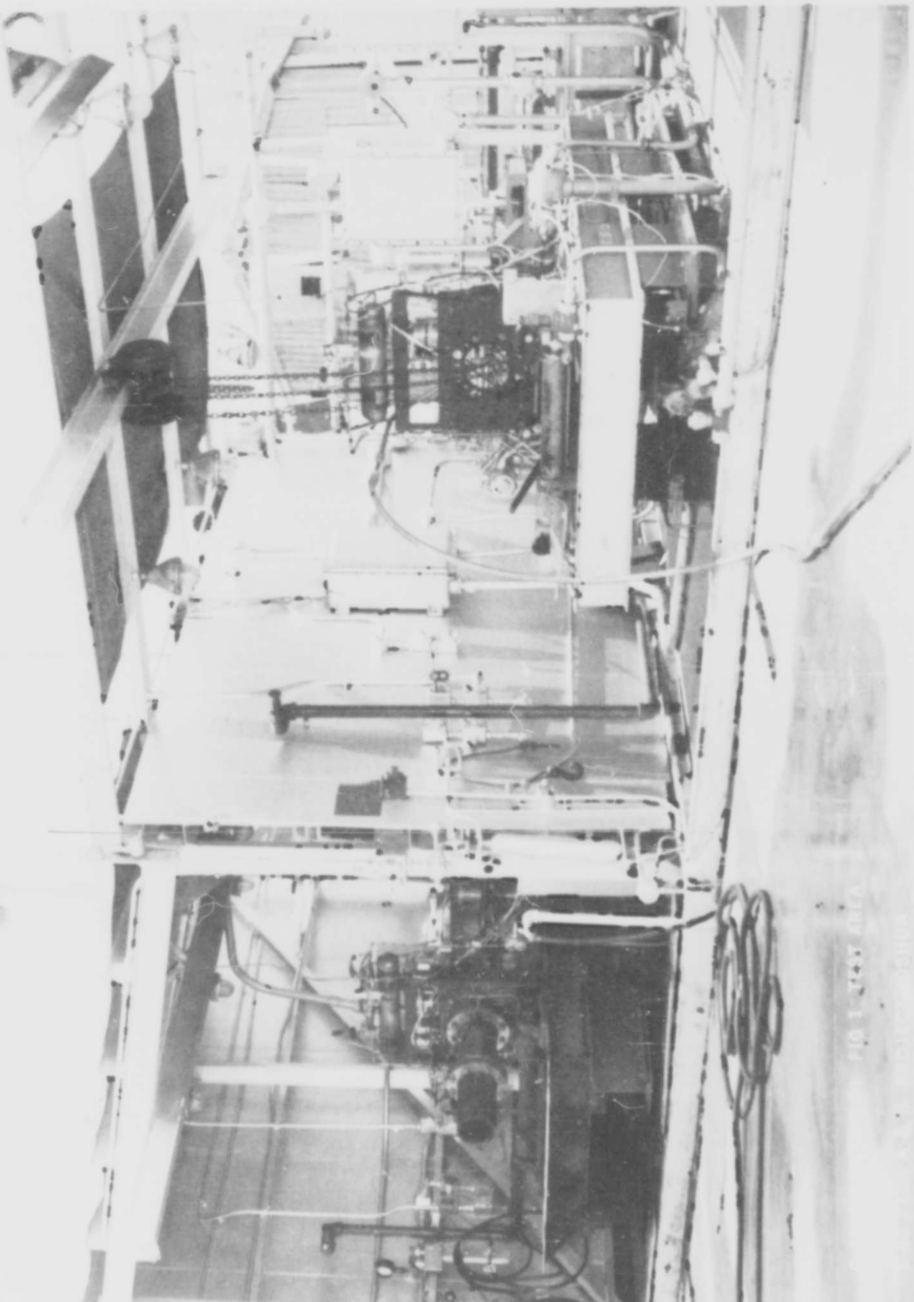


FIG 1 TEST AREA

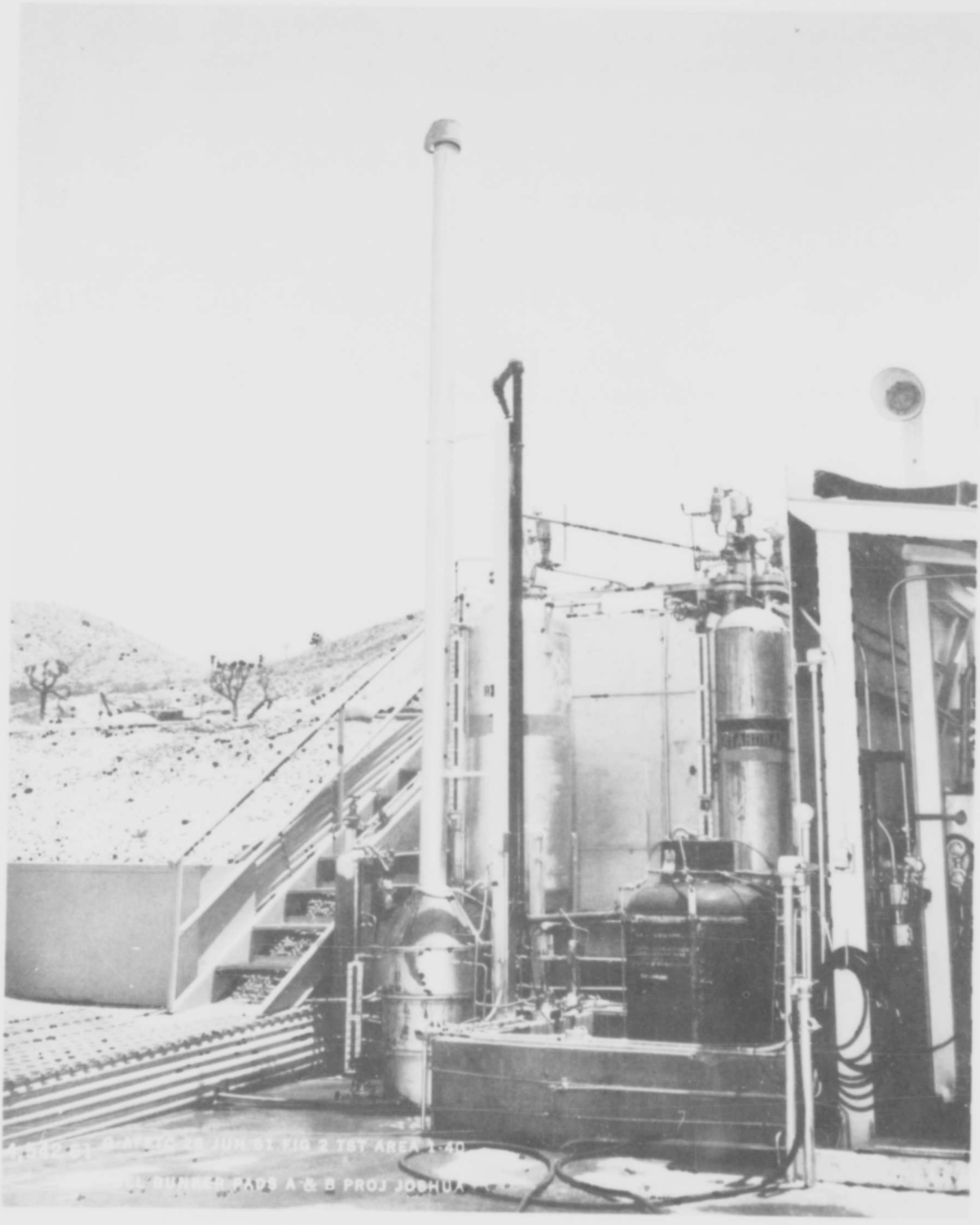
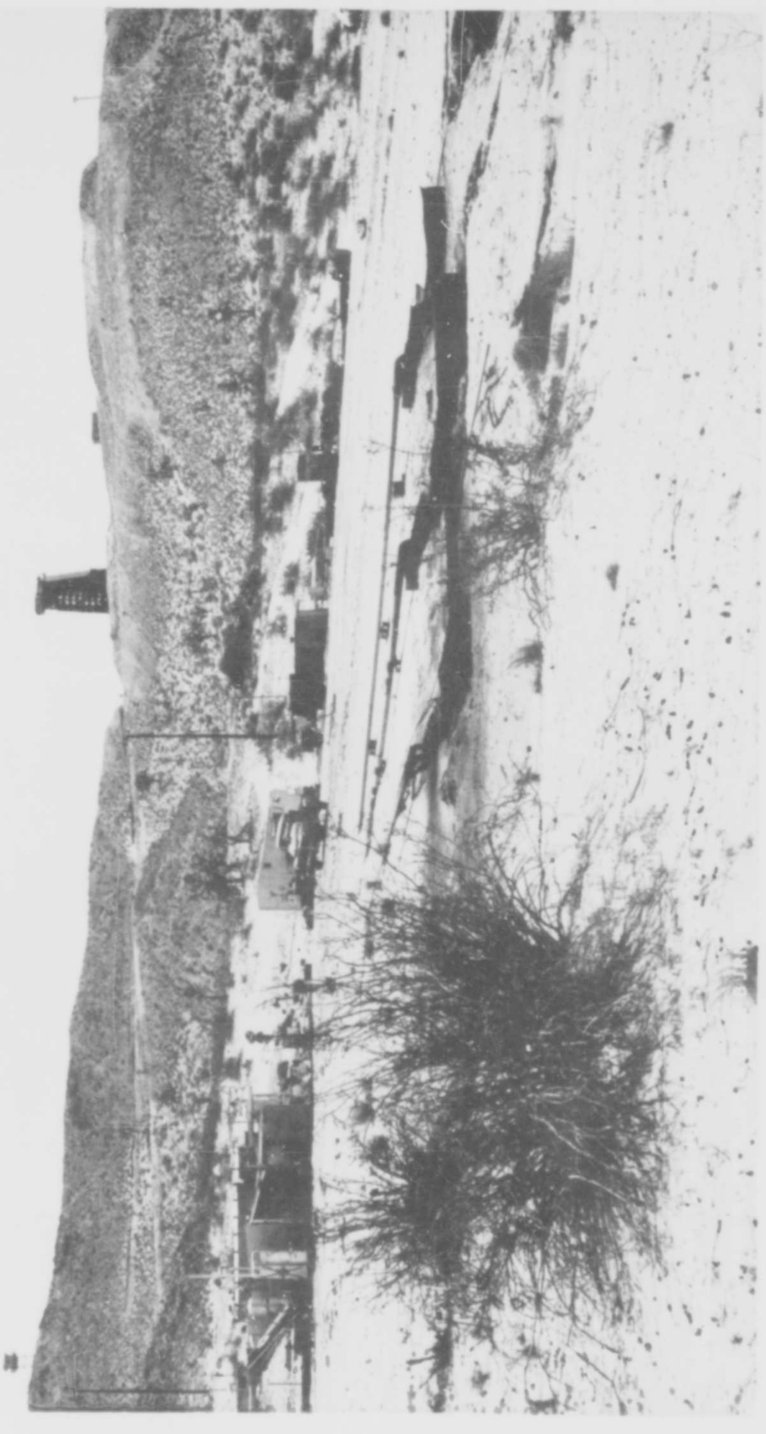
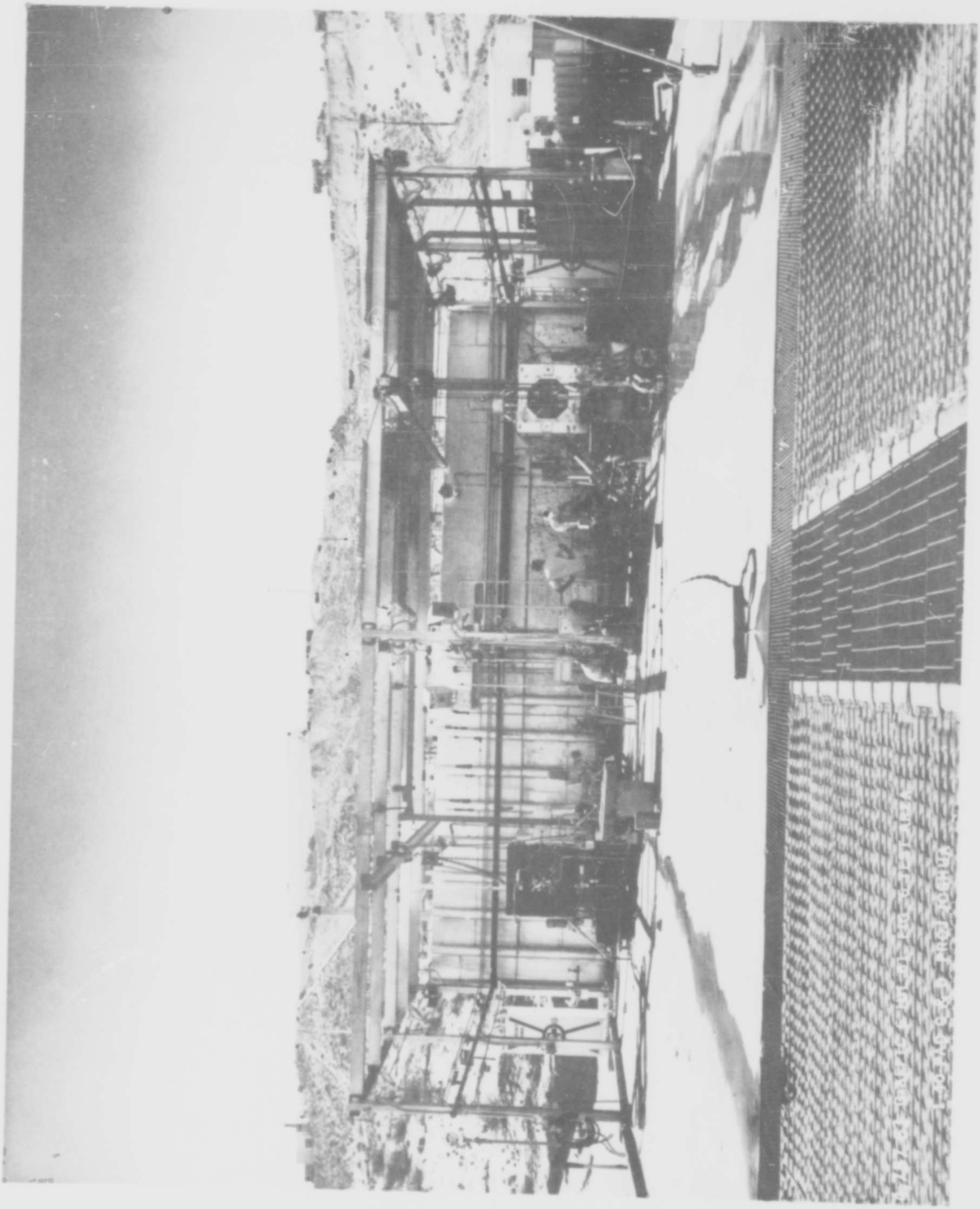


FIG 2 TST AREA 1-40
BUNKER PADS A & B PROJ JOSHUA





The Annex, which is the Decontamination Shack, contains shower facilities and clothes lockers. This wooden shack is used to process crew members in and out after firings and other possible exposure situations. The shower room divides two smaller rooms, one of which is for hanging street clothes and the other, contaminated clothing.

The test area is essentially a basin pocket in Leuhman Ridge surrounded on three sides by ridges with the fourth side (northwest) exposed to the dry lake. It extends 700 feet in all directions from a point located halfway between Test Pads A-B and C-D. Entrance to the area is controlled by test area warning lights, at which place are also located the instructions for entering the area and telephones for communication with test personnel. A sketch of this entire complex is shown in Figure 7.

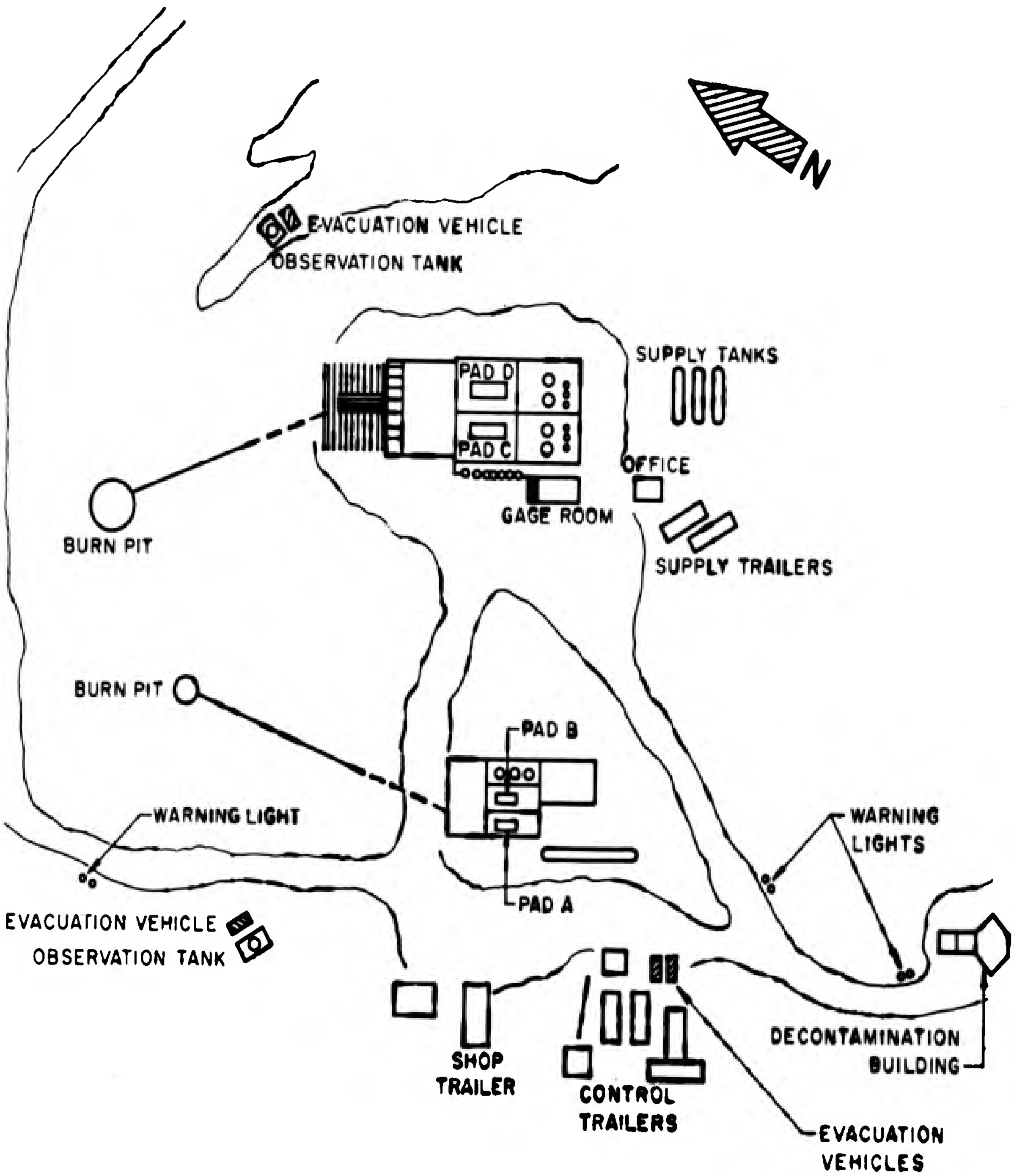
2. Operations - Test and Maintenance

Subscale testing began in December 1959 (4 firings) and full scale testing in December 1960 (2 firings). Subscale testing continued throughout almost every month in 1960 with a total of 181 firings. From January-June 1961, there were 76 firings on A and B and 3 firings on C and D.

The nature of this study makes difficult defining with any scientific objectivity the exact working conditions experienced by the subjects tested. However, some attempt will be made to describe qualitatively operational conditions during testing and maintenance, safety methods and equipment employed, and such other factors as are felt to be relevant.

The first thing to be described will be the operational setting as it exists during test firings and system servicing. An Operational Manual has been prepared which carefully outlines instructions and procedures for the safe accomplishment of all test activities in the test area. This includes SOPs defining responsibility, safety measures, area access, emergency procedures, normal operating procedures, etc.

While test firings are being conducted, the appropriate control trailer is occupied by the Test Engineer, Test Panel Operator, Test Conductor and instrumentation personnel. The instrumentation trailer



PLOT PLAN
1-40 AREA, C & D PAD

contains the remaining complement of instrumentation personnel. Gas masks and escape vehicles are in place for all personnel in case of emergencies.

The Red Crew wearing safety clothing performs the prefire checks on the engine system and also the valve operation on the stand. Gas masks are carried for ready use if leaking propellants are detected. Communication is established with the Test Conductor at all times by means of a headset located at the stand. When this operation is completed, the Red Crew remains in the control complex.

During prefire checkout and at all other times, the Tank Observer is responsible for immediately notifying the Test Conductor of any abnormal or noteworthy condition visible to him. As he is the only observer having an unhindered view of the entire test stand during firing, it is also his responsibility for reporting to the Test Conductor when all visually observable hazards have disappeared following the actual firing. In addition, he is responsible for noting and reporting behavior of crew personnel in the vicinity of the test stand when such behavior might be indicative of a toxic condition.

The tank is an almost air-tight enclosure equipped with an uncontaminated air source and also electric lighting. In the event the exterior air source fails, a gas mask or Scott Air Pack is substituted.

During countdown procedures, in addition to the Tank Observer, the Test Engineer monitoring visual records and the Test Operator monitoring the TV receiver and visual indicators at the control panel are responsible for notifying the Test Conductor of an emergency condition. If such a condition arises, the usual emergency procedures are followed, but in addition plans are immediately made for evacuating the test area.

Fifteen minutes after a firing, the Red Crew (a minimum of three men) enters the test stand area with full protective clothing including gas masks to test for borane contamination with a detector instrument. Checks are made around such critical areas as the engine nozzle, engine injector/propellant valve area, fuel tank/shipping cylinder area, etc. When the Red Crew determines there is no contamination present in the area, the

Test Stand is put in AMBER condition and the area in GREEN. A Red Crew is also used in emergencies in the case of any liquid propellant spillage. A determination is then made of the magnitude and source of the leak and corrective action taken as deemed necessary.

As an additional safety measure, readings are also taken with a detector (downwind) around critical areas three times a day and at any time the fuel system is opened for repairs. These routine readings have been negative except for two or three occasions in which a positive reading was recorded indicating a malfunctioning valve.

It should be mentioned at this time that various duty assignments within any one job category are rotated among the crew members. For example, engine mechanics are rotated for duty as members of a Red Crew.

The description thus far has been limited to presenting a picture of the positioning of personnel and environmental conditions existing during testing operations. Of significant importance, however, in defining the operational setting is some discussion of the exhaust products and the waste disposal of toxic propellants. These propellants are pentaborane (B_5H_9) which serves as the fuel, and hydrazine (N_2H_4), the oxidizer. Hydrazine is also toxic but not to the extent of pentaborane, the MAL (maximum allowable limit) being 1 ppm.

Something will first be mentioned of the bleed-off products and their disposal. Prior to propellant bleed operations, water is run continuously into a floor drain into which the bleed-off of hydrazine is funneled. The floor drain is connected to a water-filled burn pit where the propellants are further diluted and washed overboard. Pentaborane is bled into the flush drum where it remains until after the firing at which time it is drained off to the burn pit and burned.

The flush drum contains RP-1 at a level to maintain a minimum 20=1 ratio with any B_5H_9 bleeding into it. While RP-1 and B_5H_9 are not miscible, constant agitation using helium bubbling through the RP-1 diluted B_5H_9 solution keeps the B_5H_9 solution from reacting. Vapor products funnel out the 25-foot stack which can be seen in Figure 2. These bleed operations are carried out after the cycling of valves and when all personnel have cleared the Test Stand area. The stack provides not only a physical means of releasing these vapor products above the ground layer but also makes possible a more uniform diluted mixture of the escaping contents. This operation insures keeping the atmosphere at ground level free of contaminated air.

Another important consideration is the status of the test stand complex with respect to potential propellant hazards following an actual firing. This might best be described by reference to the purge system. Check valves are incorporated in the helium purge system such that the purge is shut off during firing (high chamber pressure) and reopened after firing (low chamber pressure), thus forming an automatic postfire purge system. The postfire purge clears the lines downstream of the propellant valves, the manifolds, injector and chamber of propellants and exhaust gases. The helium purge valve is cycled until all exhaust gases disappear. This leaves propellants remaining in the tanks and in the lines (about 20-30 feet) up to the propellant valves. Fifteen minutes after this operation the Red Crew checks the test stand area for borane contamination.

The flush drum need not be drained after each firing but can be drained after a second or third firing. When this is done, the line leading from the flush drum to the burn pit is flushed with RP-1 which removes all air from the line. The line is then purged with helium. With RP-1 at a lower density than the water in the burn pit, the RP-1 rises to the top where it is ignited by a remotely controlled acetylene torch. Once burning is accomplished, the contents of the flush drum are manually emptied (hand valve) and gravity-fed to the burn pit where the pentaborane which is at a lower density than both water and RP-1 floats to the top and is burned. Additional RP-1 may be added to insure good burning. After burning, the flush drum is refilled with RP-1. The only potential hazard during this operation is the contamination of air with unburned pentaborane vapors emanating from the pit. But inasmuch as it is relatively simple to insure adequate burning of pentaborane during this operation, no problem is presented. In any event at this time the area is in a RED condition.

The last point for consideration concerns the engine exhaust products. The hot exhaust cloud from the test firing rises rapidly and when it reaches ambient weather conditions disburses like any other cloud formation with variations dependent upon wind stability, temperature lapse conditions, etc. There is no evidence that these exhaust products in any way present a potential hazard to personnel within this test area.

The Chemical Laboratory in an attempt to determine toxicity of the cloud formation has on several occasions stationed a detector in the anticipated path of the drifting cloud at some location in the surrounding testareas. Only when a measurement could be taken at a very dense point in the cloud was a positive reading obtained, the highest being .05 ppm.

Another source of potential exposure to toxic propellants is that having to do with maintenance and repair of components within the propellant system, e.g., faulty valves, loose fittings (gaskets, seals), damaged lines, etc. The main task here is the cleaning and draining of the section involved. This is done by first isolating from propellants, by means of hand-operated valves, the section to be worked on and then carrying out postfiring, flushing and draining procedures in much the same manner as the postpurge operation already described. The only real difference here is that the flush drum is isolated so that pentaborane in the section undergoing repair is drained directly to the burn pit. While carrying out these repair tasks and with the suspected air contamination, personnel are in protective clothing and wear breathing masks. The decontamination of components is done by washing with ammonia solutions, alcohol and water flush. This work may or may not be done with protective clothing and equipment depending upon the extent of the problem.

There is also potential PB exposure during maintenance and repair of the engine system, i.e., changing injectors or thrust chamber. However, inasmuch as the engine system at these times has already been cleared of all propellants (postfire operations) and also as routine checks are made around the engine system three times a day with the propellant detector, the working area is detectably safe and does not normally require the wearing of protective clothing or respirators.

3. Detecting Instrument

The detecting instrument used by crew personnel is one of those which was developed by the Mine Safety Appliances Company, designated as the M-S-A Boranes-in-Air Detector, Part No. 82100. It is a portable hand-pump type which aspirates air through a specially treated filter paper. The boron hydride concentration is obtained by comparing the colored complex formed on the paper with a standard color chart.

The chart gives readings from .01 ppm and in progressions of units of 1/100ths. The specific reading is measured against number of pumps required to reach the saturation of the color standard. Some perceptual discrimination and judgment are required so that in the absence of defined objective measuring techniques the reliability of these measures according to this writer is questionable for readings more sensitive than intervals of 5/100ths ppm. It should also be mentioned that this instrument has not yet been evaluated by the Chemical Laboratory to validate its indicated limits of sensitivity.

4. Protective Clothing

Personal protective equipment clothing includes: (1) a self-contained air-supplied respirator; (2) propellant-resistant vinyl-coated gloves; (3) neoprene or GRS rubber foot protection; (4) an outer garment of Gra-Lite material for N_2O_4, and for B_5H_9, a material of asbestos impregnated with Sta-Safe Compound, N-35 (trade name).

These suits, however, have certain negative features both in the comfort and protection provided. The newly developed propellant safety suit previously referred to will correct these deficiencies. This suit is a one-piece, teflon fabric suit coated on one side with a teflon film laminated with a heat reflective coating of aluminum. A liquid air back pack refrigerates the suit and supplies breathing air for two hours. The suit also contains a transistorized transceiver system (voice actuated) for intercommunication with the control station and other workers.

5. **Health Education**

The safety training program has for the most part been informal and on-the-job type. However, beginning in the fall of 1961 a formal training program will commence which will be organized and conducted by the Air Training Command. This training program has been designed to serve as a basic qualification course for all personnel working with highly toxic propellants and will include special instruction defining supervisory responsibilities. In addition to this, course work is planned to familiarize engineers with certain engineering design requirements peculiar to systems using toxic propellants.

RESULTS

A. Analysis of Performance - Mental Testing (WAIS)

A statistical description of Experimental and Control Groups for first- and second-session testing of the WAIS is given in Table I. Using the t and F distributions,[15] respectively, for means and standard deviations, no significant differences were found at the 5 per cent level of confidence between Experimental and Control Groups for first-session testing of Full Scale, Verbal or Performance scores.

TABLE I

	Mean			Standard Deviation		
	Verbal	Performance	Full Scale	Verbal	Performance	Full Scale
First Session						
Experimental	104.6	107.25	105.9	8.74	9.53	7.95
Control	107.5	104.5	106.33	14.43	12.54	13.77
Second Session						
Experimental	105	114.31	109.25	7.73	8.91	8.26
Control	109	111	110.5	13.98	9.35	12.17

To determine if there was a statistically significant difference in performance between first- and second-session testing of the Experimental Group, the hypothesis tested was that there is no significant difference between the differences of first- and second-session testing of the Control

15. Dixon, W. J., Massey, F. J., "Introduction to Statistical Analysis," McGraw-Hill Book Co. Inc., 1957

Group and those of the Experimental Group. The statistic used to test this hypothesis[16] was:

$$t = \frac{\bar{d}_1 - \bar{d}_2}{s_p\sqrt{(1/N_1) + (1/N_2)}}$$

where,

$$s_p^2 = \frac{(N_1 - 1)\, s_1^2 + (N_2 - 1)\, s_2^2}{N_1 + N_2 - 2}$$

This statistic was chosen because it was considered the most sensitive measure for the data under analysis. It made use of all the available data, i.e., scores, as opposed to a nonparametric statistic such as the Mann-Whitney U test which uses just ranks.

Rejecting t greater than 1.706 at the 5 per cent level of confidence the results obtained do not provide evidence to reject the hypothesis of no significant differences. An analysis of the separate portions of the WAIS gives the following values for t: Verbal = +1.02; Performance = -.14; Full Scale = +.57. Neither was there anything noted with respect to qualitative changes in performance. In fact, in many cases, subjective-type responses were improved. This, of course, could be related to the practice effect or any of a number of chance factors.

B. Analysis of Psychodiagnostic Testing

The results obtained from the psychodiagnostic testing while not showing any significant relationships in a statistically critical sense might - without too much scientific freedom - be considered at least heuristic. So with some experimental license an analysis of test results will be presented.

16. Ibid., page 121.

The results of the Seitz-McFarland Inventory gave nothing of interest worth reporting. The analysis presented will therefore be restricted to the results obtained from the Cornell Index. This Index is scored from 0 to 101, the higher scores being indicative of possible personality maladjustments. Various scoring methods can be used, but as a point of reference, an "Index" score of 13 or more is predicted to screen the majority of those persons with serious neuropsychiatric and psychosomatic disturbances and a moderate number of ostensibly healthy persons.[17] Omitted as not pertinent for purposes of this study was that portion of the Index consisting of questions referring to psychopathic deviations. (These deviations are generally considered by clinicians to constitute behavior problems either in the social or psychosexual sphere in the form of social antagonism or deviations of sexual impulse. In other words, inadequate responses to moral, ethical and esthetic considerations.)

When this test is administered to individuals unselected with regard to neuropsychiatric disturbances, scores may obviously cluster at the low end of the scale of scores. In this study, the range of scores was 0-10, the arithmetic mean was 1.94, the median score was 1 and the standard deviation was 2.43. At the 5 per cent level of confidence, no statistically significant differences were found between the control and the experimental groups for means and standard deviations.

The statistic used to analyze the data was Fisher's exact probability test.[18] The chi square test was not used because the smallest expected frequency was less than five.[19] A 2 x 2 contingency table is shown in Table II. The Critical and Noncritical Groups are represented by frequencies as previously explained. The column headings indicate a classification of high (6-10) and low (0-5) scores.

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17. Cornell Index Manual, Revised 1949, the Psychological Corp., New York

18. Siegel, S., "Nonparametric Statistics," McGraw-Hill Book Co. Inc., New York, 1956

19. Ibid., page 110.

TABLE II

	High	Low	
Noncritical	1	30	= 31
Critical	3	1	= 4
Total	4	31	= 35

It is with respect to this classification of high and low that some experimental freedom has been taken. A more objective and the commonly accepted classification would be above and below the median. If this classification is used, the value of p (probability of this distribution of frequencies) is too high to reject within commonly accepted limits H_o (null hypothesis). But if in the classification of high and low only the 90th to the 100th percentiles are considered "high" and the remaining scores, "low," then the probability under H_o of this occurrence as shown in Table II or of one even more extreme is $p = .002$. The value of p is then certainly low enough to reject H_o.

Mention might also be made of the efficiency of the test, e.g., for job selection purposes, when the 90th percentile is used as the cutoff score (6). Three of the four individuals who showed themselves not altogether occupationally suited for working in a potentially hazardous environment would have been identified, i.e., not selected, and only one of 31 individuals would not have been selected who, from all available evidence, should have been.

However, the point is made again that this analysis in no way suggests using the Cornell Index as a selection device. This Index was not primarily designed for job selection purposes. It was chosen merely as the most applicable and readily available, simply-administered type test for use in this very limited exploratory study.

DISCUSSION

The results obtained from this study should be viewed in the proper perspective. Findings of such a study as was attempted here are of necessity limited in their applicability. One could not make inferences from this study to other work environments which are not similar in every critical way to those environmental conditions as exist under Project Joshua.

Secondly, the limitations of the measuring instrument (WAIS) must be fully understood. The problems consequent in a research design which requires retesting subjects using the same measuring instrument is readily apparent. Some tests are, of course, less sensitive to the effects of retest than are others. The reliability of the WAIS is such that one can expect a difference of 5 IQ points between retests to include ordinarily about 50% of the cases, a difference of 10 points, 75% or more of the cases, and so on.[20]

Differences in an individual's test performance can be related to such things as the effects of practice on specific items or item types gained during initial testing, learning and forgetting, mental set, to name only a few. Even with the use of a control group such variables as these must be considered when interpreting the research findings. Secondly, the sensitivity of the test as a measuring instrument must be considered. It remains indeterminate whether the test used in this study was sensitive enough to register any minute changes that may possibly have taken place in subjects' mental capabilities.

All of these qualifying comments are made merely to assist the reader in gaining a scientifically objective understanding of these research findings. They are presented in no way to minimize the value of such findings. Certainly the absence of observing experimentally any changes in the performance of a variety of mental abilities as measured by the WAIS is of immediate practical value. In addition, this data will hold a place in the body of empirical knowledge which for the most part has only recently begun to emerge.

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20. Wechsler, op. cit., page 157.

In any work situation which presents a potential hazard, nothing need be said - and then again, not enough can be said - of the importance or complete necessity of an effective industrial health program. Education becomes synonymous with safety. So, too, can knowledge be the best purgative of fear and anxiety. The operational history of Project Joshua, while representing a new military venture in rocket propellant research and from which there was no experience to draw, has been relatively free from unfavorable incidents. Since its beginning, only five cases were hospitalized for brief periods for possible mild pentaborane intoxication and in one of which the diagnosis of PB intoxication was "questionable."

Of the nonhospitalized cases, there were only seven. These were diagnosed as "probable" mild PB intoxication, "questionable," or "uncertain." In all cases recovery appeared rapid and exposure symptoms disappeared. Symptoms included such things as nausea, anorexia, headache, drowsiness, light headedness, euphoria, impaired coordination, difficulty with speech, dizziness, etc. It can be seen from these symptoms that anxiety or nervousness, or just a plain hangover, can easily obscure the issue. It might be mentioned at this point that all personnel on Project Joshua were required to pass a medical examination prior to employment.

All probable intoxication cases referred to the Flight Surgeon were subsequently investigated by the Sanitary and Industrial Hygiene Engineer if the condition was believed to have arisen from some particular incident occurring on the test stands. In the several cases which occurred where the employee complained of headaches and other symptoms which he related only to normal daily work on the test stands, nothing more could be done other than to put the individual under medical observation. Not only was there a lack of certainty in the diagnoses made in these cases, but also in those other cases where PB exposure supposedly resulted from some particular incident.

These cases often presented such conflicting bits of evidence - e.g., why was only one person affected? - that investigative conclusions were either tenuous or left open to choice from four reasonably possible explanations: (a) PB intoxication; (b) hypersensitivity to PB; (c) aggravation of an already existing physical condition; (d) psychosomatic reaction.

From this discussion, it can be readily appreciated that environmental conditions do not permit their being described with scientific precision. For this reason, some specific answers to the more general question concerning the effects on mental functioning with exposure to PB may be found in controlled experimental animal learning studies. Maze learning, for example, offers a simple technique. Pentaborane exposures could be varied at different subacute levels of intoxication over extended periods of time. In addition to the obvious advantages of using animals, such studies permit a much more rapid accumulation of data as opposed to human subjects.

While the results obtained from the psychodiagnostic testing (Cornell Index) were not significant in a statistically critical sense, they do suggest the possibility of using this kind of measuring tool for those purposes previously discussed. This supplementary study was admittedly only an exploratory step - and possibly an unsteady one at that. Though it hardly need be said, further research most assuredly would be required before any positive conclusions could be made. A test designed to meet this specific industrial purpose would have to be developed, though many test items might be based on those in already existing standardized tests. But whether or not this research is ever undertaken, the use of these already available personality tests may not be without some value to professional people, i.e., medical doctors and industrial hygienists, who are called upon to evaluate operational conditions and to diagnose physical complaints.

One last point will be made here which is relevant in part to the foregoing discussion. It concerns procedures in the detection of pentaborane. As already mentioned, environmental conditions are such that if PB is released into the atmosphere it rapidly dissipates. But there is always the potential hazard that toxic propellants may be present around the propellant or engine system resulting from leaks caused by faulty valves, loose fittings, damaged parts, etc. As a control for such conditions, probably the most effective available method is the systematic daily taking of readings with a detecting instrument around these critical points. Such readings should of course, be taken at any other time when conditions dictate.

Taking these daily readings would serve several purposes. Most important of all is obviously its value as a safety measure. When a positive reading is obtained, repairs and such other corrections can be made. If positive readings are not obtained, as has been with few exceptions the case in actual practice, this information is important even apart from strictly safety considerations. It provides a measure of objective data of environmental working conditions. As such, it should be used to give assurances to those individuals who attribute all perceptible odors to the presence of PB. Secondly, this information has general educational value. The possibility of receiving hazardous duty pay may very easily lead to olfactory illusions.

CONCLUSIONS

The results of this study statistically showed that there were no significant changes in mental performance as measured by the WAIS following a period of 10 months duty as engine mechanics on Project Joshua. At the five per cent level of confidence, the results obtained did not provide evidence to reject the hypothesis of no significant difference between the differences of first- and second-session testing of a Control Group and those of the Experimental Group.

The results obtained from the psychodiagnostic testing (Cornell Index) which consisted of questions referring to neuropsychiatric and psychosomatic symptoms, while not significant in a statistically critical sense, did provide some evidence for the practical use of such tests. The information obtained from these tests was seen to serve a purpose as part of the personal medical history to assist physicians in diagnosing complaints of propellant intoxication. Secondly, there is their suggested use as reference material for job placement purposes in R and D programs which present what might be considered a potentially hazardous environment.

The operational experience obtained on Project Joshua together with these research findings provided no evidence to indicate that R and D programs involving the use of toxic propellants should not be undertaken when effective safety measures are instituted.

RECOMMENDATIONS

1. That consideration be given to the advisability of conducting controlled experimental learning studies with animals exposed over sustained periods of time to various subacute levels of pentaborane concentration.

2. That an evaluation be made of the practical value of using simply administered objective-type psychodiagnostic tests referring to neuropsychiatric and psychosomatic symptoms as

a. Part of the personal medical history to assist physicians in diagnosing complaints of propellant intoxication; and

b. Reference material for job selection purposes in R and D programs which present a potentially hazardous environment.

3. That systematic daily readings continue to be taken with a detecting instrument around those critical points of both the propellant and engine systems from which pentaborane vapors may accidentally escape. These readings would be, of course, in addition to those taken by a Red Crew and at such other times as operational conditions dictate.

4. That the sensitivity of the detecting instrument together with a record of its readings be included as part of the safety education program.

5. That the safety education program also include the research findings of the Army Chemical Corps study concerned with the median detectable concentration of pentaborane by odor for man[6] and that this information be related to the sensitivity of the detecting instrument.

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